THE EFFECT OF PERSONALIZED FEEDBACK ON THE ABILITY OF STUDENTS TO OVERCOME MISCONCEPTIONS IN A PROJECT-BASED SCIENCE CURRICULUM

by

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ABSTRACT

A large part of a science teacher's role is in both helping students understand concepts, as well as helping students address common science misconceptions through a variety of means. Students in a blended-learning environment independently demonstrate mastery of content through online assessments, while teachers assist students in developing specific academic skills through project-based learning. In a blended-learning environment, a science teacher's role becomes morphed. A teacher in this learning paradigm may not be the first point of contact for new material as students learn at their own pace. Special care must be taken to monitor student misconceptions and plan interventions that support conceptual change. One of the main roles of a project-based teacher is giving feedback to students. The purpose of this research was to assess the effectiveness of the feedback and revision process in helping students identify and overcome misconceptions in their modeling skills in a project-based curriculum. The research included the evaluation of student attitudes and perceptions of feedback through pre-project and post-project surveys. Student concept attainment and the ability to overcome misconceptions was assessed through pre- and post-surveys which focused on content as well as the comparison of draft models of a climate change in a bottle experiment and final draft models after students received feedback from teachers. Further data was gathered through student interviews about feedback and the process of addressing their misconceptions. Results of the experiment indicate that feedback is effective in helping students overcome misconceptions regardless of the type of feedback, either brief or detailed.

INTRODUCTION AND BACKGROUND

Summit Atlas is a combined Middle School and High School located in West Seattle, Washington. Summit Atlas is positioned on the border of two public school districts, Seattle Public Schools and Highline School District. It is part of the larger Charter School Network of Summit Public Schools whose mission is to serve all students and prepare them for the academic rigors of university. Summit Atlas was founded in August of 2017. We currently have grades six and seven in the middle school, and grades nine and 10 in the high school, serving a total of 327 student. We will add an eighth and 11th grade in the fall of 2019 and the school will celebrate its first graduating senior class in June 2021. The overall tone of the school is that of a small and close-knit learning community. Most teachers, whether they teach in the high school or middle school, know students by their name. We have a strong school culture around teamwork and values, where students assigned to a specific mentor teacher and class that they meet with in both the morning and afternoon.

Summit Atlas serves a very diverse community of students. There is a slightly higher number of males, 55%, to females, 45%, during the 2018-2019 school year. Thirteen percent of students attending Summit Atlas were born in another country, mostly in Kenya whose families are refugees from Somalia. Summit Atlas is linguistically diverse with 20% of students speaking a native language other than English. Nine different languages other than English are spoken with the majority of students speaking Somali or Spanish. Other languages spoken at the school include Amharic, Arabic, Lingala, Swahili, Tingrinya, and Vietnamese. Our school serves three students who live in temporary accommodations or are considered homeless. Parent education background is a mix of college graduates and holders of graduate degrees which make up 39%, while parents with a high school degree and/or some college make up 48%, the remaining 13% of parents have not graduated high school or declined to state their education background. Furthermore, Summit Atlas is racially diverse; 36% of students identify as Black/African American, 32% identify as European American, 17% of Hispanic/Latino origin, 11% of students identify as two or more races, four percent are Asian, and less than one percent are Native American or Pacific Islander. Finally, 16% of our students served have an Individualized Education Plan (IEP) designed to support their special education needs. An IEP is a legally binding document that requires teachers to provide additional in class scaffolds for equitable education in regular class settings. (Summit Atlas Demographics Report, 2019)

All Summit Public Schools utilize an online learning platform, Summit Learning, that was designed and created by software engineers from Facebook and paid for by the Bill and Melinda Gates Foundation. This learning platform is provided for free to any school that would like to utilize this educational tool and was piloted through Summit Public Schools. The personalized online learning platform was designed to help students learn both independently and through a project-based curriculum. It is used as a tool for feedback on student work and the online resources replace traditional textbooks.

At Summit Public Schools the courses are organized into two areas. The first is a project-based learning curriculum with a focus on the development of specific academic skills which are coined Cognitive Skills. The second area is what Summit Learning calls

Power Focus Areas. The Power Focus Areas are a self-paced content mastery program where students independently read, watch, and interact with web-based resources to build content background needed for projects. Students take notes or show other proof of studying and then take a 10-question online quiz to demonstrate mastery. Students can take the online quizzes as many times as they need to until they pass with the 10 questions changing by random drawing from a question bank of approximately 100 questions. Students cannot see the answers that they get wrong, only the score they received; however, teachers can utilize the data to help assess student understanding and construct individualized study guides and lessons for students.

Through the Summit Learning Platform project curriculum students are assessed using rubrics that measure cognitive skills. Cognitive skills rubrics are provided to teachers and assigned to projects in the base curriculum provided through the platform. A total of 36 cognitive skills are assessed over the course of a student’s education through the Summit Platform and are identified based on expertise necessary to succeed in college. Important cognitive skills assessed include selecting relevant sources, writing conventions, organization, and academic style and language. Several of the cognitive skills are well aligned to the current NGSS standards such as modeling, justifying/constructing an explanation, asking questions, and explanation of evidence. In all courses, project work is graded with the cognitive skills rubrics provided through the platform. Teachers provide feedback to students on their formative work at various checkpoints throughout a project, helping to build the final products. A checkpoint is a section of the project, for example, an introduction paragraph or constructed or drawn model of a process or design solution to a problem. Students submit their work for feedback and receive comments from instructors as well as a color on their platform indicating whether they need to stop and revise (red), review feedback (yellow), or can move on to the next checkpoint or final product (green). Students then revise their work, if necessary, and include it in the final product.

I am in my second year of teaching at Summit Atlas, having helped open the school, and am teaching four blocks of sixth-grade integrated science in this blended learning format. One area that I spend a great deal of time refining and working on in my teaching practice is feedback to my students on their checkpoints. I use the language of the cognitive skills rubrics to help students move up levels on the rubrics to demonstrate higher levels of skills. In my sixth-grade science course I have a total of 18 cognitive skills to assess over the course of the school year. For this capstone research, I assessed and evaluated student's ability to overcome misconceptions in modeling for a climate change project. Within the climate change project, seven cognitive skills were assessed (Appendix A).

In my courses, specific phenomena are used in a 5E lesson cycle to support student understanding of concepts or processes. The checkpoints are part of the evaluation and elaboration portion of the cycle. For every checkpoint, I complete two formal rounds of feedback to students on their checkpoint work. Students are given time in class to revise their work prior to the second checkpoint round. Students who still do not receive a passing score (indicated by yellow or green color) must attend office hours, or conference with me during class about their work. These conferences help me understand what barriers students may have and allow me to provide them with specific scaffolds if necessary, as some students are still working on their basic reading and writing skills. In general, most students can complete their checkpoints to passing level by the end of the second round, but some students struggle with reading comprehension, focus in class, and motivation. These students thus require additional time and support.

Although, it was not a focus of the study, it is important to note that many teachers comment on the fact that the ten question content quizzes may be a source of student misconceptions. In discussions with my colleagues, we noticed many students maintain persistent misconceptions about course content even after taking, and successfully passing, a ten-question assessment quiz. The misconceptions tend to show up in students' project work, particularly in their modeling of a process or experiment, or in their explanations. The rubrics we use to assess student work, although aligned in ways to NGSS, are not specific to science. Rather, they are generalized rubrics which are employed across all middle school and high school courses. Therefore, many of the cognitive skills rubrics do not necessarily require students to demonstrate an accurate understanding of the science concept in order to receive a passing grade. For example, the rubric for Modeling through Summit at sixth-grade requires "a simple and partially accurate model" to receive a passing score. This is a source of frustration for the science team teachers. Thus, as a team, we have been actively working to make sure students also demonstrate clear conceptions in their projects through the feedback and revision process and the use of checklists.

The project that was the focus of the research for this capstone is called Climate Change (Appendix C). This project was highly engaging but also illuminating of student misconceptions, as it built on students' modeling skills that were introduced in an initial project called 'Explaining a Science Mystery'. In this initial project, students drew models and developed explanations from observational evidence of what was happening inside structures they could only observe from the outside. For example, the mystery box had four different mystery settings where clear water went into the box and either came out clear, yellow, blue, or not at all. Students were tasked with constructing a possible explanation for the color change, and a structure for what was happening inside of the box. This helped introduce the idea of abstract models which we built on further in the Climate Change project. In the Climate Change project, students investigate the natural phenomena of how greenhouse gases trap heat in the atmosphere and in our model experiment Climate Change in a Bottle. Students explore the causes of climate change and then design a model geoengineering structure that will help mitigate the effects of global warming. In the previous year many students demonstrated naïve conceptions or misconceptions about energy, photons of light, and the concept of the Earth's atmosphere. These did not seem to be overcome through their passing of their online quizzes for the Power Focus areas of Global Climate Change and Energy. Because the cognitive skills did not explicitly require students to accurately describe the science concepts, my previous efforts focused explicitly on giving feedback for the skill and not the concepts students were demonstrating a sparse understanding or a misconception about. This bothered me, as I felt I was doing a disservice to my students in not holding them more accountable for accurate conception through feedback. I attempted to fill the gaps with additional lessons, but without being able to force students to display correct understanding through the online quizzes; I was unable to require correct demonstration of concepts for this project.

In discussing this issue with my colleagues, several questions arose. How are students held accountable in developing accurate conceptions about science in a split curriculum format? What is the science teachers' role in addressing misconceptions? How can we as science teachers better guide our students in developing accurate conceptions through the project-based curriculum? From our constructive discussions, one possible suggestion to help students develop an accurate understanding science concepts was through the use of teacher feedback. This could lead to clearer standards for how teachers give feedback on student thinking in science and integrating feedback for science concepts for each project. Furthermore, by incorporating feedback that is specifically designed to help students develop accurate science concepts while engaging in science practices, teaching practices would likely concurrently improve.

My research questions for this capstone are designed to assess the impact of feedback as well as provide an overview of both student understanding about the science concepts involved in the climate change project, and student attitudes and perceived usefulness of feedback (Table 1). My primary research focus for this capstone is, how does personalized teacher feedback target student understanding of science concepts and does it affect a student's ability to overcome misconceptions in a project-based curriculum? My additional secondary focus questions include: 1) What misconceptions or naïve conceptions do middle school students have about global climate change and thermal energy transfer? and 2) To what extent do students utilize teacher feedback to improve their cognitive skill scores and revise their content understanding?

Table 1
Data Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. *How does personalized teacher feedback target student understanding of science concepts and does it affect a student's ability to overcome misconceptions in a project-based curriculum?*	Pre- and post-project multiple choice content survey of common misconceptions about thermal energy transfer and global climate change.	Comparison of Draft models compared to Final Product models of Climate Change in a bottle experiment.	Student Interviews about the usefulness of feedback and their process of uncovering misconceptions in their models.
Sub Question 1: What misconceptions or naïve conceptions do middle school students have about global climate change and thermal energy transfer?	Multiple choice google survey assessing content knowledge before the beginning of the project.	Students Draft Models of Climate Change in a Bottle Experiment	Student Interviews with past students and current students.
Sub Question 2: To what extent do students utilize teacher feedback to improve their cognitive skill scores and revise their content understanding?	Pre- and post-project Surveys about student use of feedback and perceptions of the usefulness of feedback.	Comparison of draft models to final product models of Climate Change in a Bottle Experiment. Tracking for misconceptions that are overcome immediately after feedback or that need additional interventions.	Student Interviews with about the feedback process.

CONCEPTUAL FRAMEWORK

There are four main areas of interest to explore that support this research: understanding of the process and role of misconceptions in learning, instructional design effective use of discrepant events, modeling and its impacts on learners, and feedback as a teaching process. Discrepant events are described as a phenomenon that causes a disequilibrium, pique curiosity, and often has surprising outcomes. In this project, I assessed student understanding based on their modeling of one main discrepant event of climate change in a bottle. In this discrepant event, students observe that a bottle with extra carbon dioxide results in an elevated internal temperature as compared to a bottle with normal air when exposed to a lamp light. I am specifically interested in the use of modeling student understanding of this phenomena and how it relates to climate change on Earth to identify misconceptions and assess the impact of feedback in overcoming misconceptions. To this end, it is useful to review the research about misconceptions and preconceptions and the role that feedback plays in developing student understanding of science concepts.

Conception Formation and the Role of Misconceptions and Preconceptions:

Students come to a classroom with a multitude of internal ideas about how the world works. These are based on their past experiences, understanding the world around them through school, observing natural phenomena, and what has been explained to them. Conception about the natural world is a network of ideas that students patch together from various experiences. Sometimes these ideas and understandings do not align with current scientific understanding, which demonstrates a true misconception, while other times ideas simply are lacking knowledge about current theories, which can be categorized as a naïve conception. However, when a student's concept of how something works is partially correct, naïve, or incorrect it will tend to be labeled in a general way as a misconception. Page Keeley, author of several books that help identify student misconceptions through diagnostic probes, warns that lumping all misconceptions together and viewing them as simply incorrect can create barriers for teachers in properly addressing the misconceptions (Keeley, 2012). She argues that not all misconceptions are created equal, some will be barriers to conceptual change, while others are simply factual or based off the interpretation of the word used in other contexts. Additionally, Keeley highlights that often teachers make the assumption that only low performing students hold misconceptions but, that in fact all students have misconceptions regardless of their education level or academic skills. Keeley presses teachers to see misconceptions less like a barrier that a student must immediately overcome and more as jumping off points for instructions and "steppingstone for student concept development (Keeley, 2012 p, 12).

In order for students to trade out their misconceptions for more accurate conceptions, students must first undergo conceptual change. Conceptual change is the process of learning new things, by replacing old ideas and constructs of understanding with new ones (Larrson, 2009). Conceptual change happens through the active attempt by the learner to grasp a concept, process, or idea (Larrson, 2009). Students demonstrate that they have developed an understanding of a concept by communicating their understanding to someone who can evaluate it. "The understanding of a concept is always an individual understanding, that is, a conception, and the quality of his understanding is decided upon by the extent to which the individual can communicate with experts in the field" (Larrson, 2009, p. 644). As teachers, we ask students to communicate their understanding through a variety of ways, by assessing their understanding of a natural phenomenon.

Previous work has looked at the role of misconceptions in the learning process, using verbal practicum interviewing to probe student understanding of electrochemical cells (Hamza & Wickman, 2007). The researchers evaluated how misconceptions were included in students' reasoning during the exam,

> Particularly, encounters with known misconceptions in electrochemistry did not constrain the ways students established relations to fill gaps noticed during the practical, neither from the point of view of their being able to continue the learning activity nor, more importantly, from the point of view of how their reasoning developed in relation to the purpose of the task (p. 33).

This observation provides evidence that misconceptions are not the barriers they are often painted as in the literature. Rather, their presence in one context does not necessarily determine they will be a barrier to learning or reasoning in another (Hamza & Wickman, 2007).

Identifying misconceptions is part of the diagnostic pre-unit work for science teachers. Simple quizzes, warm-ups and class discussions help a teacher assess and begin planning for student achievement. Several effective instruments were described that can help to diagnose student misconceptions in science (Gurel, 2015). The first and easiest diagnostic tool to assess the frequency of misconceptions in a group of students is a multiple-choice test. The advantages of multiple-choice tests are the ease at which they are administered and scored. However, multiple choice tests have the drawbacks, in that they commonly promote students to guess from a limited number of options, and do not provide an outlet for the teacher to determine the depth of student understanding. In this review study, the authors argue a variety of strategies should be employed to assess student misconceptions and help differentiate between a misconception and simple lack of knowledge. This can be done through interviews or use of multi-tiered multiple-choice tests where the confidence of the student's choice can be selected. The multi-tiered distinction is an important one, as the interventions are different for a student with a strong and true misconception which creates a barrier to learning, verses a simple lack of knowledge that can be overcome with additional instruction (Gurel, Eryılmaz, & McDermott, 2015). In my study, misconceptions are identified in a variety of ways, through a pre-unit content quiz which assessed common misconceptions about thermal energy transfer, climate change, and the Earth's atmosphere, as well as through the use of a draft model of the climate change in bottle experiment. In the case of the draft models, seeing a student put the classic "IDK" standing for "I don't know" is a great indicator of lack of knowledge verses a misconception.

Engaging Learners Through Discrepant Events:

Discrepant events are regularly used in science teaching to help generate student questions and models of natural phenomena and are core to the Next Generation Science Standards (NGSS) Science and Engineering Practices. Femsham and Kass (1988) frame the potential for misconceptions using discrepant events. The authors discuss the fact that there can often be an issue where students develop misconceptions from discrepant events, or from successive science knowledge displayed in textbooks (Fensham, & Kass, 1988). The work relates to my action research, as one of the main modes I used to help uncover student misconceptions was with discrepant events. Moving through the self-paced online learning platform, most of the concepts my students come across is through their own independent reading, which is touched on only if the concepts relates to the project being addressed. It is important to keep in mind that a disequilibrium event may engage a learner, but it does not mean that the desired learning outcome will naturally happen. Therefore, continuous monitoring and feedback is essential to help guide students through the discrepant event process so that they can form accurate conceptions of the phenomenon (Fensham, & Kass, 1988).

A thesis paper by Sharon M Hagen titled, "Surprised Into Learning; Discrepant Events and Their Various Uses in an 8th Grade Science Classroom," provides strategies for evaluating student understanding and explanation of discrepant events. Hagen's research centered around the question, "What teaching strategy increases effectiveness of a discrepant event?" In this thesis the author describes in detail the strategies that she used for teaching the discrepant events. Additionally, she described her triangulation method of using student work, informal and formal interviews, and anecdotal records to collect and analyze her data. One notable qualitative observation that the author made was to observe student reactions during the description of event.

Many conflicts exist when playing the dual role of teacher and researcher. One strategy used by Vincent Mancuso for researching impacts of discrepant events on learning was to provide both written and oral reassurance to students that, "their grades would not be affected in anyway by their choice to participate or not participate in this study" (Mancuso, 2010, p. 37). Like Hagen, Mancuso looked for student behaviors which demonstrated a curiosity or piqued an interest during the discrepant event. Research here required students to predict and explain before any of the discrepant events were conducted, which helped probe initial student understanding (Mancuso, 2010). Student predictions and explanations were shared during class discussions, prior to conducting the events.

Modeling

Modeling is one of the NGSS Science and Engineering Practices that is assessed as a Cognitive Skill multiple times in this project. To understand modeling as a skill it is important to know that models must change and adapt to new information and show how new information is integrated. A definition of modeling by the organization Ambitious Science Teaching states that, "Modeling is the process by which scientists represent ideas about the natural world to each other, and then collaboratively make changes to these representations over time in response to new evidence and understandings" (Ambitious Science Teaching, 2005, p. 1). At the middle school level, the performance expectations for modeling in grades sixth through eighth include, "progresses to developing, using, and revising models to describe, test and predict more abstract phenomena and design system" (NSTA, 2014, p. 2).

The skill of modeling has been well researched and is promoted as an alternative form of assessment of student understanding (Shademan, 2014). This study explored the strength of using pedagogical strategies such as modeling to help reach African American young men. In this paper, Shademan analyzed the game of spades played by African American young men in a low performing high school. He used in-depth observations and interviews to construct models of decision-making based on variables to demonstrate that students come to the classroom with ample background knowledge that would connect well to the pedagogical strategy of modeling. His paper indicated that modeling may be an effective way to bridge cultural gaps in learning scientific class concepts. This connected to my research focus in a general way because of my school's diverse demographics. I work with a high percentage of students of color, with special needs, and from disadvantaged backgrounds, who may benefit from modeling as an access point to demonstrate their understanding of natural phenomena. Part of the reason I chose to research this project is that I will assess students' cognitive skill of modeling for the second time. I have noticed from last year's classes, that the hands-on nature of this project is very engaging for students and has the potential to show differentiated levels of understanding.

Work by Ibrahim Halloun (2006) also details the importance of engaging learners through the process of modeling and breaks down key parts of mediated modeling and the role of the teacher in helping direct student thinking. One key component outlined in the work is the breakdown of the tenets of mediated modeling. The first tenet is, that a course must be structured in a way that provides a meaningful learning process for students. Second, teachers need to provide students with a process that simulates how scientists historically developed scientific understanding. Third, a teacher needs to provide explicit structure for modeling. Finally, teachers must put forth rigorous and flexible lesson plans. This helped inform my teaching because I was able to view the process of modeling as one output that is part of a holistic plan for student concept attainment.

Work by Tsui and Treagust (2012) examines the process by which students construct biological diagrams and explores the hierarchical order of life from micro- to macro- level organisms. A key point made by the authors, is the need to develop teacher content knowledge in order to further engage and guide students in creating comprehensive models (Tsui, & Treagust, 2012).

Finally, in an activity-based instructional framework, students must utilize all knowledge as well as content specific language, tools, and scientific practices in order to accomplish a task. A core duty of the teacher is to provide the instructional framework which relates to the NGSS storylines that provide a series of events which help engage learners. A teacher's role is to: 1) provide excellent exemplars, 2) setup thoughtful frameworks, 3) motivate students to activate prior knowledge 4) help students drill down on questions that are authentic to the issue, and 5) guide students through their analysis (Prins, Bulte, & Pilot, 2016). In this research I assessed students' ability to overcome misconceptions through the process of feedback, but the instructional framework and activities were planned and formatted for the benefit of all students in my classroom.

Formulating Feedback

The main treatment in my research is teacher feedback targeting student misconceptions in their models. This was designed to help me assess if teacher feedback is an effective tool that can be used to move students forward in their conception development. The implementation of the feedback tool was isolated, by collecting student work directly after teacher feedback is given. There is some evidence in the research that formulating the type of feedback to include not only refutations of a misconception but also an explanation for the correct answer increases the likelihood that a participant will alter their incorrect belief (Rich, Loon, Dunlosky, & Zaragoza, 2017). In general, people are more apt to believe feedback is valid if it contains an explanation (Rich et al., 2017). My treatment will include both brief as well as detailed feedback in written form to help assess whether there is a difference in student's ability to overcome a misconception through feedback alone.

In order to conduct this research with my students I needed to integrate best practices around the use of discrepant events, modeling, and feedback. Before beginning to collect information on my students and their misconceptions it was useful to examine my own biases around misconceptions and understand that there are significant differences in the types of misconceptions and a variety of reasons students may hold them as well as reasons they may replace them with correct conceptions.

METHODOLOGY

The purpose of this study was to assess the effectiveness of feedback on students' ability to overcome misconceptions. The research was designed around one main research question and two supporting questions (Table 1). Feedback was given to students, through their draft models both within the Summit Learning Platform, comments through the google docs and in written feedback on sticky notes. Additionally, students attended lessons that specifically addressed a lack of knowledge amongst all students in the class as well as being provided resources that gave additional information about the phenomena they explained and integrated this into their models. I looked at work from all four of my sixth-grade integrated science classes (*N=85*) to identify students who had unique misconceptions outside of the identified general lack of knowledge on the part of the whole group. The group sample size varied according to student participation in the pre- and post-surveys, as well as interviews. Only data from students who participated in both the pre- and post-project surveys was used. An exemption for this research methodology was received from the Montana State University International Review Board (Appendix B) and compliance for working with human subjects was maintained throughout the study.

To begin to identify areas of student misconception before the beginning of the Climate Change project, a five-question content survey was administered to each participating class (Appendix D). This was administered during class and students were told in both writing, and on the survey that participation was voluntary. The survey assessed content knowledge related to thermal energy transfer, climate change, and the Earth's atmosphere. The survey information was collected and analyzed for descriptive statistics, trends, and graphically for distributions of pre-and post-scores. To analyze whether there was a statistically significant difference between the pre- and post-project scores a Randomization Permutation test was conducted.

Additionally, prior to initiating the treatment, a voluntary survey of student attitudes and use of feedback was given through google surveys. This survey addressed sub question 2: To what extent do students utilize teacher feedback to improve their cognitive skill scores and revise their content understanding? The survey was distributed to sixth-grade students (new to the Summit Learning platform and process) after the class had already completed at least two projects in each class with full feedback cycles on Checkpoints. The survey was a mix of Likert items concerning how students used teacher feedback and Likert Scale questions about the perceived usefulness of feedback for their understanding of both cognitive skills and content. I later coded these answers in a one to five scale to do quantitative analysis. Students also had the opportunity to write in answers and provide additional thoughts about the feedback process. Data from this survey was collected and analyzed for pre-project and post-project differences. It was analyzed graphically and for normalized gains, and a Wilcoxon Signed Rank Test was used to evaluate whether the difference between the pre- and post-project scores were significant.

Both surveys were also given at the end of the project, after most students received their final project grades. The data was edited to match, including only students who participated in the pre-surveys and the post-surveys. At the time of post-survey distribution, nine students still had not received a grade for completed work.

The treatment period began in January of 2019. The entire class observed an instructor-led in-class demonstration. The demonstration showed students two plastic bottles containing water. An Alka Seltzer tablet was dropped into one of the bottles (in-fluxing extra carbon dioxide); however, with a normal-air-bottle, the cap was left off during the reaction and then screwed on for the start of the experiment. This allowed for the carbon dioxide to escape the normal-air-bottle while in the other bottle the carbon dioxide was trapped. Students predicted which bottle would be warmer after a 15-minute incubation period. Most students have some background knowledge regarding global climate change and thus correctly predict that the bottle with the extra carbon dioxide will be warmer. Most students, however, fail to provide scientific reasoning for their choice. Students were given an opportunity to review concepts related to greenhouse gas effects and also develop a draft model for how chemical reactions occurring inside their plastic bottles connect with processes occurring in the Earth's atmosphere and the effects of greenhouse gases.

Students were asked to complete a quick exit ticket, creating a model which explained what they thought was happening inside the bottle to increase the internal temperature and how they envisioned heat from the lamps transferring to the bottles. These initial models were handed in to the instructor and analyzed for accuracy and detail in explanation. Models with a high level of detail (approaching the standards for modeling) were collected and added to a google doc that students viewed in the next lesson. The following class session, students took part in a lesson which employed an alternative discrepant event focusing on the thermal energy transfer of convection. After a short discussion of how we could begin to show what was happening in the new event through a model, a teacher generated model was displayed and evaluated by the class using the rubric. The model was used to demonstrate an exemplary model for students, clarifying components that must be included in order to make it to a higher score on the rubric equal to a B or an A grade for the final product. After the discussion, students reviewed their models and general feedback given from the previous class period, discussing what modifications were needed to reach a Level two, three, or four. A short review of the experiment was given, and the data on internal bottle temperatures that had previously been collected was projected on the board. Students then drew their first draft models of the climate change in a bottle experiment for their first round of personalized feedback. The models were submitted formally to me on paper.

Feedback on the first draft models was given in class on handwritten sticky notes attached to their hard copy models. Additionally, students were given feedback on the platform (green, yellow, red color change). To prevent students from losing their initial model picture and handwritten feedback, scanned images of the model and feedback were loaded into the online platform. Additional resources were provided to the students through links in digital feedback as well as a general resource page. Student misconceptions were identified, categorized, and analyzed for trends. Misconceptions considered to be a simple lack of knowledge were addressed with the whole class and consisted of a re-teaching lesson on the day the draft models were given back. Common examples of general knowledge gaps included the idea that infrared radiation travels across the same wavelength range and visible light and that molecules of carbon dioxide should be represented in the model using symbols, like circles, to make it more accurate.

Two different types of feedback were given to students with identified unique misconceptions. Students in my second and fourth classes of the day were considered part of Group A and were given feedback that was very detailed including identification of their misconception, an example explaining how to think about this idea, and a suggestion to look at resources and revise their work. If appropriate a small drawing was included. The two remaining classes, my third and sixth classes of the day, were part of Group B and given only feedback that identified their misconception and a suggestion to review resources provided. Both groups were given handwritten feedback on sticky notes (Figure 1). Students in both groups received feedback on their models through a similar handwritten process.

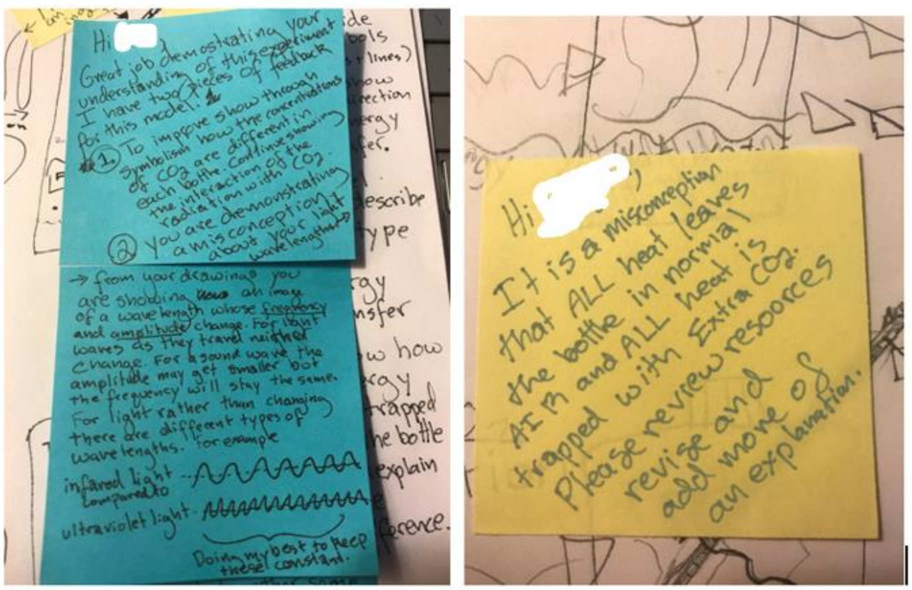

Figure 1. Typical feedback given to students in group A (left) compared to group B (right).

Time was provided in class for students to revise their draft models directly after receiving feedback. Students who completed their final models during the class period were considered to be the group directly affected by the instructor feedback. For these students, a comparison between the draft and final models was made. Students with identified misconceptions in the original models were reassessed to see if the misconception persisted in the final model. A statistical analysis of the number of students who displayed a conceptual change in their understanding was made between group A feedback and group B feedback using a Chi-squared test for comparison

(Appendix G). The data was used to assess whether there was a significant difference in student understanding if detailed or brief feedback was provided.

Finally, following project completion, interviews were conducted with students to discuss the process of overcoming their initial misconceptions. These were held informally during my prep period, with students pulled from classes. Students were reminded that the interviews were for research purposes, that participation was voluntary, and that participant responses would have no impact on their grade. Insightful comments and explanations were included in the Data Analysis section.

DATA ANALYSIS

The results of this study address the primary and sub research questions including the impacts of teacher feedback on student misconceptions, identifying student misconceptions, and student use of teacher feedback. A total of 22 students were identified to hold specific misconceptions in their first draft models. Personalized student feedback did appear to impact a student's ability to overcome misconceptions, with 45% of students overcoming their misconceptions through the process of personalized feedback alone while the remaining 55% of students required additional interventions (*N=22,* Table 2 & Figure 2). The pathway to overcoming student misconceptions was categorized based on whether a student was able to overcome the misconception from feedback alone, or whether an additional intervention was required (Appendix F). The change can be directly attributed to the feedback process, as final project drafts were created during class directly after feedback was handed back, with students working on their models independently. Additionally, the amount of detail in the personalized feedback did not significantly affect students' ability to overcome their misconceptions. In a comparison of students in group A, given detailed feedback, and group B, given brief feedback, there was a not a significant difference in overcoming misconceptions through feedback (p-value 0.70 chi-square test). Of the remaining 14 students who had persistent misconception in the 2nd draft of their models, all but two, were able to completely or partially overcome their misconceptions through a small group reteach lesson, or through a personal conference intervention (Table 3).

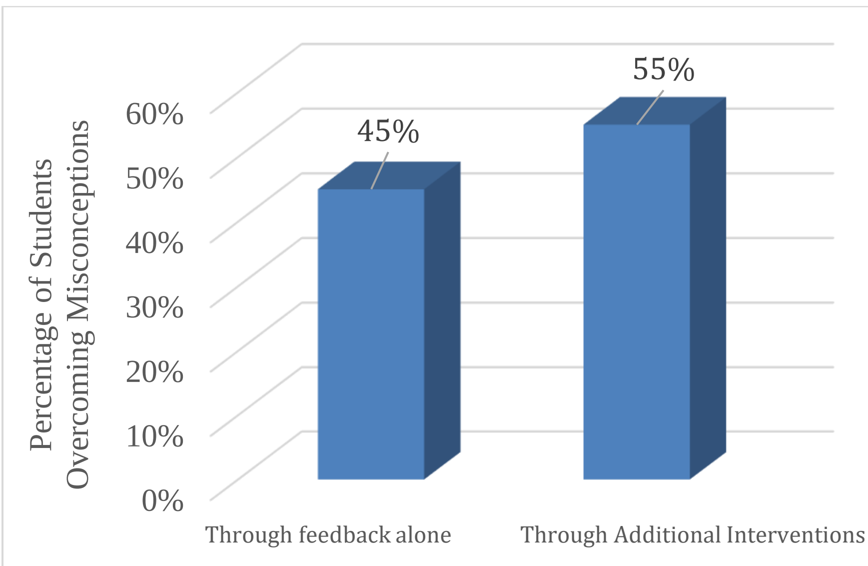

Figure 2. Student pathways to overcoming misconceptions Students who were able to overcome their misconceptions through feedback alone compared to students who required interventions to overcome misconceptions, (N=22).

Table 2

Comparison of Pre-treatment and Post-Treatment Final Models and Types of Feedback for Students with Misconceptions

	Counts	Percentage
Students given Type A feedback	12	55%
Students given Type B feedback	10	45%
Complete – Misconception overcome in final product	14	64%
Partial – misconception overcome in final product	6	27%
No – misconception overcome in final product	2	9%
Overcoming misconception can be attributed directly to feedback	10	45%
Additional Interventions needed to overcome misconception	12	55%

Note. No significant difference was determined between Type A feedback and Type B feedback, (p-value 0.70, Chi-square test, *N*=22).

Table 3

Effectiveness of Interventions

	Counts	Percentage
Interventions effective at helping overcome misconception	5	42%
Interventions not effective	2	16%
No intervention occurred	5	42%

Note. Students who needed additional interventions after personalized feedback on draft models was given, (*N*=12).

Raw data from the pre-and post-project surveys was analyzed to look for trends. Significant gains in understanding from the pre- and post-surveys included understanding about radiation energy transfer, with a 27.4% increase in correct conception observed following project completion (Table 4). Furthermore, two significant misconceptions were identified in the pre-survey related to how humans impact greenhouse gas emissions and the misconception that "the atmosphere is very large and there is no way that adding carbon dioxide or any gas to it could change the climate." These were interesting misconceptions because they directly contradict each other. In the post survey scores, the number of students still believing the misconceptions was greatly reduced. Students who believed humans were the sole cause of greenhouse gas in the atmosphere was reduced down to 12%, while students who argued it was not possible for gases to affect climate change was reduced to 18%.

Table 4

Raw Percentage Gains Between Pre- and Post-Climate Change Survey Comparison

Correct Concept	Pre-Survey Correct Conception	Post-Survey Correct Conception
Certain molecules called greenhouse gases trap infrared heat that is leaving Earth's surface and re-emit the heat.	61.2%	85.9%
Overtime changes in the Earth' s atmosphere composition such as increases in carbon dioxide can have large and lasting effects,	62.7%	82%
Objects stay warm or get warmer by trapping heat from a heat source. The sweater traps heat from your body.	72.1%	78.1%
When the particles of an object move faster (like boiling water) the temperature rises.	61.8%	69.2%
Through radiation – heat travels as energy waves through space.	50.7%	78.1%

Note. (*N*=50).

Sample sizes differed in the pre- and post-climate change survey due to participation and enrollment changes. In order to calculate normalized gains for the conceptual understandings, the data was matched so that only students who took both the pre- and post-survey were included (*N=50,* Table 5.). Normalized gains in conceptual understanding from the pre-project to post-project survey were 40% and considered a medium amount of gain from the pre-project group. A statistical analysis of the raw matched data using a randomization permutation test indicated that this gain was significant (p. value = 0.00) and not attributed to random chance (Figure 3). The distribution of scores from the pre-project survey were distributed evenly, while post-project scores were heavily skewed to show that many students were scoring in the 80% to 100% range (Figures 3 & 4). The frequency of individuals scoring 100% correct on the content survey jumped from 24% in the pre-project survey to 52% in the post-project survey (Table 5). Overall students who participated in the project lessons, feedback process, and interventions scored significantly higher on the post-project survey about content than the pre-project survey about content (p-value = 0.00, Figure 3).

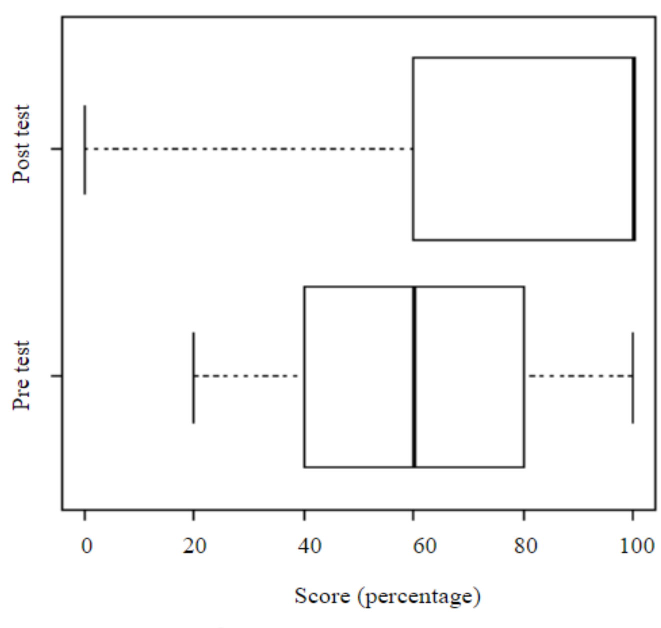

Figure 3. Pre- and post-project content scores comparison showed a significant difference between pre- and post-test that cannot be attributed to chance (p-value =0) Randomization Permutation Test, (*N*=50).

Table 5

Descriptive Statistics, Frequency of Percentage of Students with a Particular Score, and Normalized Gains of Scores from the Content Survey for the Pre-Project to Post-Project Groups

	Pre-	Post-	Raw gains	Normalized Gains
Average	63.6	81.2	17.6	0.4
Mode	40	100	0	0
Median	60	100	20	0.4
Max	100	100	80	1.0
Min	20	0	0	-2.0
Frequency 0% score on survey	0%	2%		
Frequency 20% score on survey	12%	2%		
Frequency 40% score on survey	24%	10%		
Frequency 60% score on survey	22%	12%		
Frequency 80% score on survey	18%	22%		
Frequency 100% score on survey	24%	52%	Medium Normalized Gain	

Note. (*N=50).*

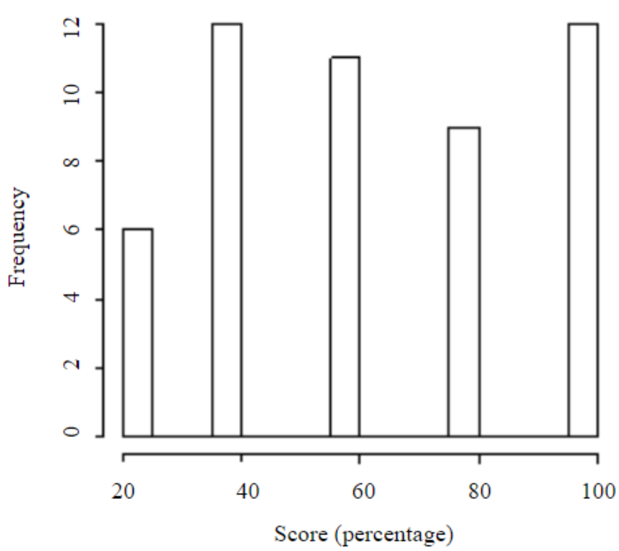

Figure 4. Distribution of scores in the pre-project survey for correct conception of content, (*N=50*).

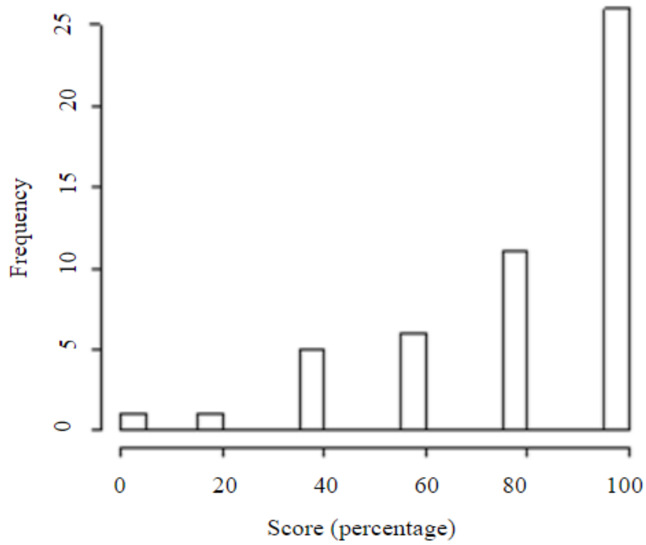

Figure 5. Distribution of scores in the post-project survey for correct conception of content, (*N*=50).

Specific misconceptions in the student models were identified. A total of 22 students demonstrated misconceptions and received feedback on each. Most student misconceptions were unique, occurring only once or twice. An exception to the trend was detected, in that six student models incorrectly described heat as either continually trapped or continually expelled from the bottle all (Table 6.)

Table 6

Specific Misconceptions Identified in Student Models and the Frequency of Occurrence

Misconceptions Identified and Frequency:	Frequency (X=1 occurrence)
Representing CO2 as a line	XX
That the heat travels in a swirly line that folds back on itself from the lamp to the bottle	X
All heat is trapped or all heat passes through the bottle	XXXXXX
Wavelengths of heat gets bigger as they gets closer to the bottle	X
Showing the symbol for radiation as radar not waves	X
Showing trapped heat as a circle	X
Heat exiting the top of the bottle. She thought the cap was left off.	X
That one bottle gets heated up and the other does not	X
Heat is trapped in one area of the bottle	X
The atmosphere is represented as the area in between the bottle and the lamp	X
In one bottle the energy transfer is radiation and in the other it is conduction	X
Representing CO2 as a cloud	X
The amount of energy coming from the lamp is different	X
Showing no difference between the bottles	X
That one bottle gets heated up and the other does not,	X
Vertical lines inside of the bottle representing convection	XX
There is only CO2 in one bottle	X
Heat is transferred directly to the thermometer	X
The water temperature is what is measured	XX

Note. (*N=22*).

Multiple forms of data also suggested students had a neutral to positive attitude about teacher feedback and its utility. Data for attitudes and perceptions about the usefulness of feedback was collected through surveys and in-person interviews. In the pre-project survey, most students (88.1%) stated they used teacher feedback to improve their work all or most of the time (*N=76*, Figure 6). Through the Likert scale questions, student attitudes were assessed, examining how feedback helped students improve cognitive skills and content retention. For questions regarding cognitive skills and content, in both pre- and post-project surveys the distribution scores were normal, with student agreement ranging from 3.51 to 3.67 on the Likert scale (Table 7). Although there was an observed reduction in the mean between the pre and post surveys for attitude (Figure 7), the difference between each group was not significant, regardless of the question. The Wilcoxon Signed rank test gave p-values that were not significant with a 95% confidence level, for cognitive skills (p-value =0.49) and content (p-value=0.87).

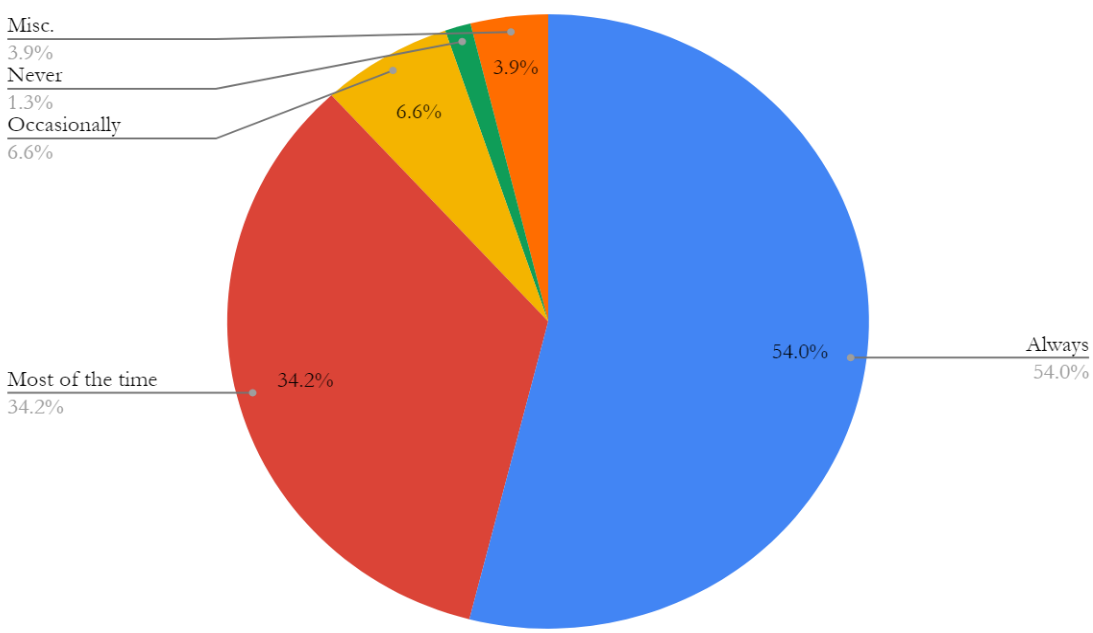

Figure 6. Pre-project survey results asking students how often they use provided teacher feedback, (*N*=76).

Table 7

Descriptive Statistics and Frequency of Students' Responses for the Likert Scale Survey Questions About Attitude

	Pre-Cognitive Skills – Mark how much you agree with the following statement – My teacher's feedback helps me understand the cognitive skills I am learning.	Pre-content – Mark how much you agree with the following statement – My teacher's feedback helps me understand science concepts.	Post-Cognitive Skills – Mark how much you agree with the following statement – My teacher's feedback helps me understand the cognitive skills I am learning.	Post-Content – Mark how much you agree with the following statement – My teacher's feedback helps me understand science concepts.
Average	3.67	3.58	3.60	3.51
Mode	4.00	4.00	3.00	3.00
Median	4.00	4.00	3.00	3.00
Max	5.00	5.00	5.00	5.00
Min	1.00	1.00	1.00	1.00
Standard deviation	1.11	1.14	0.94	0.94
Frequency 1	6.67%	8.89%	2.22%	2.22%
Frequency 2	6.67%	6.67%	4.44%	6.67%
Frequency 3	22.22%	20.00%	44.44%	44.44%
Frequency 4	42.22%	42.22%	24.44%	24.44%
Frequency 5	17.78%	15.56%	17.78%	15.56%

Note. 1=strongly disagree, 2= disagree, 3= neutral, 4=agree, 5=strongly agree, (N= 76)

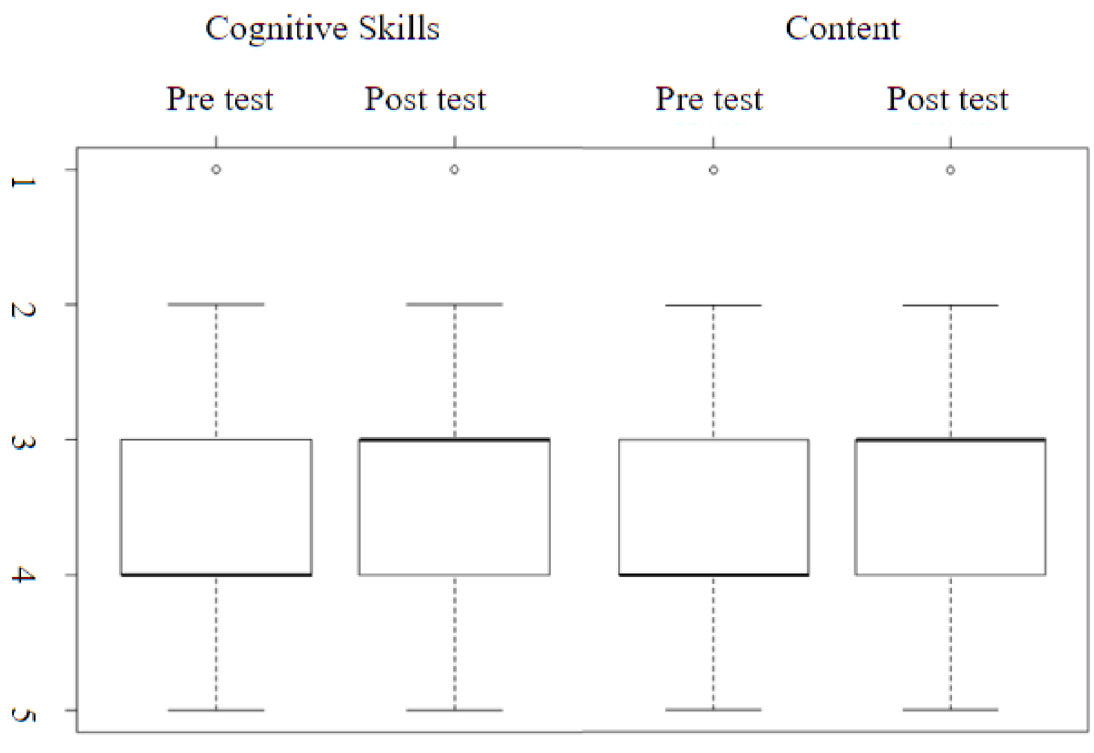

Figure 7. Comparison of Pre- and Post-Score in student attitudes towards teacher feedback. No significant shift in attitudes was observed for either cognitive skills or content learning, (*N*=45).

Further evidence of the mixed attitudes students displayed with regards to the usefulness of teacher feedback can be seen in the write-in answers on the survey. Answers ranged from very positive, as shown with statements like, “I think the feedback cycle is better than what most schools do and helps students actually learn,” to highly negative, with one student stating “it does not help me at all.” There were also some insightful comments from students such as, “In my opinion (not trying to be mean) Could you please explain what you mean more if I do something wrong because some of the time I don’t get what you’re asking and so I have to ask my teacher, so could you please explain my mistakes more, possibly/mainly by giving a big example?” This showed that students were engaging in the process and questioning the feedback process. One student shared his preference for verbal feedback over written feedback stating, “It’s just helpful for me to listen to your comments.”

Although many students oscillated around neutral to positive attitudes about teacher feedback, I found through my observations and interviews with students, that some students perceptions about the usefulness of feedback were highly variable. For one student, whenever a non-green checkpoint was provided on an assignment, her immediate reaction was anger, followed by the question, “Why did I get yellow/red on my checkpoint?” This student often rejected my feedback until redirected to read it carefully with me beside her. In this project I handed back her feedback in a hard copy with the sticky note attached to it and was able to direct her to read the feedback carefully first. The student’s work in the draft model demonstrated a clear misconception (Figure 8A). I was able to sit and talk with her after she submitted her revised work for the final draft (Figure 8C). When I asked her what her process was for using the feedback she said, “I read it and fixed it, end of story.”

When I spoke with another student who had a misconception about the way heat energy travels through space as infrared radiation (Figure 8) she generally had a positive attitude that the personalized feedback was good and useful (Appendix H). This was interesting, given her neutral answers in both the pre- and post-surveys. During the in-person interview with this student, when asked what helped her improve her work for the final model she answered, “Definitely the feedback, because the feedback told me what to fix. I understood the feedback and put it into this model.” When I asked her what she considered good feedback she explained, "Very specific feedback and just feedback that would help overall. Not just saying one part and in the next round of feedback a totally different part, so that hopefully in the next round I could fix all of the parts and not use up my rounds of feedback."

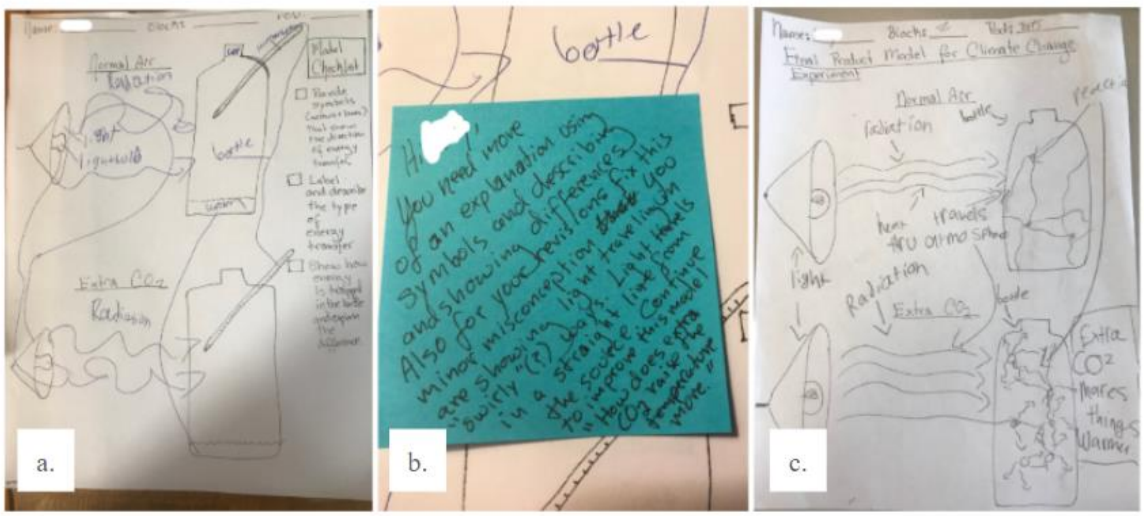

Figure 8. Student draft model and feedback (a &b) with revised final draft model showing revision to misconception.

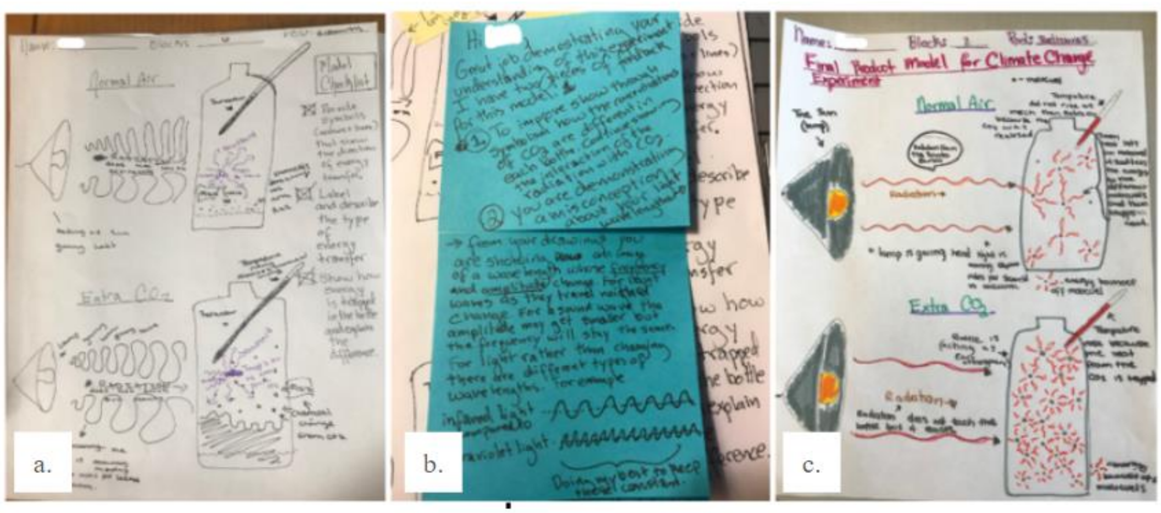

Figure 9. Student work with feedback on draft model (a. &b.) and final model with revision to misconception.

A final observation was that students who overcame a specific misconception following the personalized feedback provided for their draft model, would often introduce new misconception in their final model. For example, for student data shown in both Figures 8 and 9, new misconceptions were present in the final drafts. After fixing her misconception concerning the pathway of infrared heat (Figure 8 C), the same student demonstrated a misconception by showing that all the heat was trapped inside of both bottles. Similarly, the student from Figure 9 corrected her original misconception, but her final model included a new misconception that the radiation does not touch the bottle. In both cases students fixed their misconceptions based on the provided feedback, but then demonstrated additional misconceptions or lack of knowledge about the content.

INTERPRETATION AND CONCLUSION

Three major findings were supported from this research about students' ability to overcome misconceptions through feedback. The first is that feedback is helpful to students who demonstrate misconceptions. Personalized feedback was effective for 45% of students in helping them overcome misconceptions demonstrated in their models. The remaining 55% of students required a small group or personalized intervention to successfully overcome misconceptions, with two students having yet to overcome the misconception. The second is that the type of feedback given did not matter. There was no significant difference between providing detailed or brief feedback in helping students overcome misconceptions. This conclusion was supported by the categorical analysis using the chi-squared test (p-value >0.05). This was contrary to results generated in Rich et al., where more participants corrected their conception when feedback included a detailed explanation rather than just a refutation. The third major finding from work here is that it was observed that many student misconceptions were unique and specific. This was a surprising finding because in the previous school year, I primarily observed three to four main misconceptions regarding the transfer of thermal energy.

This research project has implications on my future teaching practices. I plan on continuing to provide students with feedback but will make my responses brief and spend the time saved planning small group interventions for students with similar misconceptions in cases where overlap occurs. For students with unique misconceptions, I will provide more opportunities for in-class feedback in person and plan in-class check-ins. Providing students with links to examples in aggregate can also be a helpful practice, although metrics for how much students interacted with provided links were not collected. Exemplars and resources can easily be given through our online platform and through google doc comments. Additionally, I will integrate the practice of reviewing student models for misconceptions and trends and preparing resources that can help them overcome their misconceptions.

The findings from this study are consistent with Hamza & Wickman's study where student misconceptions played a minor role in students' ability to explain in an alternative assessment of a verbal practicum (Hamza & Wickman, 2007). Similar to their study, in utilizing student models as my assessment I was able to look at student understanding in several modes, both visually and through their explanations. In analyzing student models for misconceptions, a variety of misconceptions were unexpected. This phenomenon has been described previously by Fensham and Kass and solidified my understanding that rigorous monitoring and adjusting is required when conducting projects where students are tasked with explaining and describing discrepant events.

Much of this research went as planned; however, the project overall was interrupted by several school breaks, successive snow days, a soft lock down, and the reading and mathematics quarterly testing. Thus, the flow of supporting lessons in the project were somewhat disjointed; however, the process of providing feedback during the same class period as when students were allowed to revise work was not interrupted. One area for improvement would be to include more rigorous pre- and post-surveys, with additional questions which probe student attitudes about the usefulness of feedback. Providing more Likert scale items like, “I enjoy reviewing feedback from my teacher” or “I find it easy to fix my work based off of my teacher’s feedback” would be helpful in further determining student attitudes about feedback. Additionally, I was only able to interview a few students during the research period, due to my school’s schedule. I had originally planned to conduct the interviews during my prep period; however, this was not possible due to other duties around the school.

This research raised many questions about the effectiveness of feedback and the influence of student attitudes on feedback effectiveness. Although there was no significant difference between the brief and detailed feedback groups in their ability to overcome misconceptions, I noticed a trend that students who received detailed feedback were often only able to partially overcome their misconceptions, while students who received brief feedback were more likely to completely overcome their misconceptions

(Appendix F). This leads me to wonder if brief and direct feedback is better for student achievement. Also, of interest to me is the effect of student attitudes about feedback and its effectiveness. While there was no significant difference in student attitudes about the usefulness of feedback between the pre-project and post-project scores, I noticed a drop in the average attitude after the project completion. This could simply be due to the timing of the post-project survey, which was distributed at the end of the official feedback cycle. At this time, several students who had turned in late work were still in the red for several checkpoints. My prediction is that students who disagree that feedback is useful, are less likely to review and use the feedback. I was surprised to find that several students in this study who had negative attitude towards feedback in the pre-project survey engaged readily in the feedback process and had significantly higher post-project scores. I am further curious to find how quickly students change their opinions about feedback and its usefulness and what might influence their attitudes.

VALUE

Feedback, along with many other processes in teaching, is a time intensive task. Teachers who work in schools where students must achieve passing scores on each project in order to move to the next grade know that feedback is an essential part of the teaching process. Through this action research project, I was able to integrate practices that helped me organize my feedback and support for students to a level of depth that I had not before. It was necessary for me to be consistent in the way that I gave feedback and evaluated its effectiveness on student learning. This research also caused me to create very clear lines about my role as a guide and as the assessor of student understanding.

The process of identifying student misconceptions in models and categorizing them helped with planning targeted interventions. For example, I was able to clearly see that many students did not view the gas in the bottle as particles that may interact with the heat from the lamp. I was able to model for them how gases can be represented as particles in models through another discrepant event and all students improved their models through this lesson. Also, I could tell that many students did not grasp that heat from the lamp travels through space in a wave. We had not explicitly covered how infrared radiation moves through space just that heat travels through space. We reviewed this idea together as a class and many students integrated the wave concept in their revised models. Students still received the feedback that they needed to include this idea, but I coded this misconception as simply a lack of knowledge that many students had and targeted it for a whole class lesson.

One outcome that this research had on my teaching practice is the implementation of mastery badging for my students. In the next project called, Human Body Book, students needed to first achieve a mastery badge before they could move on to creating a draft of their book. To achieve mastery, students needed to receive yellow or green feedback in each of the first four checkpoints before they could access art supplies. This seemed to energize my students and made them hungry for feedback. I worked with my students on classroom behavior so that we could integrate a high amount of small group instruction and one-on-one teacher conferences. I have also started to include the Cognitive Skill of Precision which requires correct use of terminology and symbols at project checkpoints.

One of the primary reasons that I pursued an action research project centered around feedback was due to my previous years' experience as a first-year middle school teacher and feeling highly ineffective as a classroom manager. I was coming back to teaching after a year off working for the National Science Teachers Association and in addition had previously taught high school classes in California. The combination of being out of practice with classroom management, teaching middle school students for the first time, the cultural differences of Seattle students, and the high level of students with trauma experiences, left me with few options for a controlled study of dynamic models of teaching. Socratic seminars, weekly labs, discussions, and small group lessons that I used to fluidly run in my high school classes seemed impossible to do at the beginning of the year. I looked at what I could control even if my lessons did not go as planned. The process of feedback seemed like a natural fit.

Throughout last year and this year, I worked to expand my locus of control in the classroom, by integrating practices from Doug Lemov's Teach Like a Champion. Through this research I have been able to see how, in addition to feedback, my instructional practices and teaching practices have a large impact on how students overcome their misconceptions. Through this research I was able to think deeply about what happens in my class and how I use my classroom time to help meet student needs. By improving my classroom management skills, I have found room to reintegrate the level of academic discourse which I know helps my students gain knowledge, and understanding, as well as practicing important skills like formulating arguments based in evidence.

In refining my skills and processes related to student feedback, I have created a strong net with which to catch students in their learning process and have them replicate the process that scientist must go through. This is an essential piece of student learning in science and for society. It is important for students to know that they can regularly make mistakes, adapt by integrating new evidence more correct scientific concepts, and adopt new models of thinking. Currently, in the United States and the world there is an increasing number of people who reject evidence-based science around such things as the process of evolution, the efficacy and safety of vaccines, and human created climate change. This is due to rigid forms of thinking that do not integrate the preponderance of evidence and shows a lack of understanding for how conclusions are made through the scientific process. It is paramount that we as science teachers provide our students with opportunities to be wrong and to go through the process of revising their work and their thinking around scientific concepts like scientist. Perhaps, if we do this, we may produce the critical thinkers our society needs.

We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.

- E. O. Wilson

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APPENDICES

APPENDIX A

COGNITIVE SKILLS RUBRICS FOR 6TH GRADE SCIENCE

PROJECT CLIMATE CHANGE

Rubric for Climate Change

Grade 6 - Levels 2 ~ 4 | Search with keywords | Export Actions

Analysis & Synthesis	2	3	4
Justifying / Constructing an Explanation Using logic and reasoning to justify a response or explain a phenomenon	Provides some detail in explaining steps, procedures, or a phenomenon. Uses concrete details/examples to explain reasoning.	Provides a logical chain of reasoning to justify steps or procedures, or to explain a phenomenon. Uses concrete details/examples and/or disciplinary ideas to justify reasoning.	Provides a logical chain of reasoning to explain or justify specific steps, procedures, or phenomena. Develops explanation/justification with some detail/examples.
Making Connections & Inferences Connecting ideas and making inferences based on evidence or reasoning	Makes an inference based on evidence. Refers to a specific example relevant to the inference.	Makes relevant inferences based on evidence. Makes clear connections between two or more specific examples relevant to the inferences.	Makes relevant inferences based on evidence and identifies the larger significance of the inference. Connections between a specific example and the larger idea are clear and appropriate.
Modeling Representing concepts** with models, visual representations or symbols. And/Or Using appropriate tools to understand and analyze situations. **"Concepts," in this dimension, refers to abstract situations/information, processes, and systems	Identifies specific components of a concept and develops a simple and partially accurate physical, visual and/or abstract model to represent key features	Identifies specific components of a concept and develops a simple but accurate physical, visual and/or abstract model to represent key features.	Identifies significant components of a concept and develops an accurate physical, visual, and/or abstract model to represent key features.

Products & Presentations	2	3	4
Conventions Using discipline-appropriate conventions to support clear expression of ideas and information	Uses the conventions of the discipline. Errors are few/minor, and do not impede understanding.	Uses the conventions of the discipline with some consistency. Minor errors, while noticeable, do not impede understanding.	Uses the conventions of the discipline with consistency. Minor errors do not impede understanding.
Precision Expressing ideas and information with exactness, specificity, correct use of terminology, and refinement	Expresses some ideas with specificity appropriate for the given purpose. Correctly uses relevant terms, symbols, etc.	Expresses ideas with specificity appropriate for the given purpose. Defines key terms, symbols, etc.	Consistently expresses ideas with adequate specificity for the given purpose. Defines terms, symbols, etc.
Style and Language (Tone, Academic Language, Syntax) Using appropriate style in a written product, including academic language, tone, and syntax	Uses general academic or specialized language appropriately, and uses formal language when appropriate to purpose. Word choice is precise and supports the purpose.	Uses general academic or specialized language precisely and uses formal language when appropriate to the purpose. Sentences vary in structure; word choice is precise and supports the purpose and reader/listener interest.	Consistently uses a formal style with some academic or specialized language. Sentence structure is functional; writing may demonstrate strong control over basic sentence structures but limited control over more complex structures.

Speaking & Listening	2	3	4
Norms / Active Listening Using roles and norms to support collegial discussions and completion of group work	Participates in discussions and follows agreed-upon rules. Carries out assigned roles.	Participates in discussions and follows agreed-upon rules and deadlines. Carries out assigned roles.	Mostly adheres to established norms for collegial discussions. Tracks progress toward specific goals & deadlines. Enacts individual roles independently.

APPENDIX B

INTERNATIONAL REVIEW BOARD EXEMPTION

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

MONTANA STATE UNIVERSITY

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MEMORANDUM

TO: Amanda Wolfe and Marcie Reuer

FROM: Mark Quinn *Mark Quinn CTJ*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 5, 2018

RE: *"The Effects of Individualized Feedback on Science Concept Formation in a Project-based Classroom" [AW110518-EX]*

The above research, described in your submission of November 1, 2018, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

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

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

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

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

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

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

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

Principal Investigator: Amanda Wolfe
Title of Study: The effects of individualized feedback on science concept formation in a project-based classroom.

Your school is invited to participate in this focus group research about feedback and science concept formation. I am interested in finding out your students' views about howthey use feedback and what they currently understand about the concepts of energy, Earth's atmosphere, and climate change and how their understanding changes over the course of the next project.

Your students' participation in this study will require participation in a focus group/survey and possible completion of a questionnaire. This should take approximately 5 -10 minutes of the students' time. Their participation will be confidential/anonymous and no identifying information about their answers will be reported.

Your students will not be paid for being in this study. This focus group/survey and questionnaire does not involve any foreseeable risk to you and there are no direct benefits. However, the benefits of their participation may impact society by creating a better way for teachers to help students in understanding science concepts through project-based learning.

Students do not have to be in this study if they do not want to be. We will be happy to answer any questions you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact me Amanda Wolfe at awolfe@summitps.org.

If you have any questions about your students' rights as a research participant you may contact Montana State University, Masters of Science in Science Education Institutional Review Board (IRB) at **406-994-6783**. An IRB is a group of people that reviews research studies to make sure that participant rights and safety are protected.

Thank you in advance for you participation in this study.

"AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, AKlein *(name of principal) give authorization to* Amanda Wolfe *(name of principal investigator) to conduct* this research. I understand that the students may later refuse participation in this research and that the subject, through his/her own action or mine, may withdraw from the research study at any time. I have received a copy of this consent form for my own records.

Principal's Signature: ________

Signed: ________

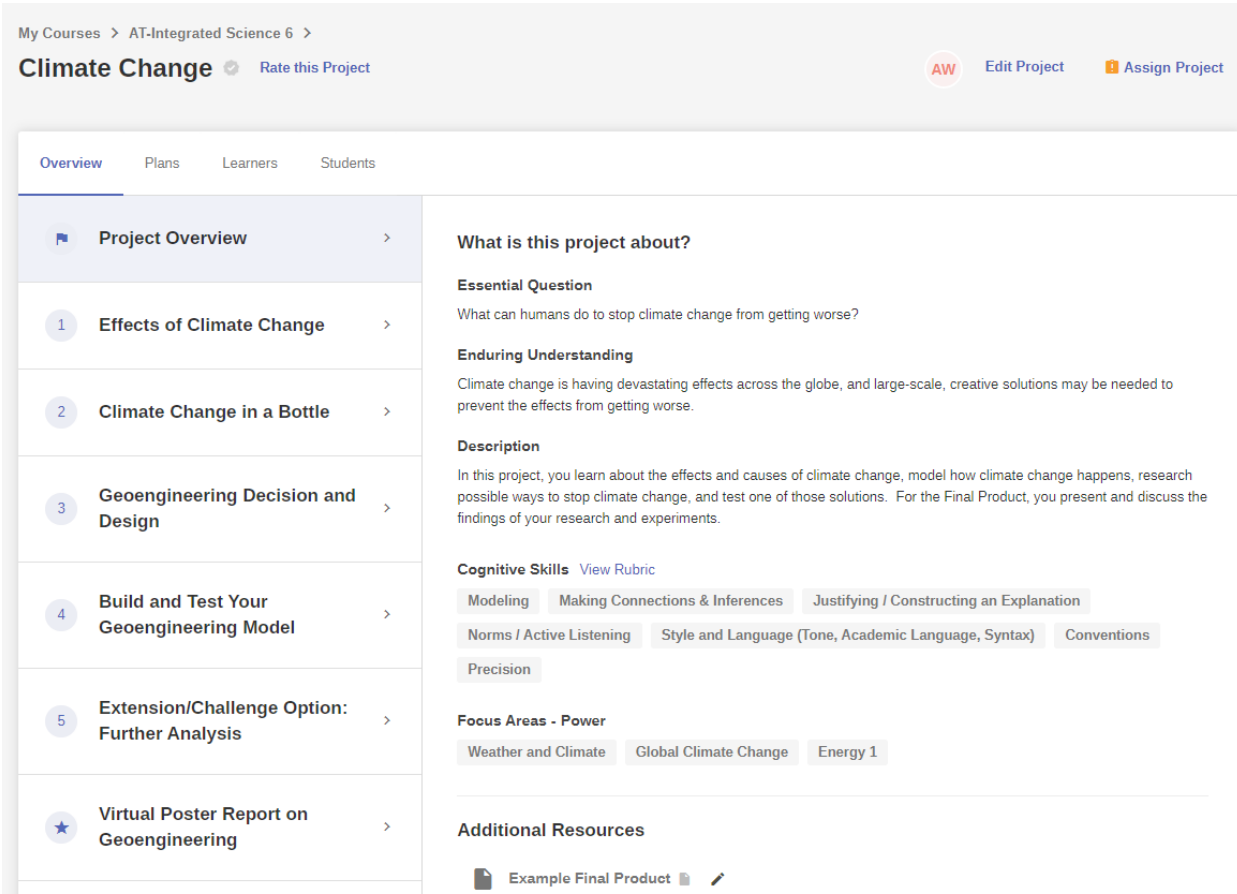
Investigator: ________

Date: 11/1/18

APPROVED
MSU IRB
11/05/2018
Date approved

APPENDIX C.

CLIMATE CHANGE PROJECT OVERVIEW


My Courses > AT-Integrated Science 6 >
Climate Change
Rate this Project
AW
Edit Project
Assign Project
Overview
Plans
Learners
Students
Project Overview
1 Effects of Climate Change
2 Climate Change in a Bottle
3 Geoengineering Decision and Design
4 Build and Test Your Geoengineering Model
5 Extension/Challenge Option: Further Analysis
Virtual Poster Report on Geoengineering
What is this project about?
Essential Question
What can humans do to stop climate change from getting worse?
Enduring Understanding
Climate change is having devastating effects across the globe, and large-scale, creative solutions may be needed to prevent the effects from getting worse.
Description
In this project, you learn about the effects and causes of climate change, model how climate change happens, research possible ways to stop climate change, and test one of those solutions. For the Final Product, you present and discuss the findings of your research and experiments.
Cognitive Skills
View Rubric
Modeling
Making Connections & Inferences
Justifying / Constructing an Explanation
Norms / Active Listening
Style and Language (Tone, Academic Language, Syntax)
Conventions
Precision
Focus Areas - Power
Weather and Climate
Global Climate Change
Energy 1
Additional Resources
Example Final Product

APPENDIX D.

PRE- AND POST-SURVEY FOR CLIMATE CHANGE PROJECT

How is heat from the sun trapped in the Earth's Atmosphere?

- ◯ Certain molecules called green house gases trap infared heat that is leaving Earth's surface and re-emit the heat.
- ◯ Human activities alone like driving cars cause heat to stay in Earth's Atmosphere.
- ◯ Only the ocean traps heat from the sun the Earth's Atmosphere is made out of gas and does not trap heat.

What are the effects of adding carbon dioxide to the Earth's atmosphere over time?

- ◯ Overtime changes in the Earth's atmosphere composition such as increases in carbon dioxide can have large and la...
- ◯ The atmosphere is very large there is no way that adding carbon dioxide or any type of gas to it could change climate.

How does a sweater make you warmer?

- ◯ Objects stay warm or get warmer by trapping heat from a heat source. The sweater traps heat from your body.
- ◯ Objects like sweaters provide heat. The sweater itself makes you warmer because it is the heat source.

What makes the temperature of an object rise?

- ◯ When the particles of an object move faster (like boiling water) the temperature rises?
- ◯ When the particles of an object move slower the temperature rises?
- ◯ Temperature is the measure of the concentration of particles in a substance.

How does heat energy from the sun reach planet Earth?

- ◯ Through radiation - heat travels as energy waves through space
- ◯ Through convection - heat travels up in space to reach the Earth.
- ◯ Through conduction - heat energy from the sun conducts directly to Earth

APPENDIX E

PRE- AND POST-SURVEY ATTITUDES AND USE OF FEEDBACK

How often do you submit your checkpoints on time for feedback?

- Always - I submit my work every time for both round 1 and round 2 of feedback for each checkpoint
- Most of the time - I submit my work for at least one round of feedback for each checkpoint
- Occasionally - I submit some of my checkpoints for feedback
- Never - I do not submit my checkpoints for feedback
- Other...

How often do you use feedback from your teacher to improve your work?

- Always - I always read and revise my work based on my teacher's feedback.
- Most of time - I usually read and revise my work based on my teacher's feedback.
- Occasionally - I sometimes read and revise my work based on my teacher's feedback.
- Never - I never read or revise my work based on my teacher's feedback.
- Other...

Mark how much you agree with the following statement - My teacher's feedback helps me understand the cognitive skills I am learning.

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree
- Other...

Mark how much you agree with the following statement - My teacher's feedback helps me understand science concepts.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly Disagree
- Other...

Please provide any additional comments or thoughts that you have about the feedback cycle.

Long answer text

APPENDIX F

STUDENT PATHWAYS FOR OVERCOMING MISCONCEPTIONS IN FINAL MODELS

Student Number	Feedback type	Misconception overcome in final product	Overcoming misconception can be attributed to feedback alone	Additional interventions needed besides feedback?	Intervention lesson or conference effective?	Type of intervention
1	A	yes	no	yes	yes	personal conference
2	A	yes	yes	no	n/a	
3	A	partial	no	yes	no intervention	
4	A	yes	yes	no	n/a	
5	A	partial	no	yes	no	personal conference and small group
6	A	partial	no	yes	no intervention	
7	A	yes	no	yes	yes	small group reteach lesson
8	A	yes	yes	no	n/a	
9	A	partial	no	yes	yes	small group reteach lesson
10	A	yes	yes	no	n/a	
11	A	partial	no	yes	no intervention	
12	A	yes	yes	no	n/a	
13	B	partial	no	yes	no intervention	
14	B	yes	yes	no	n/a	
15	B	no	no	yes	no intervention	
16	B	no	no	yes	no	small group reteach lesson
17	B	yes	no	yes	yes	small group reteach lesson
18	B	yes	yes	no	n/a	
19	B	yes	Yes	no	n/a	
20	B	yes	no	yes	yes	personal conference
21	B	yes	yes	no	n/a	
22	B	yes	yes	no	n/a	

APPENDIX G

CHI – SQUARED TEST CONTINGENCY TABLE

Chi-Square Calculator

Success! The contingency table below provides the following information: the observed cell totals, (the expected cell totals) and [the chi-square statistic for each cell].

The chi-square statistic, *p*-value and statement of significance appear beneath the table. Blue means you're dealing with dependent variables; red, independent.

You'll notice we've also calculated a chi-square statistic with the popular Yates correction. There's probably a consensus now that the correction is over-cautious in its desire to avoid a type 1 error, but the statistic is there if you want to use it.

	Feedback helped	**Feedback did not help**	***Marginal Row Totals***
Group A	5 (5.45) [0.04]	7 (6.55) [0.03]	12
Group B	5 (4.55) [0.05]	5 (5.45) [0.04]	10
Marginal Column Totals	10	12	22 (Grand Total)

The chi-square statistic is 0.1528. The *p*-value is .695895. This result is *not* significant at $p < .05$.

The chi-square statistic with Yates correction is 0.0015. The *p*-value is .968821. *Not* significant at $p < .05$.

APPENDIX H

TRANSCRIBED INTERVIEW WITH STUDENT

Transcribed Interview with Student:

Looking at your first draft, the feedback that was given, and then looking at your final product. What do you think helped you get to this level of understanding?

“Definitely the feedback, because the feedback told me what to fix. I understood the feedback and put it into this model.”

What part of the feedback was useful?

“When I drew my wave, the radiation waves, I did not know that they were even.”

Besides my feedback and telling you what helped you confirm that the wavelengths were even?

“I assumed your feedback was correct. But if you think about it, it does not make sense that the wavelengths would get larger.”

Was there anything else that happened besides this feedback that helped you with this model.

“I think that the little packets that we got helped, about the trees but those came after, but I do not know, maybe from the CA’s that I took. I am not quite sure”

Is there anything about this model that you would change if you continued to study light and how it is transferred?

“Yes because you can always get better.”

What do you consider good feedback?

“Very specific feedback and just feedback that would help overall. Not just saying one part and in the next round of feedback a totally different part, so that hopefully in the next round I could fix all of the parts and not use up my rounds of feedback.”