



**Michigan
Technological
University**

**Michigan Technological University
Digital Commons @ Michigan Tech**

Dissertations, Master's Theses and Master's Reports

2019

Quit Doing the Lesson and Start Doing Physics

Katelyn McCarthy

Michigan Technological University, kpsutton@mtu.edu

Copyright 2019 Katelyn McCarthy

Recommended Citation

McCarthy, Katelyn, "Quit Doing the Lesson and Start Doing Physics", Open Access Master's Report, Michigan Technological University, 2019.

<https://digitalcommons.mtu.edu/etdr/816>

Follow this and additional works at: <https://digitalcommons.mtu.edu/etdr>



Part of the [Curriculum and Instruction Commons](#), [Science and Mathematics Education Commons](#), and the [Secondary Education Commons](#)

QUIT DOING THE LESSON AND START DOING PHYSICS

By

Katelyn P. McCarthy

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Applied Science Education

MICHIGAN TECHNOLOGICAL UNIVERSITY

2019

© 2019 Katelyn P. McCarthy

This report has been approved in partial fulfillment of the requirements for the Degree of
MASTER OF SCIENCE in Applied Science Education.

Department of Cognitive and Learning Science

Report Advisor: *Shari Stockero*

Committee Member: *Amy Lark*

Committee Member: *John Irwin*

Department Chair: *Susan L. Amato-Henderson*

Table of Contents

List of Figures	vi
Acknowledgements.....	viii
Abstract.....	ix
Introduction.....	1
Past Reforms in Science Education	1
Next Generation of Science Reform.....	3
New Assessments	4
Goals of Science Students.....	6
Research Questions.....	8
Literature Review.....	10
Doing Science: Inquiry	10
Doing the Lesson versus Doing Science.....	12
Measuring Students' Expectations of Science.....	14
Focused Feedback.....	18
Summary	23

Methodology	25
Approach.....	25
Ethics	26
Participants.....	26
Intervention and Data Collection.....	31
Data Analysis	34
Weekly feedback surveys.....	35
Student work.....	36
Perception survey.	38
Results.....	41
Survey	41
Weekly Feedback.....	50
Student Work.....	55
Discussion	57
Addressing the Questions	57
Implications	60
Future Work.....	62
Lessons Learned	65

Reference List68

Appendix A: Modified CLASS instrument used in the study72

Appendix B: Weekly Feedback Survey74

List of Figures

Figure 1. Categorized statements used in the study from CLASS.....	29
Figure 2. A description of the different levels of complexities identified from student questions.	36
Figure 3. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>personal interest</i>	43
Figure 4. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>real-world connections</i>	44
Figure 5. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>problem solving</i>	45
Figure 6. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>sense making/effort</i>	46
Figure 7. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>conceptual understanding</i>	47
Figure 8. Survey responses for both the comparison and experimental groups, showing shifts in perceptions in the area of <i>importance of grades</i>	49
Figure 9. A sample of correlated student responses for the first two questions of the weekly feedback survey.....	52

Figure 10. A comparison of the level of complexity of questions students posed in the weekly feedback survey.....53

Figure 11. Comparison of student-created questions posed for the second and third weekly feedback questions from the beginning to end of the intervention.54

Figure 12. Points assigned for student responses in both the comparison and experimental groups for the same question in an assignment early in the intervention and another question in an assignment later in the intervention.....55

Acknowledgements

I would like to thank Shari Stockero for her always timely and immensely thoughtful feedback throughout the duration of this research project. Additionally, I wish to thank my students - past, present, and future - for inspiring me to constantly better my craft and become a better teacher. And finally, a special thanks should be given to my husband, Connor McCarthy, for his never ending support and encouragement.

Abstract

Getting students to shift from *doing the lesson* to *doing science* (physics) is not only the goal of science teachers across the state, but it is the goal of the most recent standards released by the state of Michigan. To aid students in shifting from thinking like students to thinking like scientists, this study sought to explore how increased feedback, provided by the teacher on students' work, as well as feedback provided by the students on their weekly learning, could shift students' perceptions of science. Students' perceptions of physics were measured using an adapted Colorado learning attitudes about science survey [CLASS] at the start and end of the study to measure shifts in perceptions between the comparison group and the experimental group that received this increased feedback. While the survey results indicated no significant shift in students' thinking, evidence of a shift in students acting like scientists was discovered through student work, both on completed assignments and on weekly feedback surveys.

Introduction

Science education in the United States has been in the spotlight for quite some time. Critical opinions of science education, as well as educational reforms to try to change (science) education, are scattered throughout the last hundred years of history. Even in 1910, John Dewey criticized science education, stating that “science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking” (p. 122). Changing the way science is taught in schools is not an easy task, and requires significant resources, including both time and money. This study proposes to explore how simple changes in the classroom, specifically the type and amount of feedback teachers provide and students receive, as well as feedback provided by the students on their own learning, could impact students in a positive way. Would it be possible to get students into thinking and/or acting more like scientists engaging with science, and less like a student trying to complete tasks?

Past Reforms in Science Education

In the late 1950s and early 1960s, policy was created to try to better science education in response to the Cold War and the Russian launch of the satellite Sputnik (Rudolph, 2014). The National Defense Education Act (NDEA) showcased how the United States government is extremely hesitant to provide federal aid to education, unless education has significant societal implications. Senator Lister Hill used the fact that the nation was second in the race to space behind communist Russia to attach education to

national defense in order to successfully pass NDEA in 1958. This act has been considered a successful policy to inject funds into higher education to improve (in part) science education (Senate Historical Office, 2017).

In the 1980s and since then, continued and renewed concerns over America's place in the global scientific community has prompted the publication of many reports and policies. Some of these reports include: *A Nation at Risk* (National Commission on Excellence in Education, 1983), *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989), *Benchmarks for Science Literacy* (AAAS, 1993), and *National Science Education Standards* (National Research Council [NRC], 1996). Within the last ten years, the National Research Council also released the *Framework for K-12 Science Education* (2012), which serves as a foundation for the most current reform in science education curriculum. As with past reforms, science educators are now pressed to teach science in a way that is not necessarily consistent with how they learned science in school. Not only does this mean that some teachers may struggle to lead their students by example, but it also leads to a disconnect between how science should be taught (as defined by the state curriculum standards), how science is taught (by the teachers in the classroom), how science is assessed (through low and high-stake assessments), and how post-secondary schools are valuing science (through university entrance requirements and how science is taught at this level).

Next Generation of Science Reform

The Next Generation Science Standards [NGSS] (NGSS Lead States, 2013) were created from the *Framework for K-12 Science Education* (NRC, 2012), which has the ambitious goal of all students graduating with:

some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC, 2012, p. 1)

The emphasis of science education is no longer on memorizing facts and seeing science as a collection of those facts that is taught through a series of teacher-directed lessons, a long-standing issue with science education. Instead, the *Framework*, as well as the NGSS, focus on students engaging in the practice of *doing* science.

To articulate this shift in emphasis to educators and administrators alike, the NGSS (NGSS Lead States, 2013) designates three dimensions of science: the Science and Engineering Practices (SEPs), the Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs). While the three dimensions of science are introduced separately within the *Framework*, NGSS contains Performance Expectations (PEs) that are three-dimensional. That is, each PE (or standard) contains at least one DCI, one SEP, and one

CCC. The combination of the three dimensions shows that any aspect of science cannot be done in isolation. The DCIs are by far the most familiar to educators and the public - these are the scientific facts and concepts that have always been present in science education. Science departments that are struggling to bring NGSS into their current curriculum often use the DCIs (and their strand, whether it be life science or physical science) to help group the standards into courses. However, the SEPs really have students engaging in the science, by doing things such as asking questions and solving problems, planning and carrying out investigations, and using mathematics and computational thinking. The final dimension brings the connection between science and the real world to the surface, by highlighting seven fundamental concepts that cut across the sciences.

New Assessments

With science curriculum changing, and with students and educators alike *doing science* in the classroom, the focus turns to assessment as a way to prove that students in science classes are actually *doing science*. At the classroom level, assessments can be and are quickly adjusted or rewritten to better reflect the NGSS. This is no different than teachers modifying their classroom instruction to tailor to the needs of their students. However, at the larger (state and national) level, this change is not as easy to make. Nineteen states, including Michigan in November 2015, have adopted the NGSS as their science standards. In other states, districts, and schools the major ideas of NGSS are being incorporated into science classrooms. Each state must modify their current high-stakes mandated testing to reflect these new standards. In Michigan, the state-mandated

test that must be modified to reflect NGSS is the Michigan Student Test of Educational Progress (M-STEP). One problem complicating the transition is that federal law requires states to regularly assess students in science at set periods of time in their education. This means that states are still required to assess while trying to create new assessments. “Many states are giving tests aligned to their previous state standards, despite the fact that students may be learning the updated standards” (Loewus, 2017, Federal Pressure section, para. 1). With instruction in the classrooms responding quickly to the new standards, but assessment taking more time to adjust, a gap has formed leaving teachers and students alike struggling to master both the content in the classroom and the assessments that students take each year.

The M-STEP has responded to Michigan’s fall 2015 adoption of the NGSS by creating an assessment timeline, projecting a spring 2020 deadline for full NGSS assessment implementation (Smolek, 2017). Between now and then, pilot and field tests are occurring across Michigan to test the new assessments. The results of those tests indicate mixed results. On the administration side, creating groups of questions (clusters) around one phenomena or situation takes significant time. The assessments are being developed for online testing; this will require significant resources (space and computers) for administering the tests in schools. Also, a lot of the constructed-response items are hand-graded, which takes time after the assessment to get results. On the student side of things, notes from the 2017 field test suggest that while students loved the computers and graphics, they were sometimes frustrated by the technology. Students liked being able to

figure out the answer (thereby engaging in science), but lower-achieving students tended to base their responses off of their prior knowledge and not the stimulus (situation) presented.

With all of the work that is going on in the classrooms and at the state assessment level, teachers and students alike are going to feel the pressure to adjust how they think about assessment. The focus is now, more than ever, on critical thinking and the scientific/engineering process; multiple choice identification questions are no longer adequate. Memorizing facts or being able to plug numbers into an equation mean nothing if students cannot synthesize the information. And yet other high-stakes tests that span across multiple states, namely the SAT and ACT, are still predominantly multiple choice. This leads to a larger gap between curriculum and assessment. The gap varies, though, between the different levels of assessment. Arguably, it also varies from class-to-class and student-to-student. Some students are naturally more flexible and able to adjust to the ever-changing expectations of curriculum and assessment. Others are not, and frustrations and anxiety over these changes can arise.

Goals of Science Students

While changes in both assessment and curriculum have been ongoing to try to strengthen science education, the goals of most students have not changed. Over 80% of high school students want to go to some kind of college or university after high school; only 10% do *not* want to get some kind of additional education (YouthTruth, 2017). It

could be argued that even many of the latter group of students want to at least graduate high school with a diploma in order to successfully enter the workforce. In order to achieve either of these goals, students need to pass their required classes. This creates an atmosphere where students are very grade conscious; they look to see why they got the score they earned.

Grades can make or break a student in terms of passing and achieving their goal; this is true regardless of the way the class is taught (NGSS or not). With Michigan graduation requirements, some students find that they are taking a class, for graduation, that they deem to be useless to them. “I’m never going to need to know this” or other statements often made by students in class highlight the lack of connection between a particular course and the student’s desired college/career choice. And yet, while the student may not think the content of a course applies to them, they know they still need the credit to graduate. This can lead to increased grade consciousness – students counting points and watching their grades for the sake of passing a class and not for the sake of learning (because students see the value or connection of the content to their lives). Science teachers can find these students frustrating or worrisome, especially since with the new standards teachers have focused their efforts on teaching the *process* of science. Students wanting to get through a class using rote learning find that they cannot do this in science class, leading to frustration for both students and teacher.

This gap between the goals of science education, as dictated by the educational curriculum reforms as well as reformed assessments, and students’ personal goals is

troublesome. How can students achieve their goal (good grades) without education professionals also achieving their goal (engaging in science)? Only 50% of high school students report feeling as though their high school courses prepared them for post-secondary education, with one student stating “the things we learn help us pass tests so we can get a good grade, but we don't learn basic skills for studying that will help us survive in college” (YouthTruth, 2017). This suggests that students might see the gap between grades and true learning, or the difference between doing the lesson in science and doing the science in the lesson.

Research Questions

This discussion of the difference between student and teacher science goals naturally leads to the focus of this research, which can be written as the following research questions:

1. How do students feel about the extent to which their science grade accurately reflects their science learning and the importance of truly learning science versus receiving a grade?
2. To what extent can small interventions such as targeted feedback support students in focusing less on their grades and more on their learning?

This study aims to explore what students think of science (specifically physics) and their learning within science, as well as how student perceptions are changed over time.

Additionally, if the goal of science education is to get student engaging with and *doing* science, learning how to stimulate faster changes in student perceptions could be beneficial for both the teacher and the students. Through the course of this study, increased and targeted feedback is utilized as a simple intervention, to see if and how students may shift to become scientists quicker with additional guidance.

Literature Review

Doing Science: Inquiry

Traditionally, science has been presented as “ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry” (Dewey, 1910, p. 124). Since the early 18th century, the desire to shift science instruction from focusing on fact to process has been evident in the numerous educational reports and reforms that have dotted the history of science education. These reports and reforms include the National Defense Education Act (Senate Historical Office, 2017) in the 1950s, *A Nation at Risk* (National Commission on Excellence in Education, 1983) and *Science for All Americans* (AAAS, 1989) in the 1980s, *Benchmarks for Science Literacy* (AAAS, 1993) and *National Science Education Standards* (NRC, 1996) in the 1990s, and the *Framework for K-12 Science Education* (NRC, 2012) and Next Generation Science Standards (NGSS Lead States, 2013) of the 21st century. The desire to increase the amount of inquiry in the classroom may be apparent, however, the benefits of shifting science education towards student inquiry are relatively unstudied. In an analysis of 138 educational studies spanning over eighteen years, Minner, Levy and Century (2010) found that 51% of the studies showed a positive correlation between inquiry and student learning/retention, while 33% studies had mixed results (also, 14% of studies found no correlation between inquiry and student learning/retention). It is promising that in their

study, Minner et al. only discovered 3 of 138 studies (2%) that had a negative correlation between inquiry and student learning/retention.

Research has indicated several benefits of inquiry including increased student ownership of learning (Crawford, 2000) and increased literacy and process skills (Gormally, Brickman, Hallar, & Armstrong, 2009). There are also drawbacks to learning and doing science through inquiry including a different, more complex role for the teacher (Crawford, 2000) and frustration and lack of confidence for the students (Gormally et al., 2009). Although the majority of the research suggests that inquiry is more impactful to student learning and achievement than traditional methods, some work suggests that problem-based learning and inquiry may not be as impactful as more traditional methods like direct instruction, note taking, and worked examples of problems (Australian Society for Evidence Based Teaching, 2015).

Yet, even with inquiry's understudied benefits and impact on student learning, inquiry is a teaching and learning method that is at the forefront in science education across the world. In *Inquiry in Science Education: International Perspectives*, Abe-El-Khalick et al. (2004) discusses inquiry in Lebanon, United States, Israel, Venezuela, Australia, and Taiwan. Contributing authors from each country describe their country's definition of inquiry and the extent to which inquiry is being done in the classroom. The countries demonstrate varying views, definitions, and levels of implementation of scientific inquiry, yet all are trying to shift from traditional science education to science inquiry.

Doing the Lesson versus Doing Science

Students' various attitudes and expectations relating to science can often come from differences in how they approach science. Chin and Brown (2000) cite several sources that appear to group student learning into two broad forms: surface and deep learning. Surface learning, or rote learning, "is arbitrary, verbatim, and not related to experience with events or objects" (p. 109) and does not require students to connect prior knowledge with new knowledge being acquired. Deep learning, or meaningful learning, requires students to engage in meaningful tasks to make significant connections between prior and new knowledge.

Getting students to quit doing the lesson and start doing science is synonymous with getting students to transition from surface learning to deep learning. Chin and Brown (2000) found differences in how students explain phenomena based on whether they approach learning as deep or surface learners. They found that surface learners had explanations that "tended to be reformulations of the question, a black box variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible" (p. 130). Meanwhile, deep learners' explanations were more like mini-theories that "described nonobservable entities and cause-effect relationships or referred to relevant daily life experiences" (p. 130). While both types of learners sufficiently created explanations, the level of detail and depth of explanation varied greatly. The authors also suggested that students often used both types of learning at different times; this may suggest that all students are able to approach learning with a deeper approach if

appropriately taught to do so. Furthermore, Chin and Brown (2000) describe types of questions that could facilitate deep or surface level explanations. Students were more likely to give surface level explanations when the questions were “more basic factual or procedural information” while questions that “focused on explanations and causes, predictions, or resolving discrepancies in knowledge” required deeper level explanations (p. 130).

Jiménez-Aleixandre, Bugallo Rodríguez, and Duschl (2000) differentiated students’ approach to science in a different manner. Instead of looking at surface and deep learning, they looked for instances of students doing school and doing science in a high school classroom working on a genetics lesson. The authors were specifically looking at how students discussed or engaged in argumentation differently depending on if they were discussing the assignment (doing school) or discussing the scientific concepts at hand within the activity (doing science). For example, while completing a handout, one small group seemed to struggle to construct a claim and explanation, because what they were thinking about (food) did not directly relate to the class lesson, genetics. Students were focused on the classroom task at hand and were discussing school as opposed to discussing science. One student was summarized as saying, “if we are studying genetics, then the answer to this question has to be related to genes, not to food” (p. 770). However, later in the lesson, students were engaged in whole-class discussions, and were “really talking science, hotly engaged in the debate about crucial genetics concepts,” even including definitions and use of terminology in the discussion (p. 777).

Another way to state this difference is by examining the goal of the class/activity, whether is it to “(1) fulfill expectations of what students and teachers do while in school (e.g., review homework assignments, take lecture notes, take tests, and complete lab activities) or (2) provide a learning environment that both promotes and facilitates students’ construction, representation, and evaluation of knowledge claims and investigative methods” (p. 759). This distinction between the two possible goals of an activity is an important one for teachers to critically think about during the planning of their lesson. Paired with the types of questions described by Chin and Brown (2000), science teachers can do a lot during pre-planning and implementation to help their students stop doing the lesson and start doing science.

Measuring Students’ Expectations of Science

A number of instruments have been developed to measure student attitudes and expectations about science. For example, Redish, Saul, and Steinberg (1998) designed a survey, named the Maryland Physics Expectation survey (MPEX) to determine expectations in the physical sciences. Using several groups of students at various educational levels, the survey was calibrated and designed to be used to measure student expectations in a science course (specifically an introductory college physics course). The survey examined six dimensions of student expectations:

1. independence (is knowledge acquired from the teacher or do students participate in developing the knowledge)

2. coherence (viewing physics as one structure as opposed to a collection of facts and laws)
3. concepts (are physics problems math story problems or truly physics problems)
4. reality link (connections between what is studied in class and the real physical world)
5. math link (using mathematical thinking to make physical predictions of phenomena)
6. effort (putting work into physics to gain mastery)

The survey was designed to be taken by students at various post-secondary schools (i.e., not high school students), including large four-year public universities, small two-year colleges, and small four-year private universities. While the MPEX survey could be used in any science course, it was specifically designed for physics courses. At the post-secondary level, it is often expected that students have a mathematical background. Therefore, a physics course at a university will have more math than a physics course at the high school. This difference in the courses means that for the survey to be applied to high school students, some of the dimensions would need to be pared down or cut completely. The math link and concepts dimensions would be much more secondary than the independence, coherence, reality link and effort dimensions if the survey was to be used at the high school level.

Adams, Perkins, Podolefsky, and Wieman (2006) modified and adapted MPEX, along with two other physical science student surveys to create the Colorado Learning Attitudes about Science Survey (CLASS) to further explore students' attitudes and thoughts in a more concise manner. The CLASS instrument is designed to be used not just in a single instance, but at different points to measure how student perceptions shift over time from a more novice or beginner's perception to (hopefully) that of a more expert or experienced science student's perception. The authors considered CLASS unique from other surveys for several reasons that include:

1. Careful wording to remove ambiguity and promote conciseness - each statement has one interpretation regardless of the student being surveyed. This includes students other than those in physics that take the survey.
2. Removal of reflection statements. The survey can be taken by any student, even those that have not had a physics course yet.
3. Shortened survey. 40 short statements allow the survey taker to complete the survey in about ten minutes. The shortened length allows for wider acceptance of the survey. Additionally, it is thought that students may respond better to the shorter survey.

Additionally, the CLASS instrument was expanded and elaborated on in the last ten years to include a survey specifically designed for chemistry or biology, as well as tools and

documentation to allow instructors to conduct the survey and analyze the results within their own course (Science Education Initiative, n.d.).

Another questionnaire that measures student motivation in learning science is the students' motivation toward science learning (SMTSL) questionnaire (Tuan, Chin, & Shieh, 2005). This questionnaire was designed for junior high school science and was tested with 1407 junior high students in Taiwan, with review and input of the questionnaire by experienced science teachers, educational psychologists and science educators. This survey, like the MPEX and CLASS, gathers data about students' attitudes in several different dimensions, including:

1. self-efficacy (believing in oneself)
2. active learning strategies (using different strategies to learn new material)
3. science learning value (seeing science as solving problems that are relevant to the real world)
4. performance goal (seeing learning as a competition between classmates)
5. achievement goal (getting satisfaction from doing well in science)
6. learning environment stimulation (interactions between students and their teacher, material, and curriculum).

This survey differs from the MPEX and CLASS in that SMTSL looks to link students' responses to their achievement in prior and current science courses. The authors were able to find significant correlations between "students' science attitudes, and with the science achievement test in previous and current semesters" (p. 639). This may suggest that a student's ability to do well in science class depends, at least partially, on their attitudes and opinions about science.

Focused Feedback

With apparent connections between students' attitudes towards science and science achievement (Adams et al., 2006; Redish, Saul, & Steinberg, 1998; Tuan, Chin, & Shieh, 2005), teachers must find ways to positively influence students' attitudes in an attempt to change the quality of work (achievement) done in the classroom. One way to possibly accomplish this shift has already been discussed; that is, finding ways to transition students from surface level thinking/learning to deeper levels of thinking (Bugallo Rodríguez et al., 2000; Chin & Brown, 2000) through the use of different learning activities and/or the type of questions students are asked to answer. Another way to improve the quality of students' work may be to provide them with the tools and feedback to allow them to become aware of their own learning. In order for feedback to improve student learning, students need to be able to interpret and use the provided feedback. This means that the feedback cannot be vague, or else the student will not be able to use and apply the feedback to their work (Weaver, 2006).

In *The Power of Feedback*, Hattie and Timperley (2007) describe three key questions to help teachers focus the feedback they provide to students for positive results (i.e. higher quality of work). The first question, “where am I going?” focuses on clarifying the learning goal, and “reducing the discrepancy between current understandings and goals” (p. 89). Without this feedback and clear goals, students can become unsure of the purpose for their work and may not push themselves to learn deeper. By not providing students with specific feedback, teachers may fail to reduce the discrepancy and mislead students in the important aspects of the goal. An example of this is when teachers provide feedback on technical details (presentations, spelling, grammar, etc.) instead of the focus of a report (say how tesla coils utilize electromagnetic induction in their function). This leads students to focus on doing the lesson, rather than the science. The second question, “how am I doing?” allows students to receive feedback on their own learning progress, as well as how to move forward. This is the most common form of feedback, and tests or other assessments are often used to provide this feedback to students and teachers alike, as it can point out areas of strengths and areas of concern or weakness. The final question, “where to next?” can be frustrating for students, because often the answer is “more”. However, Hattie and Timperley suggest that teacher feedback centered around the question, “where to next?” can direct the student to more opportunities to learn, including “enhanced challenges, more self-regulation over the learning process, greater fluency and automaticity, more strategies and processes to work on the tasks, deeper understanding, and more information about what is and what is not

understood” (p. 90). It is through this type of question that students can transition from minimal surface answers to deeper answers that display a difference in learning.

Besides the three guiding questions, Hattie and Timperley (2007) also describe four domains of feedback: about the task itself, the processing of the task, self-regulation, or about the person (student) themselves. Feedback about the task (often in terms of correctness or the building of more surface knowledge) is some of the most common in classes. While this type of feedback can be very useful for students, as it speaks specifically to the assignment at hand, it does not transfer well from question to question or task to task. Furthermore, feedback about the task is “more powerful when it is about faulty interpretations, not lack of information” (p. 91). Therefore, instead of identifying areas where students are lacking information or have incomplete answers, the feedback is more impactful if it brings misconceptions to the surface and allow students to face these misconceptions head-on. Feedback about the processing of the task takes feedback to a deeper level as it goes beyond the surface of gaining and sharing information, into describing relationships between information. Feedback about conceptual relationships and how to make connections between ideas can be very powerful, as students can apply the feedback to more than just the specific task at hand. This feedback should be paired with feedback about the task itself, as the two go hand-in-hand.

Feedback regarding self-regulation has the greatest transferability of the four feedbacks. This type of feedback focuses on the thinking behind answers and provides ways for students to think about their own learning and develop metacognition skills to

self-evaluate their work. It can be difficult for teachers to deliver this type of feedback, and difficult for students to receive it. One example of self-regulation feedback is that which focuses on getting a student to become confident in their work and seek thoughtful, complete, and correct answers. While confirming the correctness of an answer has little effect, getting students to go back to their work to fill in gaps in the response or to develop their response more through self-regulation feedback informs the student of ways to self-check their work. It is through this type of feedback that students can learn ways to push their explanations from surface learning to deep learning, or to begin to focus on the *science*, rather than the *lesson*. Feedback about the person, however, is the easiest for teachers to deliver and for students to receive as it is often regulated to “great job” or other forms of praise. This form of feedback is the least useful for students, however, and will often keep learning at the surface level. Because it is most often the easiest for teachers to give and the easiest for students to receive, it is a common type of feedback in the classroom.

Receiving feedback may not only be useful for students, but also for their teachers. Etkina (2000) describes the importance of using student provided feedback to determine current student thinking. Instead of using traditional evidence (i.e. assignments) of student understanding, Etkina suggests using a simple three question report as a way for students to provide feedback on their own learning to the teacher. It is important that teachers are aware of where students are at with the material, because “without knowing what students are thinking, an instructor can offer only limited

assistance in helping them learn” (p. 604). The suggested feedback reports consist of three questions that students answer each week. They are:

1. What did you learn during this week?
2. What questions remain unclear?
3. If you were the professor, what questions would you ask to find out whether the students understood the most important material of this week?

Etkina found through informal research that the students generally knew the key concepts of the week (question one). Responses to question two were typically directly related to homework difficulties (doing the *lesson*) rather than more conceptual questions (doing *science*); however, it allowed students to have a voice in the classroom. The third question proved the most difficult for students. The questions students asked varied from very general advice, to questions that mimicked what was already asked (i.e., from the homework), to low-level questions. Etkina suggested that the reason for the students’ difficulty with this last question was that students are accustomed to completing tasks because their teachers told them to and not because students saw the tasks as valuable. Students were unable to see specific concepts as key pieces of learning because they were clouded by the number of questions or problems to complete. So, when students needed to create questions themselves, they missed concepts and instead asked more procedural or unrelated questions; that is, they asked questions that would have their peers doing the *lesson*, rather than doing *science*.

Student provided feedback can clearly highlight whether they find themselves *doing the lesson* or *doing science*; additionally, it provides evidence for their teachers about whether any shifts from doing the *lesson* to doing *science* may or may not be occurring for students. For Etkina, the weekly reports form “an essential part of teaching—as important as labs or lectures—and a wonderful way to create a positive student–teacher relationship for learning” (p. 604). More generally, it illustrates how feedback is useful for both the party receiving it and those providing it.

Summary

The goal of current science curriculum reforms center around getting students to engage with the practices of science, as opposed to memorizing rote facts. Scientific inquiry often increases student ownership of learning (Crawford, 2000) and allow the student to critically think about and practice real science. However, it has been assumed that for many students, the goal of school is to complete the required work assigned by the teacher to achieve the desired grade and move on to the next thing. The literature suggests that getting students to shift from *doing the lesson* to *doing science* is possible if students engage in worthwhile activities like class discussions that allow students to critically think about the science and go hand-in-hand with scientific inquiry in the classrooms. Additionally, shifts may occur if students begin to answer different types of questions, from those that are more factual or procedural to those that require explanation.

To help facilitate growth in students, teachers can provide focused feedback to highlight areas of growth and provide students with specific routes to achieve shared goals (doing science *and* receiving good grades). Students can use their teacher's feedback; they can also shape their own learning by providing feedback to their teacher about the course. But the question remains: Can the use of feedback in the classroom impact student learning? More importantly, can increased, more elaborate feedback, as well as feedback provided by the students, change the way students feel about their science class? Teachers want students to focus more on doing science, as opposed to doing the lesson. Do students want this as well, or do they feel as though their grade is attached to them simply doing the lesson? For students in an introductory physics course that contains little to no math, a survey like the CLASS instrument might provide insight as to student perceptions and growths or shifts in those perceptions over time as a result of exposure to physics and increased feedback.

Methodology

Approach

The study used a quasi-experimental approach to the research. Two groups of students were created from the teacher researcher's existing course load and the change in attitudes regarding science, learning, and grades were compared between those students that received traditional limited feedback and those that received and engaged with detailed feedback, similar to experiments conducted in the natural sciences. As in most experiments, an independent variable (the amount and type of feedback provided to and provided by students) and dependent variable (attitudes towards science and specifically physics, classroom grades, and student learning) were studied to find correlations and possible relationships. However, since the participants of the study were humans and inherently complex, this experiment was unable to control all variables and keep all variables other than the independent and dependent variables constant, unlike the natural sciences, where most of the variables can be controlled. Also, in the natural sciences researchers can often group the subjects/variables in whichever manner they choose, specifically by random assignment. With this quasi-experimental design, the human participants were already grouped according to their class schedule (as dictated by class ranking, math and English level, and chosen electives) and so a convenience sampling, based on the course load of the teacher researcher, was used in this study.

Ethics

All students and their parents/guardians enrolled in the first trimester of Physics A were given an assent/consent form the second day of school, detailing what the research was about, the benefits and risks of the research, and the ability for participants to opt in or out of being a part of the research. The teacher researcher read the student assent form aloud to students and provided an opportunity for students to ask questions. The consent forms sent home to parents/guardians with the students noted that all students were still required to complete the required coursework, as the coursework was a part of the state-mandated curriculum. Students and parents were informed that if the student took part in the study (i.e. took the pre- and post- surveys; described below), all research results would remain anonymous; all names and identifiers from the student work and feedback forms would be removed before being used and reported as a part of this study. Only data from those students who gave consent were used in the study. A week after the assent/consent form was passed out, a reminder email was sent to all students and parents yet to sign and return the form; any missing responses after two weeks were considered to be a refusal of permission and those students were not included in the study.

Participants

Participants were chosen from the four sections of Physics A that took place during the first trimester (September - November) of the 2018-2019 academic year at a southwest Michigan urban school district of approximately 4,000 students. In response to

the state adopting the NGSS as the state science curriculum in the fall of 2015, the science department at the high school spent two years (2016 - 2018) preparing for a major shift in the sequence and scope of the science curriculum. The new curriculum was unveiled to the administration, counseling staff and parents in the spring of 2018, with students beginning the new curriculum in the fall of 2018. Students at the high school are now required to take the first half of each science course (Biology A, Chemistry A, and Physics A) during the first two years of high school, in any order before moving to the second half of each science course. For example, Physics A is a course designed for students beginning science (freshman and sophomores, predominantly) and covers the concepts of electromagnetism, waves, sound, and electromagnetic radiation (light). There are no prerequisites for this portion of physics, and so the students may not have any (including no) mathematical background and may or may not have taken any other science courses at the high school level. During their second, third, and fourth years, students revisit each of the sciences to take the “B” portion, in any order. Physics B covers the second half of the physics curriculum; upperclassmen students study motion, forces, work and energy, and momentum. It is required that students have taken each of the “A” sections of science before taking the second section, however there are no requirements regarding math (although Algebra I is strongly encouraged).

However, since the academic year of 2018 - 2019 was a transition year, Physics A courses involved in this study not only had underclassman taking the course under the new scope and sequence, but also upperclassman taking the course under the old scope

and sequence (Physical Science, Biology, and Chemistry or Physics). Therefore, there was a heterogeneous mix of students that included those with very little exposure to the sciences, as well as students that had taken two or three years of high school science courses, including an introductory physics course (Physical Science). This mixture appeared in each of the four sections of Physics A; there were freshman, sophomores, juniors, and seniors in relatively equal numbers in each class.

Students who consented to participate in the study took a survey halfway through the first unit of study in the course (the second to third week of school), to establish current thoughts and opinions about science. Due to the voluntary nature of the survey, not all of the participants completed a survey; the survey had a 75% response rate (64 of the 85 students that provided consent/assent to be in the study). Specifically, an adapted version of the CLASS survey (Appendix A) questioned students about how well they felt a (physical) science grade accurately reflected their science learning and about their perceived importance of truly learning (physical) science versus receiving a grade. The majority (24 of 30) of the survey statements were taken from the CLASS instrument and were grouped into six categories to measure student's' attitudes towards physics (some statements were not sorted into a specific category and therefore not used in analysis). The statements that were contained within the categories are listed in Figure 1.

<i>CLASS Category</i>	<i>Statements</i>
personal interest	<p>4. I think about the physics I experience in everyday life.</p> <p>7. I am not satisfied until I understand why something works the way it does.</p> <p>10. I study physics to learn knowledge that will be useful in my life outside of school.</p> <p>19. Learning physics changes my ideas about how the world works.</p> <p>21. Reasoning skills used to understand physics can be helpful to me in my everyday life.</p>
real-world connections	<p>19. Learning physics changes my ideas about how the world works.</p> <p>23. The subject of physics has little relation to what I experience in the real world.</p> <p>26. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.</p>
problem solving	<p>11. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.</p> <p>12. Nearly everyone is capable of understanding physics if they work at it.</p> <p>30. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.</p>
confidence	<p>11. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.</p> <p>12. Nearly everyone is capable of understanding physics if they work at it.</p>
sense making/effort	<p>7. I am not satisfied until I understand why something works the way it does.</p> <p>24. There are times I solve a physics problem more than one way to help my understanding.</p> <p>28. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.</p> <p>30. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.</p>
(applied) conceptual understanding	<p>1. A significant problem in learning physics is being able to memorize all the information I need to know.</p> <p>5. Knowledge in physics consists of many disconnected topics.</p>

Figure 1. Categorized statements used in the study from CLASS (Adams et al., 2006).

Additionally, six statements were written by the researcher and added to the CLASS statements listed in Figure 1; these statements centered on students' attitudes towards their grade in science. These statements were:

- 2. My grade in physics represents my level of understanding of the subject.
- 8. My grade in physics represents the amount of effort I put into the class.
- 13. My grade in physics is important to me.
- 22. I am surprised when I get a physics question wrong, but I often don't know how to fix it.
- 25. It is not enough for me to know that a physics concept works; I also need to know why it works.
- 29. It is important to show work when solving a physics problem.

The results from the survey were examined for any significant differences in average attitudes within a class, and along with class demographics, course schedule, and school schedule (when lunch and announcements take place during the day), were used to separate the four sections of Physics A into two equivalent heterogeneous groupings of students to form the comparison and experimental groups for the study.

Intervention and Data Collection

The pre-intervention survey results from the two groups of students in Physics A were kept and later compared to the post-intervention survey results as a part of the data analysis. Students that had withdrawn from the study, either by participant choice, scheduling changes, or because the student missed more than the allotted days (15% of the intervention period, which was three or more days of school), were not invited to take the post-intervention survey nor was their individual student work used in analysis. However, because of the anonymous nature of the surveys, the responses of the withdrawn students could not be pulled from the pre-survey data.

The comparison group was formed from 44 students that provided consent (8 students were removed due to scheduling changes or too many absences during the course of the study) in two sections of Physics A. These students used learning methods and activities that are aligned to the NGSS curriculum developed and used in all sections of the course at the school, regardless of teacher. As the teacher received artifacts of student work (i.e., labs), they graded the work in the traditional manner. This means that all coursework received a numerical score symbolizing the participation attempt and/or accuracy of the assignment (as pre-determined by the teacher) and occasional short (one to two word) comments on portions of the assignment to indicate why students earned the numerical score. These short comments included feedback statements such as “*good*”, “*why?*”, “*and ...?*”, or “*say more*”, and generally targeted either the person or the task itself (Hattie & Timperley, 2007). The assignments were passed back a few days after

they were completed, often without a discussion of commonly missed concepts or a highlight of the important ideas from the learning experience.

The experimental group was formed from 40 students that provided consent (10 students were removed due to scheduling changes or too many absences during the course of the study) in the other two sections of Physics A in the teacher researcher's caseload. These students also used the same learning methods and activities and completed the same coursework as the comparison group. From the students' point-of-view, the two sections were as identical as possible. However, the form of feedback provided by the teacher differed in that more detailed and pointed feedback was provided wherever appropriate on student work. The feedback provided rarely targeted the person (praise or simple "*good work*" statements), and often targeted not only the task itself, but the processing of the task. Feedback provided prompted students to consider, "*How can you connect your first and second thoughts to push your explanation further?*", or "*Why is this? Is it the same when [phenomenon changes slightly]? Why or why not?*". These questions targeted higher thinking skills by paralleling the types provided by Hattie and Timperley (2007) of "how am I doing?" and "where am I going?"

The school requires grades to be given on coursework, so there was still a numerical score given at the top of each assignment. To be as consistent in grading as possible, both groups' classwork was graded at the same time; the experimental groups' work was then qualitatively reassessed to provide targeted feedback on each assignment. Feedback included longer (phrase to sentence) comments on individual portions of the

written assignment as well as additional verbal comments provided to the class as a whole that were designed to push the thinking of the students when the assignment was returned and briefly discussed as a class. Once a week during the intervention period, students in the experimental group completed an individual weekly report (Etkina, 2000) as an exit ticket for the week to provide feedback about their own perceived learning (Appendix B). This exit ticket consisted of three parts; students first identified an important concept from the week, they then asked a question they had about the learning from the week (i.e. something they were still confused about), and finally students constructed an assessment question as if they were a teacher testing their peers on the important concept(s) of the week.

Research artifacts, in the form of copies of graded and teacher-commented student work, both from those students who received the targeted feedback and those that received traditional feedback, were copied and kept by the teacher before returning the original graded work to the students. These artifacts highlighted student voice; they illustrated the depth of student thinking and the thoroughness of student responses and provided documentation of how student work changed over the course of the study. The weekly reports from the experimental group were collected as well to determine if and how student attitudes and thoughts changed over the course of the intervention. At the conclusion of the intervention period, both groups were invited to complete the same survey that they took at the beginning of the research. Average responses between the pre- and post-intervention surveys for each group were compared to see how students'

thoughts changed over the course of the two science units that took place during the study and as a result of the type of feedback received.

Data Analysis

Both qualitative and quantitative data analysis were needed to analyze the data collected during the research study. Quantitative data analysis was used to analyze the closed responses included in the pre- and post-intervention student surveys. Qualitative data analysis was used with the artifacts collected during the intervention. Together, the data were used to answer the research questions about (a) student perceptions about science grades and learning and (b) how feedback could facilitate change in those student perceptions.

Weekly feedback surveys. The weekly feedback surveys completed by the experimental group were analyzed using techniques similar to those used by Etkina (2000); each of the three questions were examined separately, and connections were made between the questions. The first question, which required students to self-identify an important concept from the week, was examined to see the percentage of students that could accurately identify one (or more) of the major or minor concepts from the week that matched the teacher's list of topics. Changes in the percentages of students that correctly identified important concepts from the first week of the intervention to the last week of the intervention were also explored. The percentage of students that answered the second weekly feedback survey by identifying at least one question about what was learned during the week was identified, and those questions were further broken down into those that were considered to be more procedural (*doing school*) in nature compared to those that were more conceptual (*doing physics*). Connections between the first and second question were made to see if individual students could not only identify but also understand the important concepts, or if they still had questions about what was learned that week. The number of students that were able to create a plausible test question (weekly feedback, question three) was examined and compared between the first and last week of the intervention.

Additionally, analysis of the second and third weekly feedback questions was carried out using techniques similar to those used by Etkina (2000) to explore the complexity of the student-created questions and explore if students could produce higher

quality (i.e., more complex) questions by the end of the study. A numerical score was assigned to each of the questions based on level of complexity (Figure 2). These numerical scores were compared between the students' questions created for understanding (weekly feedback question two) and those created for the purpose of assessing their peers (weekly feedback question three). The numerical scores were also compared between the beginning and end of the intervention to determine any possible growth in the complexity of student-created questions for understanding and assessment.

<i>Level of Complexity</i>	<i>Description of Sought-after Traits</i>
1 (Lowest)	Off topic or vague question; not a physics question from the week's topics
2	Factual or identification question (i.e. "what"); statement of concept
3	Comparison, procedural, or application-based question (i.e. "how")
4 (Highest)	Explanation question (i.e. "why"); a question not originally presented in class

Figure 2. A description of the different levels of complexities identified from student questions (adapted from Etkina, 2000).

Student work. During the course of the study, students completed two instructional units, including a total of eight hands-on learning experiences. These

experiences, often group work, allowed students to engage with content and practice constructing explanations and connections through supplemental lab handouts. Several of these artifacts of student work were gathered. Specifically, one question from a beginning experience (during the first unit) and one question from a later experience (during the second unit) were directly compared to see how student responses grew or changed in quality during the course of the intervention. Both questions contained multiple parts and required students to make connections to previous questions/experiences in the assignment in order to fully answer the question. A four-point scale was used to score each written answer. A score of four represented a complete and correct response, while a three was for a mostly complete and correct response but was missing a detail or two. A rubric score of two represented a response that would have resulted in a loss of points at the time of the original grading; the response was missing components and did not answer both parts of the question. Finally, a rubric score of 1 represented a response that was incorrect, or too vague/incomplete to accurately determine the thoughts of the student. The assigned rubric scores were then totaled for the assignment and compared between the comparison and experimental groups and between the beginning and end of the study.

Additionally, codes were assigned to student responses that highlighted responses that answered just one part of a multi-part question or contained misconceptions as opposed to those that had an explanation that contained multiple thoughts or sentences that combined into a full answer. The number of responses that contained a given code

were compared between the comparison and experimental group, as well as from the beginning and end of the study.

Perception survey. The modified CLASS instrument consisted of several Likert scale statements grouped into seven categories that examined student attitudes towards science (physics), learning, and grades. Student responses to these statements were collected and analyzed using similar techniques to those used in the original use of the CLASS instrument (Science Education Initiative, n.d.). Responses that were “strongly agree” or “agree” were combined and “strongly disagree” or “disagree” were combined due to the different interpretations of the term “strongly” between students of different beliefs and convictions (Adams, et al., 2006; p. 5). However, unlike the CLASS instrument, which identified shifts in responses for each student, this study looked at shifts in the total percentages of responses. This is due to the anonymous nature of the survey, which did not link responses to any student identifier, as well as the purpose of this study, which was to examine the effects of an intervention that could cause systematic changes within a course as opposed to subtle change within individuals. During the creation and validation of the CLASS instrument, several “experts” in the field (i.e. physics faculty) were interviewed to establish “expert” (or favorable) responses for each of the statements in the survey. The CLASS instrument also claims that “the ‘expert’ and ‘novice’ responses to each statement were unambiguous so scoring of the responses was simple and obvious” (Adams, et al., 2006; p. 3). Therefore, the percentages of overall student responses were compared to the expert, or favorable,

response to indicate whether students thought more like a novice or an expert in that particular category of the CLASS instrument.

Shifts in perception were compared for both groups pre- and post-survey, to determine how their attitudes may or may not have grown to emulate a more expert perception of physics over the course of the study. An increase in the percentage of combined favorable (expert) and unfavorable (novice) responses from pre- to post-survey highlights statements in which students became more opinionated. This would mean that fewer students responded neutrally in the post-survey than they did in the pre-survey, indicating that students formed an opinion about science during the course of the study.

Some statements (2, 8, 13, 22, 25, and 29) were not adapted from the CLASS instrument, but rather, were written specifically for this study to gain an understanding of students' perceptions about the importance of their science grade and what students believe their grade represents. Since these statements were not calibrated and validated, there is not an "expert" or "novice" response and shifts in perceptions under this line of thinking cannot be made. However, shifts in responses were still compared between the comparison and experimental group.

Independent t-tests were conducted to determine if the results from the pre-intervention survey were significantly different between the comparison group and the experimental group, and if the results between the two groups for the post-survey responses were statistically different. Two more independent t-tests were performed to

see if the survey results for both the experimental and comparison groups were statistically different from the beginning to end of the study.

Results

In order to assess students' perceptions about learning science and their impressions of what their science grade stood for, a survey was given at the start and end of the intervention period. Additionally, student work was collected to see how students did or did not act (i.e., write) like scientists, which provided evidence as to how they may have thought like scientists. The students in the experimental group received increased feedback from their teacher and also provided their own feedback about their learning through the use of weekly feedback surveys. The data collected was used to determine if the intervention of increased feedback could stimulate change in students' perceptions of science.

Survey

An independent t-test was conducted on the pre-intervention survey responses to compare the comparison and experimental groups. Of the 20 statements analyzed as a part of this study, only statement 22 ("I am surprised when I get a physics question wrong, but I often don't know how to fix it.") was determined to have a statistically significant difference between the comparison and experimental groups. The post-intervention survey responses were also tested to determine any statistically significant differences between the comparison and experimental groups. In the post survey, none of the responses were statistically different between the two groups of students, other than

statement 24 (“There are times I solve a physics problem more than one way to help my understanding.”)

Generally, the CLASS statements were phrased such that a favorable response agreed with content experts; an unfavorable response disagreed with experts and could be interpreted as a more “novice” response. There were a few exceptions where an unfavorable response agreed with the experts. For these statements, students demonstrating a growth in attitude would show an increase in unfavorable responses. These exceptions are noted in the discussion that follows.

Figure 3 shows the result for both groups within the *personal interest* category. The comparison group displayed shifts in all *personal interest* statements (Figure 3a). While they were often towards a novice perception, statement 21 showed a 24% increase in a favorable response with only a 1% increase in an unfavorable response – students not only became more opinionated but responded more like experts over time for this statement. However, even with a large shift towards an expert perception for statement 21, there does seem to be an overall indication of a more novice perception in the area of *personal interest* in physics for the comparison group at the end of the study as four of the five statements showed at least small shifts towards a more novice perception. An independent t-test conducted on the comparison group’s pre and post survey responses showed no statistically significant difference for these five statements.

Comparatively, the experimental group displayed small shifts across the *personal interest* statements (Figure 3b) that showed decreases in favorable responses; that is,

students in the experimental group thought less like an expert over the course of the study for all statements. The decreases in favorable (expert) responses were also accompanied by at least small increases in unfavorable responses (i.e., the students changed their opinions from (strongly) agree to (strongly) disagree). This was especially true for statements 4, 10, and 19, where small drops in favorable responses (4%) were accompanied by large increases in unfavorable responses (23%, 18%, and 14%, respectively). Additionally, statement 21 showed a large drop in the number of favorable responses (20%) and a marginal increase in unfavorable responses (10%) – students became less opinioned or neutral towards science (an overall drop in favorable/unfavorable responses) or thought less like an expert over the course of the study. Together, this data highlighted a possible shift towards a novice perception in the area of *personal interest* of physics. However, similar to the comparison group, none of the shifts in responses to these five statements were statistically different.



Figure 3a & 3b. Survey responses for both the comparison (3a) and experimental (3b) groups, showing shifts in perceptions in the area of *personal interest*.

Neither the comparison group (Figure 4a) nor the experimental group (Figure 4b) showed overall shifts in perception in the area of *real-world connections*. For both groups, there appeared to be a shift towards a more novice perception for statement 19, but towards a more expert perception for statement 26. The comparison group (Figure 4a) showed a small (6%) increase in unfavorable responses, while the experimental group had a 14% increase in unfavorable responses for statement 19; the shifts in both groups for statement 26 were small in comparison to statement 19. Statement 23, which was inverted (a favorable response was a novice perception) showed no shift in perception for the comparison group (the group generally became more neutral about this statement), but did show a large shift (14%) towards an unfavorable or expert perception for the experimental group. However, independent t-tests performed on both groups showed no statistical difference in responses from the pre to post survey.

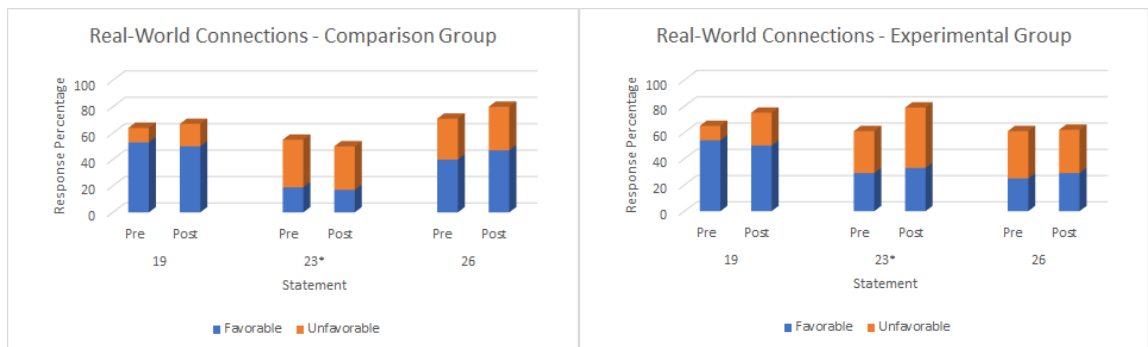


Figure 4a & 4b. Survey responses for both the comparison (4a) and experimental (4b) groups, showing shifts in perceptions in the area of *real-world connections*.

There does appear to be broad shifts in perception in the areas of *problem solving* and *confidence* (Figure 5). From Figure 1, the statements used from the CLASS

instrument in the area of *confidence* (statements 11 and 12) overlap the statements summarizing *problem solving* (statements 11, 12, and 30; shown in Figure 5). The comparison group (Figure 5a) showed small shifts in the area of *confidence* and *problem solving*; small increases for the favorable response were present in all three statements, suggesting that students in the comparison group grew to think more like experts. However, the experimental group (Figure 5b) showed decreases in the favorable responses, suggesting that students in the experimental group gained a more novice perception of physics over the course of the study. This seems to be especially evident for statement 30 (Figure 5b), where the experimental group had a 18% decrease in favorable responses in addition to a 22% increase in unfavorable responses. However, independent t-tests performed on both groups showed no statistical difference in responses from the pre to post survey for the three statements contained in these two categories.

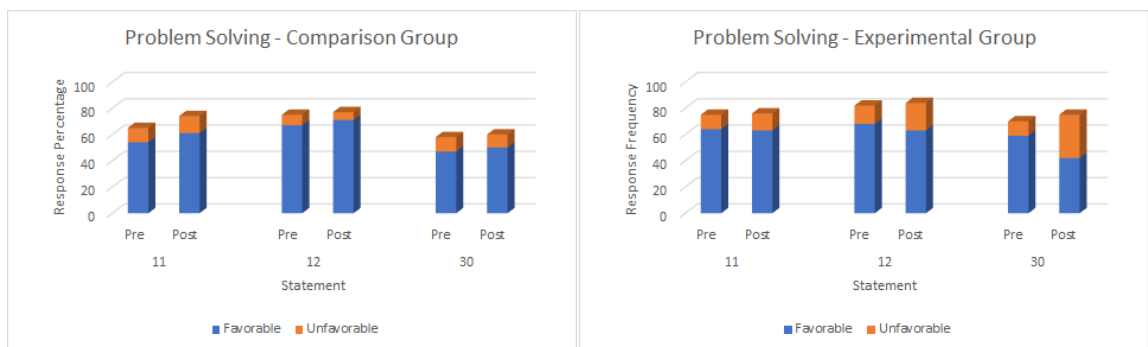


Figure 5a & 5b. Survey responses for both the comparison (5a) and experimental (5b) groups, showing shifts in perceptions in the area of *problem solving*.

Figure 6 shows the results for the *sense making/effort* category. There was no overall shift in perception in the area of sense making/effort for the comparison group

(Figure 6a). Data indicated a more novice perception of physics was present for statements 7 and 24 but a more expert perception of physics for statements 28 and 30. Additionally, statements 7 and 28 saw large shifts; for statement 7 there was a 17% increase in a novice perception accompanied by a 21% decrease in an expert perception, while statement 28 saw a 15% increase in an expert perception paired with a 11% decrease in a novice perception. The independent t-test performed on the comparison group data from pre to post showed no statistically significant change in either direction for any of the statements in this category.

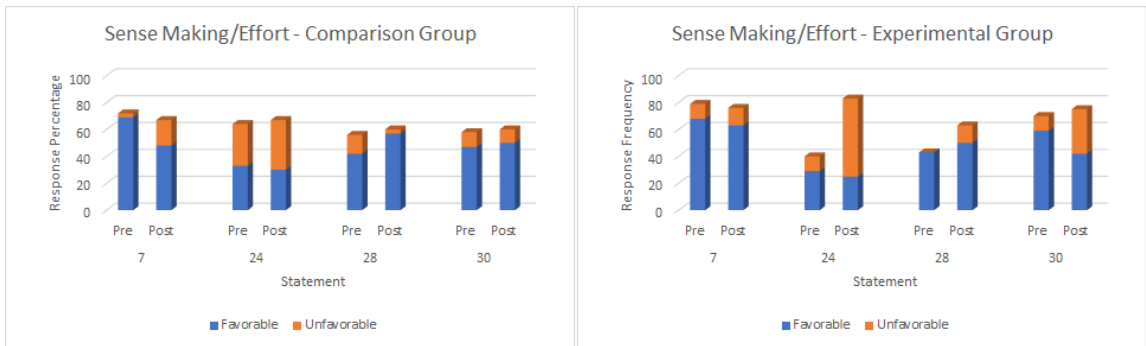


Figure 6a & 6b. Survey responses for both the comparison (6a) and experimental (6b) groups, showing shifts in perceptions in the area of *sense making/effort*.

Meanwhile, the experimental group showed an overall shift towards a more novice perception of physics (Figure 6b), with some shifts larger (statements 24 and 30) than others. In fact, statement 24 had the largest shift in responses for any statement or group – the experimental group had a 48% increase in a novice perception for this statement, paired with a 4% decrease in favorable response. Statement 30 did not see as large of a shift, but the increase in unfavorable responds (22%) was accompanied by a

18% decrease in favorable responses. Of the four statements contained in the category *sense making/effort*, only statement 24 was found to be statistically different between the pre and post survey responses; statement 24 showed a significant shift toward a more novice perception for the experimental group.

Both statements in the CLASS category *conceptual understanding* are inverted; that is, an expert response would be an unfavorable response, as opposed to a favorable response. For both groups, there was not an overall shift in perception; both groups showed a possible shift towards a more novice perception for statement 1, but a more expert perception for statement 5 (Figure 7). Students became more opinionated regarding statement 1 for both groups – there was an increase for both the favorable, or novice, (20% comparison and 18% experimental) and unfavorable, or expert, (8% comparison and 17% experimental) responses. However, neither the comparison nor the experimental groups had statistically significant differences from the pre to post survey responses for the statements contained in *conceptual understanding*.

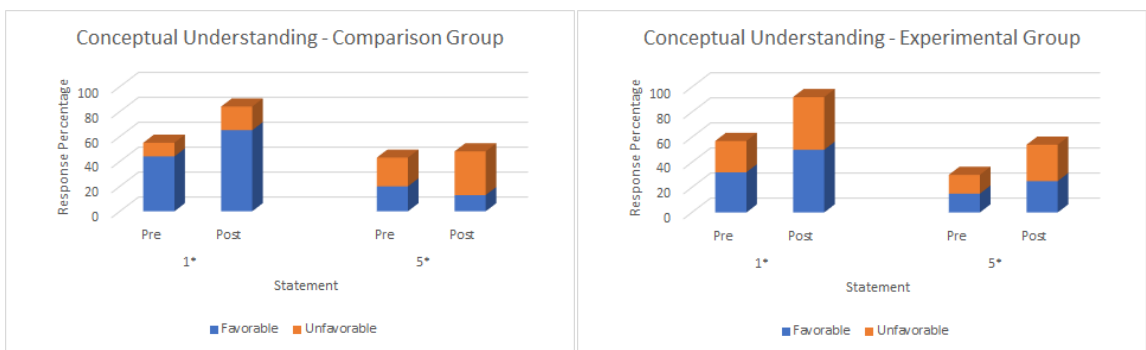


Figure 7a & 7b. Survey responses for both the comparison (7a) and experimental (7b) groups, showing shifts in perceptions in the area of *conceptual understanding*.

Figure 8 displays the results of the survey responses to those statements that were categorized as *importance of grade*. These statements were constructed by the researcher for this study; they were not validated like those from the CLASS instrument. As such, the responses were kept as (strongly) agree and (strongly) disagree, as there are no “expert” responses to compare them to.

Statements 2 and 8 asked students to consider what their grade in physics represented - understanding (statement 2) or effort (statement 8). Students in both groups seemed to show a shift during the course of the study that indicates that their grade is not a representation of their effort put into the course (both groups had a decrease of an agreeable response); however, the two groups did not agree to what extent the level their grade reflects their understanding (Figure 8). The comparison group showed a shift from “(strongly) agree” to “(strongly) disagree”, as there was a 13% decrease in (strongly) agree accompanied with a 11% increase in (strongly) disagree, while the experimental group showed small increase for both responses (3% agreeable and 2% disagreeable) – they became only slightly more opinionated during the course of the study.

Students in both groups agreed that their grade in physics was important to them - statement 13 received a large majority of agreeable responses compared to all other statements, regardless of if the response was given pre- or post-intervention. There was a decrease in the total percentage of opinionated (either agree or disagree) responses for this statement in both groups, which indicated an increase in the number of neutral responses for statement 13; thus, students became less opinionated on the importance of

their grade in physics. Both groups showed shifts in similar directions for statement 25 (“It is not enough for me to know that a physics concept works; I also need to know why it works.”), although students in the experimental group demonstrated a larger decrease in an agreeable response (13% compared to 4% for the comparison group) and the comparison group showed a larger increase in a disagreeable response (12% compared to 10% for the experimental group).

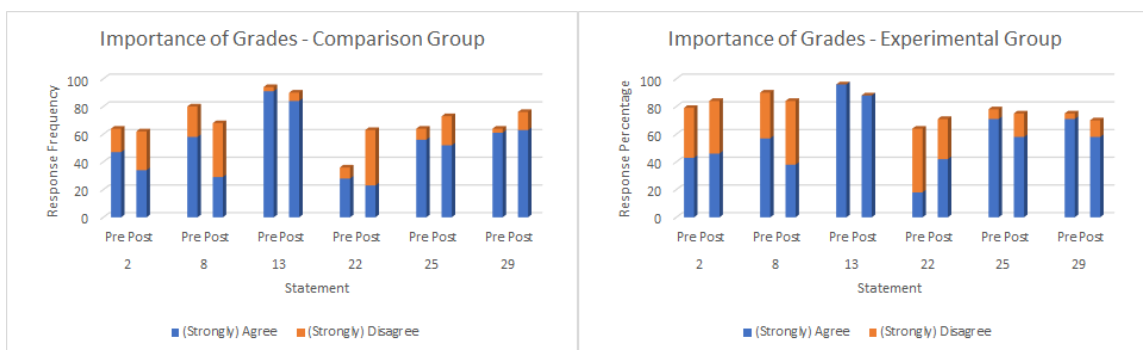


Figure 8a & 8b. Survey responses for both the comparison (8a) and experimental (8b) groups, showing shifts in perceptions in the area of *importance of grades*.

The experimental group showed no statistically significant changes during the intervention, as indicated by the results of the independent t-test. This was similar for the comparison group, although their responses to statement 22 (“I am surprised when I get a physics question wrong, but I often don’t know how to fix it) were found to be statistically different from the pre survey to the post survey. The comparison group (Figure 8a) displayed a 32% increase in a disagreeable response to statement 22, compared to only a 4% decrease in an agreeable response.

Weekly Feedback

A total of 95 individual responses to the weekly feedback questions were collected over the course of the intervention from students in the experimental group. Of those 95 responses, 87% of the responses for the first question (“what is something important you learned this week in physics?”) correctly identified at least one of the concepts taught during the week. This included 92% of student responses from the first week of the intervention, compared to 82% of responses from the last week of the intervention. Students often did not explain their important concept (e.g. “Mechanical wave[s] need matter to travel. Electromagnetic waves don't need matter”), but simply identified the concept (e.g. “I learned the different types of waves”). When distinguishing between a major physics concept introduced during the week and a minor concept described during the week (or, a concept that was a major concept of a prior week), 34% of the students identified a minor concept instead of a major concept. This included 17% of the students from the first week of the intervention, compared to 35% of the students from the last week of the intervention.

Of the 12 responses to the first feedback question that did not correctly identify an important topic, five provided a one-word answer (e.g. “waves”) that was too vague to be considered a correctly identified main concept. Additionally, four responses were about the course, but not the concepts. These included responses of “teamwork”, “always look on the back of labs?”, and “you can't do a [sic] group work alone”, which while important

classroom skills or concepts, were not directly related to the physics-content being learned and practiced in class.

The second feedback question asked students, “What is something you still have questions about from this week in physics?”. 72% (68 out of 95) of students identified at least one question or concept they were confused about; 85% of the students identified a question during the first week of the intervention compared to 71% of the students during the last week of the intervention. 7% of those identified questions (5 out of 68) were more procedural or school-based as opposed to conceptual physics questions. These included responses such as, “How can I improve my grade?”, “Can we get more equation practice?” and “What did we learn from the lab?”.

Of the 63 responses that were identified as conceptual, 8% matched the student’s response for the first item and another 25% were related to the student’s response for the first item (Figure 9). Twenty-one students identified an important concept in physics during the week, and also recognized that they themselves did not understand (all aspects of) this important topic. The number of students who had questions about the important topics did slightly drop; from 41% that had matching/related questions to the self-identified important concepts (from question 1) during the first week of the intervention, to 35% the last week.

<i>What is something important you learned this week in physics?</i>	<i>What is something you still have questions about from this week in physics?</i>
The different kinds of waves	Transverse and longitudinal waves
How waves work, how sound waves work, differences between different kind of waves	How exactly does sound waves travel. The motion of the energy in relation to the particles
Sound waves are mechanical	more detail about sound waves and how to calculate them
An idea of how resonance a standing waves work	resonance & standing waves
Sound has resonance	What effect can resonance have on amplitude

Figure 9. A sample of correlated student responses for the first two questions of the weekly feedback survey.

The third weekly feedback survey question asked students to become the teacher and create a test question based on the most important material from the week. Three of the 95 responses were struck from consideration because the student did not take the question seriously (i.e. their “test question” asked if they could get the answer key to the test) or because they did not provide a question; two additional responses started with a non-answer, “IDK,” but then provided a plausible test question. Of the 92 responses, 73% of the possible test questions provided by students mimicked questions that were asked on actual assessments within the unit or were related to questions the students were asked in other assignments. This percentage dropped from 81% of test questions the first week of the intervention, to 64% of the questions created the last week of the intervention.

A total of 162 questions were assigned a level of complexity (see Figure 2 for level definitions); 28 responses were removed from consideration because they were not a conceptual question (as identified earlier). As shown in Figure 10, while 19% of the questions posed for the second question of the weekly feedback were non-specific or off topic questions (level 1), all but 3% of the questions constructed for the third weekly feedback question were complete questions that tended to begin with “what”, “how”, or “why”.

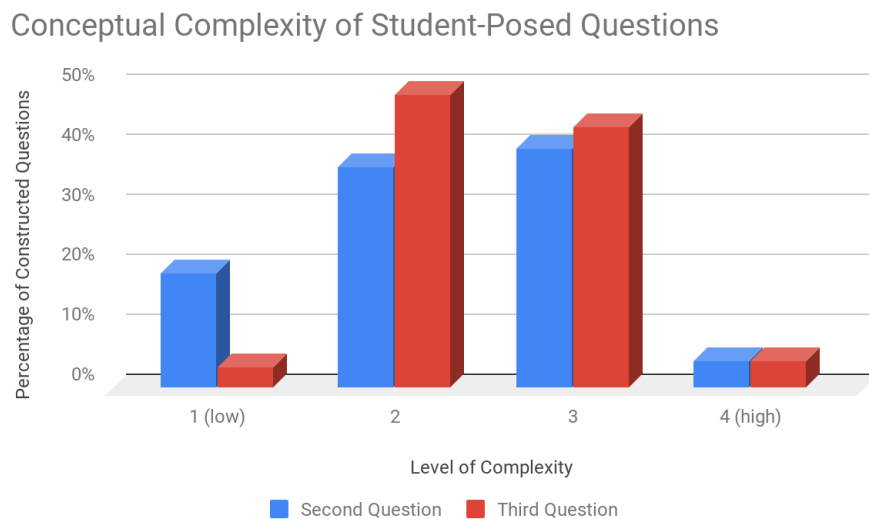


Figure 10. A comparison of the level of complexity of questions students posed in the weekly feedback survey.

A larger percentage of questions that were posed for student understanding (second question) were a higher level of complexity (three) as compared to a lower complexity (two); students asked about relationships between concepts or how to apply

physics concepts as opposed to factual or identification questions. When students constructed questions they thought would appear on an assessment (third weekly feedback question) they often (49%) posed questions that were factual or identification based, as opposed to higher level complexities (43% questions were a level three). Rarely (4%) did the questions posed by students for the second and third questions of the weekly feedback survey require an extended explanation or were new questions that were not modeled after questions already posed in class.

The questions posed for understanding (second weekly feedback question; Figure 11a) showed small shifts in complexity over the course of the intervention. There was a 5% decrease in the number of off topic or vague questions (complexity level 1), a 3% increase in level 2 (i.e. “what”) questions and corresponding 3% drop in level 3 (i.e. “how”) questions, and a 1% increase in the most complex form of question (i.e. “why”) at the end of the intervention compared to the beginning.

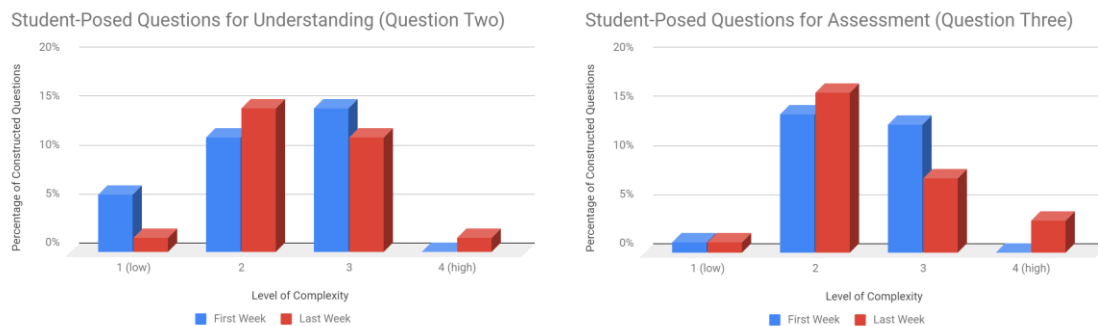


Figure 11a & 11b. Comparison of student-created questions posed for the second (11a) and third (11b) weekly feedback questions from the beginning to end of the intervention.

These trends were similar in the questions students created for assessment (third weekly feedback question; Figure 11b). While there was no shift in the percentage of level 1 questions, there was a 2% increase in level 2 questions, a 5% decrease in level 3 questions, and a 3% increase in level 4 questions by the end of the intervention.

Student Work

The overall breakdown of the student responses to multi-part questions of similar cognitive demand at both the beginning and end of the study are reported in Figure 12; a clear shift to a higher rubric score (specifically, from a rubric score of one or two to a rubric score of three or four) is evident in both the comparison and experimental group from the earlier assignment (Figure 12a) to the later assignment (Figure 12b).

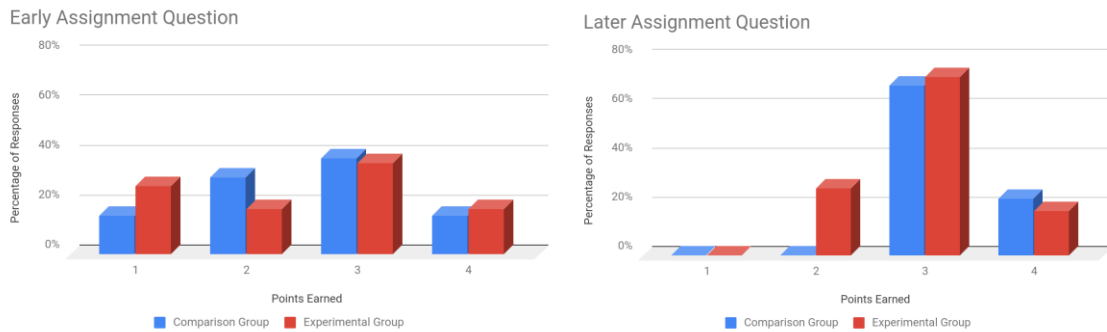


Figure 12a & 12b. Points assigned for student responses in both the comparison and experimental groups for the same question in an assignment early in the intervention (12a) and another question in an assignment later in the intervention (12b).

Diving deeper, each of the student responses were examined and coded for evidence of response completeness and quality. 69% of responses provided by the comparison group and 64% of responses provided by the experimental group towards the beginning of the study did not fully answer all parts of the question related to the learning experience that took place earlier in the study. Those percentages dropped to 8% (comparison group) and 0% (experimental group) for the multi-part question posed towards the end of the study. Additionally, the percentage of responses that contained multiple thoughts (sentences) and an attempt at a more thorough answer rose from 31% to 92% (comparison group) and from 36% to 100% (experimental group). The learning experiences were designed to allow students to work collaboratively and explore concepts; their answers often represented their experiences and thinking while making connections to the physical concepts. However, there were instances where the student response was incorrect or highlighted a misconception; these instances dropped from 15% (comparison group) and 27% (experimental group) early in the study to 0% (both groups) in the question answered towards the end of the study (one point earned on the rubric scale; Figures 12a & 12b).

Discussion

After the study was over and the experimental group experienced the intervention (i.e., increased feedback), the data was analyzed to answer the questions that were the focus of the study. While the survey responses spoke directly to the first research question (How do students feel about the extent to which their science grade accurately reflects their science learning and the importance of truly learning science versus receiving a grade?), students may have demonstrated changes in their student work that they themselves did not pick up on. That is, it is possible that while students did or did not change their perceptions of science over the course of the study, they may have *acted* more like scientists and turned away from *doing the lesson* and towards *doing physics*. This is why the collected student work and student-provided feedback given by the experimental group was also important to analyze. Putting together evidence of students *thinking* like scientists and *acting* like scientists, it may be possible to answer the second research question (To what extent can small interventions such as targeted feedback support students in focusing less on their grades and more on their learning?).

Addressing the Questions

How do students feel about the extent to which their science grade accurately reflects their science learning and the importance of truly learning science versus receiving a grade? The changes in the survey results, from before to after the study, were generally neutral. While the comparison group showed some possible growth over the

course of the study towards a more expert view in the areas of problem solving, confidence, and sense making/effort, the changes were not found to be significant. Both groups showed some growth towards a more mature (expert) view of physics in the areas of real-world connections and (applied) conceptual understanding, but again, the changes were not found to be significant. Students were able to start making connections between what they were learning in class (by doing the lesson), and applications and uses outside the classroom (i.e. doing physics). However, since students in the comparison group had generally larger shifts in their thoughts and attitudes towards science, and tended towards shifting towards a more favorable view of science, and neither group demonstrated statistically significant growth, the intervention (increased feedback) could not be credited with the shift in attitude. It is possible students started to think more like scientists over the course of the study because they were exposed to more science and engaged with two units of study in physics. It is also possible that significant growth in some students was masked by shifts in the other direction by other students; this could account for the insignificant small shifts that occurred within the whole group.

Although there is no conclusion that can be drawn regarding shifts in student thinking, it is evident that students generally acted more like scientists, as the samples of student work demonstrate. Through the course of the study, students constructed more complete and thorough responses to open-ended questions, indicating a shift from doing the *lesson* to doing *physics*. There appeared to be slightly larger shifts in the experimental group over the comparison group, which could suggest that the feedback received may

have helped inform and shape future responses. However, since there were measurable shifts for students in both the comparison and experimental groups, it cannot be concluded that the intervention alone made a significant difference in the quality of student work.

Looking specifically at those students in the experimental group, the data from the student work and the weekly feedback forms suggest conflicting results. As stated above, all students, including those in the experimental group, constructed more detailed, thorough, and accurate responses in their work over the course of the intervention. However, the experimental group also completed weekly feedback surveys, which they may or may not have taken seriously. While their work produced for a grade improved in quality, students asked less questions and struggled more to identify important concepts on the ungraded weekly feedback surveys by the end of the intervention. While it is possible that students struggled to identify important concepts from the week because they were thinking of the unit of study as a whole (which spanned over several weeks) rather than just the week in question, the fact that students generally tended to ask simpler questions (from “how” to “what”) over the study suggests it was more of a matter of time spent on task when constructing responses for the weekly exit ticket. Anecdotally, it did seem as though students spent *less* time on the weekly feedback surveys as time went on; the data seems to confirm this in that the responses were not as thoughtful. However, not all is bad news; some students were able to start constructing higher level questions (those that required an explanation or were more “why” in nature) by the end of the

study, suggesting that more exposure to physics and their increased feedback helped shape their own understanding and formation of “good” questions.

There may be an alternative explanation of the level of complexity of questions posed by students, especially for the third feedback question (posing a question for assessment); the level may have to do with the purpose of the questions students created. It is possible that students thought that their created questions would be used on an upcoming assessment and therefore wanted to ask lower complexity level questions to be sure they got the question correct on the assessment. However, this was not the intention of the survey question, nor were questions put on an assessment because of student input. Some questions on the subsequent assessments were very similar to student-posed questions, but this was coincidence (and a somewhat rare occurrence). More often, student questions on the weekly feedback were similar to questions they already seen on previous assignments or assessments.

Implications

The shifts in students’ thoughts, attitudes, and actions, that may or may not suggest an overall shift from *doing the lesson* to *doing physics*, cannot be attributed to the intervention that formed the heart of this study. However, there are some shifts that appeared in the data, so the question becomes what caused these shifts in both groups. To some extent, the length of the study provided opportunities for students to engage with and become more familiar with the field of physics, so students could think and

act/respond more like physicists, regardless of the guidance (i.e., feedback) provided by their teacher. Also, with the redesign of the science curriculum at the high school, students were engaging with more learning experiences that were hands-on, inquiry-based experiences over the more traditional (i.e., direct instruction or lecture) style of teaching science that had been used in the past.

The differences in quality of student work from the start of the study to the end of the study are also supported by the nature of the physics class (through experiences and practice students become scientists). However, the experimental group did show slightly larger growth in the length, quality, and accuracy of responses over the course of the study, so it could be possible that engaging with additional and more elaborate feedback does help students shift faster in forming more complete, accurate, and thorough responses than those that do not receive guidance. Additionally, the weekly feedback students in the experimental group provided to their teacher (through the weekly feedback surveys) were *starting* to possibly show higher levels of thinking and constructing responses. It could be possible that extending the study, say over the length of the entire course, would have allowed the impacts that receiving and providing additional feedback can have on student work and perceptions regarding science to begin to show in the data.

Future Work

The lack of statistically different survey responses between the two groups at the conclusion of the study indicates that the intervention itself cannot be attributed to causing any shifts in perceptions about science, learning, and grades in the group as a whole. While it is possible that students already went through a conceptual shift during the first unit of study (while perceptions were being collected but before the study began), the fact that the students did not have statistically different perceptions at the start of the study would indicate that if any pre-study shifts occurred, they had occurred in *all* students. Alternately, shifts in some students during the study were masked by opposite shifts in other students. While this study's goal was to see if a simple intervention could cause a *quick* shift in students' attitudes, it would be interesting to repeat the study over a longer length of time to see if more significant shifts occurred; evidently two units of study (about six to eight weeks) were not enough time to significantly shift the overall perceptions of science through feedback, but maybe a full (introductory) course is enough time for students to shift their thinking with the help of feedback. Additionally, if the study were repeated with survey responses linked to individual students, it could be possible to examine shifts in individuals; maybe a majority of individuals did significantly grow to think more like scientists during the study, but those growths were masked by others. Again, the purpose of this study was to explore an intervention that could possibly influence an entire class or course, but through linking responses a

researcher could determine if any shifts were occurring within the class that could positively impact the group as a whole.

The study was designed to study if a simple intervention like increased feedback could stimulate faster shifts in students from *doing the lesson* to *doing physics*. The data collected shows possible shifts towards this goal, however, nothing conclusive or statistically different from just experiencing the course as is (without the intervention) was found. Perhaps the intervention was not the correct one to instigate fast changes. It is possible, for example, that some students did not read the feedback they received (increased or traditional); the teacher would often witness graded and returned papers tossed in the trash or left on the table/floor. Also, when students provided feedback themselves through the weekly feedback survey, it is possible they thought of the exit ticket as a simple task, an obstacle keeping them from leaving, and therefore did not put significant thought into the feedback. Another study could be done that ties these two pieces together and creates a feedback loop. If students were required to read *and respond* to the feedback provided to them by their teacher, it would ensure that they at least read, if not processed, the feedback. This processing might assist students in making change and not recreating their mistakes time after time. Additionally, if the students received teacher feedback based on their own feedback (from the weekly feedback surveys), students might be able to more quickly elevate their thinking from asking more factual to more explanation-based questions. While this is no longer a “simple” intervention, it could be possible that the feedback loop (getting students and teachers to

respond directly to provided feedback) could cause meaningful change in student work and attitudes.

This study could be altered a slightly different way by keeping the feedback a simple intervention (i.e. not creating a feedback loop), but changing the way the feedback is provided to students. Instead of written feedback, which students may find easy to ignore, the feedback could be provided in an auditory and/or visual fashion – students and teachers could make and watch video or audio recordings sharing feedback with one another. This may be difficult to do when the original work was done on paper, but there are instances where students complete work electronically (via Google Classroom) and it would be easy to introduce video/audio clips that students could watch/listen to in order to receive feedback. By doing this, students would not have to flip through a handout or packet of writing – they could instead listen (and watch) to summary feedback provided in a concise manner. Additionally, some applications have a way to identify whether or not a student actually played the file (some can even record how long they spent with the material), so the expectation could be easily established that students must engage with the feedback provided to them. The teacher would then have an increased level of assurance that students spent time processing and internalizing the feedback.

Finally, this study was conducted with students of many different experiences. Due to the timing of the study, some participants had little to no science background (freshman and sophomores), while others had two to three years of science experience (juniors and seniors). These students were grouped together in the study, so it makes

sense that any shifts one group experienced could have been covered up with the perceptions of the other group. It would be interesting to repeat the study, either in a course where students have many different levels of exposure to science (where students are identified on the survey for tracking) or in different courses where students all have similar levels of experience. This would allow the different (shifts in) perceptions based on science experience to become clearer to determine whether simple interventions like feedback can facilitate larger shifts over a short period of time for students with various science backgrounds.

Lessons Learned

How do students feel about their science education? Is it possible for simple interventions like the type and amount of feedback provided to students to influence student thinking and actions? This study produced mixed results. It is possible that feedback can impact students, but it's equally as possible that the redesigned curriculum at the school prompted by the most recent science education reform was the change that facilitated growth in student work. While this study demonstrated some possible shifts from *doing the lesson* to *doing physics*, these shifts occurred for both groups, which suggests they may have occurred as a result of the new, NGSS-aligned, hands-on, phenomenon-based activities that students got to engage with. Since completing the study, the teacher-researcher has witnessed similar growths in other students who did not engage with increased feedback, which seems to support the new and improved learning activities helping to stimulate change in student learning. And yet, the study results did

suggest that increased feedback prompted students to make the shift from school to science a bit faster than their peers that did not receive targeted feedback. To that end, this teacher-researcher has begun to incorporate more opportunities for feedback within the classroom. However, instead of writing feedback on completed, turned-in, and graded work, which can be viewed as being done “post-mortem”, feedback is being introduced much earlier in the process of students producing their work. Now in the teacher-researcher’s classroom, students extensively use whiteboards to draft models and scientific explanations. This provides a safe way for them to “learn on the go” and make changes on the fly. Additionally, the large poster board sized whiteboards makes group work and viewing work much easier, so the teacher can quickly monitor progress from afar. Students are also using several engagement strategies to view and review their peers’ work. In particular, students are providing feedback to one another and are then given a chance to use that peer-provided feedback to make changes to their work before committing it to paper and turning it in for a grade (and the more formal teacher-provided feedback).

Due to the timing of this study (which was conducted during a transition time from the old curriculum to the new curriculum), it is hard to separate the impact of feedback from that of the learning experiences. One takeaway from this study is that in education, it is extremely difficult to isolate simple cause and effect relationships when so many things are working together and happening at once. This teacher-researcher, moving forward, plans on spending time focusing on the new learning activities and

supplemental materials, to see if that does help instigate and speed up the shift from *doing the lesson* to *doing physics* as the results of this study seem to suggest. Once that link is (or is not) established through time and experiences of the teacher, then the idea of feedback – whether written, recorded (via audio/visual), or the creation of a feedback loop—can be added in to see if shifts occur in different amounts or different speeds.

Reference List

Abe-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A.,... Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, 88, 397-419. DOI: 10.1002/sce.10118

Adams, W. K., Perkins, K. K., Podolefsky, N. S., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado learning attitudes about science survey. *The American Physical Society*, 2(1). DOI: 10.1103/PhysRevSTPER.2.010101

American Association for the Advancement of Science. (1989). *Project 2061: Science for all Americans*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (1993). *Project 2061: Benchmarks for science literacy*. New York, NY: Oxford University Press.

Australian Society for Evidence Based Teaching. (2015). *Hattie & his high impact strategies for teachers*. Retrieved from <http://www.evidencebasedteaching.org.au/hattie-his-high-impact-strategies/>.

Chin, C. & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching*, 37(2), 109-138. DOI: 10.1002/(SICI)1098-2736(200002)37:2<109::AID-TEA3>3.0.CO;2-7.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37(9), 916-937. DOI: 10.1002/1098-2736(200011)37:9<916::AID-TEA4>3.0.CO;2-2

Dewey, J. (1910). Science as subject-matter and as method. *Science*, 31(787), 121-127.

Etkina, E. (2000) Weekly reports: A two-way feedback tool. *Science Education*, 84(5), 594-605. DOI: 10.1002/1098-237X(200009)84:5<594::AID-SCE3>3.0.CO;2-U

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2009). Effects of inquiry-based learning on students' science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning*, 3(2), Art. 16. DOI: 10.20429/ijstl.2009.030216

Hattie, J. & Timperley, H. (2007) The power of feedback. *Review of Educational Research*, 77(1), 81-112. DOI: 10.3102/003465430298487

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A. & Duschl, R. A. (2000), "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, 84, 757-792. DOI:10.1002/1098-237X(200011)84:6<757::AID-SCE5>3.0.CO;2-F

Loewus, L. (2017). Next-Generation Science Tests Slowly Take Shape [Education week article]. Retrieved from <https://www.edweek.org/ew/articles/2017/05/24/next-generation-science-tests-slowly-take-shape.html>.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction - What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474-496. DOI: 10.1002/tea.20347

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform. A report to the nation and the secretary of education*, United States Department of Education. Washington, DC: Author.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American Journal of Physics*, 66(3). DOI: 10.1119/1.18847.

Rudolph, J. L. (2014). Dewey's "Science as method" a century later: Reviving science education for civic ends. *American Educational Research Journal*, 51(6), 1056-1083. DOI: 10.3102/0002831214554277

Science Education Initiative. (n.d.). CLASS (Colorado Learning Attitudes about Science Survey). Retrieved from <https://www.colorado.edu/sei/class>.

Senate Historical Office. (2017). Sputnik spurs passage of the national defense education act. Retrieved from https://www.senate.gov/artandhistory/history/minute/Sputnik_Spurs_Passage_of_National_Defense_Education_Act.htm.

Smolek, T. (2017) Science assessment webinar: What a year! [Webinar]. Retrieved from http://www.michigan.gov/documents/mde/170829_Science_Assessment_Update_Webinar_599361_7.pdf.

Tuan, H., Chin, C. & Shieh, S. (2005). The development of a questionnaire to measure students' motivation towards science learning. *International Journal of Science Education*, 27(6), 639-654. DOI: 10.1080/0950069042000323737

Weaver, M. R. (2006). Do students value feedback? Student perceptions of tutors' written responses. *Assessment & Evaluation in Higher Education*, 31(3), 379-394. DOI: 10.1080/02602930500353061

YouthTruth. (2017). Learning from student voice: How prepared do students feel for college and career? Retrieved from <http://www.youthtruthsurvey.org/college-career-readiness-2017/>.

Appendix A: Modified CLASS instrument used in the study

For each of the statements below, put an X in the box with the number that best states your level of agreement with the statement. Use the following scale:

[1 = Strongly Agree 2 = Agree 3 = Neutral 4 = Disagree 5 = Strongly Disagree]

1. A significant problem in learning physics is being able to memorize all the information I need to know.	1	2	3	4	5
2. My grade in physics represents my level of understanding of the subject.	1	2	3	4	5
3. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.	1	2	3	4	5
4. I think about the physics I experience in everyday life.	1	2	3	4	5
5. Knowledge in physics consists of many disconnected topics.	1	2	3	4	5
6. There is usually only one correct approach to solving a physics problem.	1	2	3	4	5
7. I am not satisfied until I understand why something works the way it does.	1	2	3	4	5
8. My grade in physics represents the amount of effort I put into the class.	1	2	3	4	5
9. I cannot learn physics if the teacher does not explain things well in class.	1	2	3	4	5
10. I study physics to learn knowledge that will be useful in my life outside of school.	1	2	3	4	5
11. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.	1	2	3	4	5
12. Nearly everyone is capable of understanding physics if they work at it.	1	2	3	4	5
13. My grade in physics is important to me.	1	2	3	4	5
14. Understanding physics basically means being able to recall something you've read or been shown.	1	2	3	4	5
15. There could be two different correct values to a physics problem if I use two different approaches.	1	2	3	4	5

16. To understand physics I discuss it with friends and other students.	1	2	3	4	5
17. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.	1	2	3	4	5
18. It is important for the government to approve new scientific ideas before they can be widely accepted.	1	2	3	4	5
19. Learning physics changes my ideas about how the world works.	1	2	3	4	5
20. To learn physics, I only need to memorize solutions to sample problems.	1	2	3	4	5
21. Reasoning skills used to understand physics can be helpful to me in my everyday life.	1	2	3	4	5
22. I am surprised when I get a physics question wrong, but I often don't know how to fix it.	1	2	3	4	5
23. The subject of physics has little relation to what I experience in the real world.	1	2	3	4	5
24. There are times I solve a physics problem more than one way to help my understanding.	1	2	3	4	5
25. It is not enough for me to know that a physics concept works; I also need to know why it works.	1	2	3	4	5
26. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	1	2	3	4	5
27. It is possible to explain physics ideas without mathematical formulas.	1	2	3	4	5
28. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.	1	2	3	4	5
29. It is important to show work when solving a physics problem.	1	2	3	4	5
30. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.	1	2	3	4	5

Adapted from: Adams, W. K. et al. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado learning attitudes about science survey. *The American Physical Society*, 2(1). DOI: 10.1103/PhysRevSTPER.2.010101

