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USING DIGITAL COMMUNICATION TECHNOLOGIES TO RECORD A STUDENT'S THINKING DURING THE SOLVING OF PHYSICS PROBLEMS

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by

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A capstone project submitted in partial fulfillment of the requirements for the degree of Master of Arts in Teaching.

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CHAPTER ONE

Introduction

In my time as a physics and math student and teacher, the ability to work through and solve a problem has always been valued and practiced. Most often this problem solving takes place in a written context and as a teacher, I have been struck by situations where the formal written assessment that I do of a student's problem solving does not match the informal in-class conversations that we have about the problem. This can go both ways where some students could solve a problem well on paper but not be able to explain the steps well while other students could explain the concepts and process well but not produce a well-written solution. This can be frustrating for both the student and teacher.

New technologies that allow for the simultaneous recording of writing and audio, as well as the easy access that students have to simple video recording devices like cell-phones, have led me to try to find ways for students to submit a written problem solution with an audio recording of their own thinking during the process.

In this chapter, I lay out my background as a physics and math teacher in order to provide context for the question I will be investigating in this capstone project: *How can the use of digital recordings of a student's thinking during physics problem solving help the teacher in assessing the student's work?*

Introduction to Teaching

I have been teaching high school physics and mathematics for 19 years. One of the simultaneously best and worst things about teaching (like many professions) is that you can always do a better job at it. It is in this spirit of continuous growth that I hope to expand my strategies for teaching and assessing problem-solving and using digitally recorded solutions in order to do this.

In August of 1998, I took some of the first steps towards what would become my career teaching physics. As an undergraduate physics student at the University of Minnesota, I was invited to apply to be a teaching assistant for the introductory physics courses. At the time there was a lot of research being done there about physics problem solving and as part of this research all of the incoming TA's had 40 hours of instruction about how to teach and assess physics problem solving in both individual and group contexts. This involved several different strategies. Encouraging students to break the solution into many parts, identify relevant (and irrelevant) information, identify the physics principles at play in the situation, select appropriate variables and equations to use in the situation, carry out mathematical steps to solve for the target variable, and check your answer for reasonableness.

To this day, those 40 hours of TA instruction have probably had a bigger impact on my current practice as a physics teacher than any other specific course I have taken. Being a physics TA over the next two years showed me how much I enjoyed interacting with students and helping them understand and work through difficult physics concepts. I also came to realize that the ability to successfully navigate and solve a unique physics problem was not just something innate in a student but rather something that could be expressly taught and modeled.

My time as a TA helped me to decide on trying out a career in teaching high school physics and after finishing my B.S. in physics I was hired as a physics teacher in St. Paul in the fall of 2000. I would later start my teacher licensing program concurrent to my teaching. As I started teaching that fall, I leaned heavily on what I had learned about problem solving in the TA course. I worked hard to model and assess explicit problem solving strategies but found that this type of work was always a challenge for my students.

The Goals of Physics Education

Throughout my career as a physics teacher, I have often struggled with the different pulls and pushes of education. I would find myself asking about what the true goals of instruction and assessment are. While putting an emphasis on the skills involved in solving physics problems was I shortchanging the ability to conceptually describe the physics involved in some phenomenon? Was the assessment I was doing of my students about helping them learn or about sorting them into categories? What were the lasting lessons that I wanted my students to take away from a physics class?

Though I do not know that I have settled on solid answers to all of these questions, I do know that the ability to break down a problem into its parts and to select and apply the correct principles to the problem will be skills that should transcend the realm of physics.

The questions about assessment are ones that I think every high school teacher deals with. Towards the end of high school, the grades that students are earning become important measuring sticks for university applications. At the same time, the assessment I am doing is intended to help direct students to a better understanding of the material we are studying. These two goals can sometimes seem at odds with each other. For example, a student who is truly aiming only to improve in physics will be more engaged with difficult work and critical feedback that might include lower grades while a student who cares only about the grade they get for university admission reasons will aim only for the good grade even if that means they are not getting any better in physics. In practice, it is often that a student is somewhere between these two extremes.

A Shift in My Approach to Teaching Physics

In 2007, I moved to Canada and started working in an independent school in Toronto. This job shift opened my eyes to some new approaches in teaching physics. Some of these changes were easier to adapt to than others. One big change in Canada is that with no reliance on standardized tests like the SAT or ACT for university admission, Canadian universities look mostly at a student's performance in their academic courses in their last two years of high school. On the whole, this seems like a great idea but for the teachers of these students in the last two years of high school, it presented a challenge. There was an immense amount of pressure on these students to get good grades and this pressure was often transferred to the teacher as well. This led to a feeling that my assessment of my students became almost legalistic. I needed to be very clear in my requirements and my justifications for giving certain grades. This also seemed to have a negative side-effect of me not being willing to take chances on new and untested assessment methods. This led me to a rut of using very static assessment methods like written lab reports and unit tests that gave what in my mind was a concrete record of the student's work.

At the same time, the Ontario Ministry of Education was advocating for schools in Ontario to move towards different methods of assessment. We were directed by the Ministry to make sure we were using triangulated assessment in our courses. This triangulation means that students should be assessed through products, observations, and conversations (Ontario, 2010). A product might be something written by the student like a unit test or lab report. An observation might involve a teacher's observation of a student's problem solving or laboratory procedures. And a conversation might be a group or one-on-one conversation getting into the details of the course. Some of the rationale for this type of triangulated assessment is that it allows students multiple ways to demonstrate their understanding and allows for teachers to observe students while they are performing tasks (Ontario, 2010)

This shift for me towards varied types of assessment tasks presented a challenge and it is one that my science and math teaching colleagues also struggled with. These types of courses have such a long history of being seemingly clear cut in terms of assessment. Either the student gets the problem right or wrong. But this approach to assessing physics problem solving leaves very little room for anything in between right and wrong.

I have noticed in my years of teaching physics that I can often assess for myself how much a student understands and can do physics with a simple conversation with that student. Sometimes the written product on a unit test does not match what I have seen and heard in conversation. This can go both ways in that I might have a student who does poorly on a written problem solution but when I speak to them about it they have some great insight and show real understanding. Conversely, I will also encounter students who are great at solving problems on paper but cannot explain what it is that they are doing with that solution.

Furtak and Ruiz-Primo advocated that student understanding is best demonstrated orally (Furtak & Ruiz-Primo, 2008). For this reason, I would like to start using this type of assessment triangulation, giving students a venue to record oral explanations, to tease out any of the inconsistencies that might exist between their written solutions and oral explanations. Given a combination of a student's written solution and corresponding oral explanation of that solution I can categorize each as good or poor and break students down into categories based on their solutions and explanations as shown in Table 1.

Table 1
Matrix of possible solution matching

	Good oral explanation	Poor oral explanation
Good written solution	Match	Mis-match
Poor written solution	Mis-match	Match

Though there are likely more categories than good and poor, we can see that there are four possible outcomes. Students could have both good written solutions and oral explanations, they could have both poor written solutions and oral explanations, they could have good written solutions and poor oral explanation and they could have poor written solutions and good oral explanations. The students in the latter groups of mismatching responses would present the most interesting learning for me as a teacher but the addition of oral explanations that match the written work for both good and poor solutions would be valuable as well.

What Next?

It will probably come as no surprise that assessing students with different strategies gives a better overall picture of how the student is progressing in a course but when it actually comes time to put this type of assessment into practice teachers can run into trouble assessing in this way for several reasons.

The first reason teachers might give for avoiding conversations as assessment is that they did not do those types of assessments themselves and are not familiar with how to do it.

The second reason has to do with the practical aspects of formally assessing student work and the time that it takes to do it. I am sure that many teachers would love to be able to have conversations with each of their students for each unit of inquiry in order to check that student's understanding. If we imagine that an average high school physics teacher has 30 students per class. If the teacher is able to spend just ten minutes speaking with each student it will take a full week of classes to go through an assessment.

I plan to use this capstone project in an attempt to address this second reason most specifically. I believe that new teaching and communication technologies will allow teachers to introduce some conversation-based assessment without having to devote large chunks of in-class instructional time. In order to do this I will do the following in the next chapter.

First, use what I can find in the literature about physics problem solving in general to develop a common understanding of the types of skills and knowledge that are required for good solutions. Second, bring in literature about using conversations as an assessment practice to show how a teacher can start to use them regularly in the classroom. And third, look for literature that explores how new communication technologies offer teachers and students ways to generate meaningful conversation that does not have to happen during class time. Because any topic related to technology can change so quickly, it will be important to be looking at the most recent literature and to explore all possible technologies.

CHAPTER TWO

Literature Review

The information that a physics teacher gains from having their students solve physics problems on paper can sometimes give limited insight into the student's thinking and understanding. An attempt to shed more light on student understanding while solving a physics problem could involve recording the students thinking while they are solving the problem.

This literature review focuses on three areas in an attempt to answer the question: *How can the use of digital recordings of a student's thinking during physics problem solving help the teacher in assessing the student's work?* The three areas of research explored here are physics problem solving, assessment conversations, and educational communication technologies.

Physics Problem Solving

Solving physics problems is an integral part of most introductory physics courses. The relative merits of problem solving as an instructional tool in physics are debated (Huffman, 1997) but you would be hard pressed to find a physics instructor that does not rely on the practice at some point in their course. The problem-solving literature presents two main objectives in instruction related to solving physics problems. One is to be able to solve a physics problem correctly and the other is to understand conceptually the physics involved in a certain situation and to be able to effectively communicate that understanding (Huffman, 1997).

The goals of problem solving as a physics teaching strategy. Before any attempt can be made to improve upon the use of problem solving in a physics classroom, we must first understand the purpose of it. The rationale for problem solving in a physics classroom can take on different forms depending on the level of education but generally attempts to do the following. It is a way for a teacher to teach and assess a student's grasp of a certain skill or concept (Williams, 2018). This means that some problem solving may be presented in a more straightforward manner so that in solving the problem the student has to demonstrate some knowledge or skill that is an ultimate goal of the course. In much of the literature, this is referred to as a traditional or textbook style of physics problem solving (Huffman, 1997; Williams, 2018) and in these scenarios the problem is an avenue toward some other goal rather than the direct development of problem solving as a skill in itself.

Huffman pointed out that problem solving in physics is a great way to root out well-entrenched misconceptions that students have about physical phenomena and that these misconceptions often remain even after direct instruction related to them (Huffman, 1997). These misconceptions can only be illuminated if students are explicit in their solutions and clear about the principles of physics they are using in their solution.

Williams (2018) was more critical of the unchallenged esteem that physics problem solving has in education. He pointed out that even though the act of solving physics problems is imagined to prepare physics students for the ability to solve real-world problems in many different fields, the reality is not so. He posited that most physics problems are too well defined for the student to truly show any problem-solving skills that will translate to real-world possibly non-physics applications. For him, problem solving in physics should involve the student identifying their own questions and working through the messiness that comes with real problems (Williams, 2018)

What makes for a good physics problem? Effectively assessing a student's understanding and abilities in physics starts with writing good questions and problems for them to respond to. The literature points to several things that constitute a good physics problem.

First, Huffman pointed out that a good physics problem should get a student involved in both quantitative and qualitative aspects of physics thinking (Huffman, 1997). This means that a problem should not be a so-called "plug-and-chug" exercise that can be completed only using equations and not having to demonstrate any thinking about the physics involved. He contended that in order to tap into both of these parts of a solution the problems presented must be context rich and require the student to make important decisions about their solution along the way.

Further, Ogilvie (2009) endorsed a multi-faceted problem. A multi-faceted problem lies "somewhere between well-structured problems found in textbooks and large, ill-defined, open-ended challenges in the degree-of-difficulty these pose to students" (Ogilvie, 2009, p. 3). These types of problems would also involve multiple concepts that would have to be integrated into the same problem. This could be seen in a problem about a particle accelerator where magnetic force and circular motion both need to be taken into consideration.

Williams suggested that if the lessons learned in solving physics problems are to extend beyond the field the students must be generating their own questions. He argued that the types of problems that physics students are going to encounter in the "real-world" are not going to be as clearly defined as those that show up on a physics problem set or exam. This means that questions could be open-ended, have no particular right or wrong answer, and may have a multitude of ways that they can be successfully approached (Williams, 2018).

What kind of things lead to successful solutions of problems? With the goals and types of problems defined, the literature can turn its attention to how students can be successful in approaching and solving good physics problems. There are several key points made about what leads to a successful solution and what types of steps indicate good problem-solving strategies.

One of the most prominent aspects of a good solution to a physics problem is good diagrammatic representation of the situation (Huffman, 1997; Mansyur, 2015; Saputri & Wilujeng, 2017). This often involves a diagram of what is physically going on but can also refer to mathematical representation (Mansyur, 2015).

Huffman emphasized that a good physics solution follows an explicit problem-solving strategy. This strategy is similar to many step-by-step approaches to problems but is more explicit in the format of each of these steps. These explicit steps include "(a) focus the problem; (b) describe the physics; (c) plan the solution; (d) execute the plan; and (e) evaluate the solution" (Huffman, 1997, p. 555). This explicit strategy includes steps that allow for a mix of the qualitative and quantitative aspects of the problem to show up in the solution and keeps the student from just aiming for equations that fit the problem.

Yavuz (2015) picked up on the idea of presenting both quantitative aspects like correct algebraic representations and qualitative aspects like descriptions of physics principles of a problem solution and points out that students must strike the right balance between trusting their mathematics and trusting their intuition. Though Huffman pointed out that often that intuition can be misleading for the student (Huffman, 1997), Yavuz wrote that too much faith in the mathematics can also be misleading. The explicit strategy advocated by Huffman hopes to take care of these things.

Toraman and Karadag (2018) advocated the idea that creative approaches to problem solutions demonstrate the most understanding. For a student to demonstrate creativity in their approach to a solution, the crafting of the problem becomes very important so it allows that flexibility. The creativity might show up in a student's willingness to try a previously untested strategy or make reasonable assumptions about a situation.

In summary, the goal of solving physics problems should be to teach and assess certain knowledge and skills but also to involve students in explaining their thinking and demonstrating their conceptual understanding of the material. A good physics problem generally is context-rich and multi-faceted, allowing for choices to be made and justified about the course of the solutions. And good solutions involve explicit steps that are both quantitative and qualitative in nature and are creative in their approach to the problem.

Next is to think about how we present these problems to students and how students present their solutions. Traditionally physics problems have been solved with pen and paper but the use of assessment conversations around these problems can help illuminate student understanding.

Conversation as Assessment

In the last twenty years, formative assessment has risen in prominence as a vital part of education. It is not that formative assessment was not happening before that. Hattie and Timperley (2007) outlined the value of feedback in the teaching process and pointed out that test-like assessments do not offer the same kind of feedback opportunities as less formal conversations can. This informal assessment was likely happening every day in every classroom without being explicitly planned and described but Hattie and Timperley pointed out that it must be more explicitly planned and evident for both student and teacher. Every time a student and teacher interact and they in some way assess the students performance there is formative assessment going on. Formative assessment might also include things like short, ungraded quizzes, or regular homework. One very important part of formative assessment is conversation. This conversation can take many forms and can vary in its formality but there are fewer ways to get insight into a student's understanding of a concept better than having them articulate that understanding orally (Furtak & Ruiz-Primo, 2008).

The shift towards using conversation as a type of assessment is not surprising as there is great consensus in the value of oral explanation. Anderson et al. pointed out that talking science is prioritized over reading and writing about it and that in the real creation of scientific knowledge the conversation is way more important and powerful than anything written (Anderson, Zuiker, Taasoobshirazi, & Hickey, 2007). Duschl and Gitomer explain that science itself is an exploration and an argument (Duschl & Gitomer, 1997). In order to fully engage in a discipline, students should be immersed in the language and culture of that discipline (Ruiz-Primo, 2011). These explorations happen formally in written journal articles but before they get to that point they are argued and discussed less formally.

Types of assessment conversation. Assessment conversations are varied in their complexity, formality, and setting. The most well-known type of conversation happens nearly every day in every classroom and involves a whole-class discussion about a topic. A teacher might ask a guiding question and elicit responses from the students. As the students and teacher discuss the question they both are making small assessments of the students' understanding and the teacher can use the various student input in order to direct the classroom understanding and gradually correct any misconceptions or misunderstandings (Ruiz-Primo, 2011).

Another important conversation is one-on-one teacher and student conversation. Lee (1988) pointed out that this is a good way to have students explain and justify their thinking. This type of conversation can be much more focused on the individual student and their needs. In many classrooms, students are encouraged to meet and discuss with a teacher when they are having trouble with something but Lee (1988) stressed that these conversations should be happening for all students.

Student-student conversations can also be a very important part of formative assessment. A peer-conference gives students a chance to assess and be assessed at the same time and allow for students to possibly speak more freely without concern about being judged by the more authoritative teacher (Reinholz, 2017).

These different types of assessment conversations can vary in terms of their complexity and formality. The whole-class discussions mentioned above are relatively informal and unstructured while teacher-student and student-student discussions can range from the informal to very formal if teachers have given very specific instruction about the way the conversation should take place. These conversations can be ungraded and have no explicit feedback or they can be more formal with graded or detailed feedback from teachers or peers. Some conversations might be initiated by proactive students, while others might involve a teacher prodding a less-engaged student (Ruiz-Primo, 2011).

Goals and strengths of assessment conversations. Like any type of assessment, the goal of an assessment conversation is to improve student learning and understanding (Ruiz-Primo, 2011). With this in mind, it is important to focus on what specific role assessment conversations have in this process.

Starting with the most common type of assessment conversation, the whole-class discussion, this type of conversation allows for the teacher and students to very quickly check the general understanding of the class and to compare and combine student understanding in order to move the whole class forward in its overall understanding. It also has the advantage of providing feedback immediately rather than sometime later when it might not be at the top of a student's mind (Ruiz-Primo, 2011).

Teacher-student conversations have great value in giving the teacher insight into a student's thinking and giving the student very specific real-time feedback about their understanding. This type of conversation also allows the teacher to respond to the student with specific questions aimed at probing particular issues with their understanding (Ruiz-Primo, 2011).Student-student peer feedback activities in classes provide opportunities for students to practice analyzing another student's work as well as an opportunity to see their own work from someone else's perspective (Reinholz, 2017).

The work of Ruiz-Primo (2008, 2011), Furtak (2008) , and Hattie and Timperley (2007) forms the basic rationale for using conversations as assessment in science classes and this project will be based on these ideas.

Strategies for Successful Assessment Conversations

The strategies used for assessment conversations are varied and depend greatly on the type of assessment and the goals of that assessment but there are several general strategies that are proposed in order to get the most out of it.

Construction of the task. Care must be given to the construction of the task. There might be a tendency to be less focused on the task creation because nothing is written down, but many scholars emphasize the importance of a well-crafted task. The tasks should be guided by specific learning goals (Ruiz-Primo, 2011), and should be designed to elicit a wide range of student responses (Furtak & Ruiz-Primo, 2008). The task should also engage students in work with some purpose so that students understand why they are doing what they are doing (Duschl & Gitomer, 1997). The task must also be open-ended enough that a variety of diverse ideas can be presented and discussed (Duschl & Gitomer, 1997; Ruiz-Primo, 2011) so that student understanding can be refined in the process of the conversation. The task must also match the setting in which the conversation will take place. Open format formative tasks generally work better for individual responses while tasks with more constrained outcomes are better for whole-class discussions where a teacher might have a particular goal in mind for the discussion (Furtak & Ruiz-Primo, 2008)

Explicit modeling of quality conversation. Like any other type of assessment that teachers have for their students, it is important to model explicitly what a good conversation looks like. Many teachers are likely already doing this in their classrooms but their students may not know that this is happening and would benefit from very straight-forward guidance about how to proceed during an assessment conversation (Reinholz, 2017). Reinholz (2017) pointed out that after explicit training on peer feedback conversations student conversations improved greatly.

Providing feedback. Feedback is one of the primary goals of any assessment and the assessment conversation is a great tool because it allows for almost instantaneous feedback while a student is engaged with an idea or concept (Furtak & Ruiz-Primo, 2008). The feedback provided should focus most on process and self-regulation in order to benefit learning most. This type of feedback is less concerned with the right or wrong answer but more focused on the process, thinking, and approach that a student takes to a problem or situation (Reinholz, 2017).

In summary, the value of assessment conversations in education is clearly indicated (Reinholz, 2017; Ruiz-Primo & Furtak, 2006). Though many teachers are likely including some form of assessment by conversation, it might not be very explicit and it might at times be aimed only at students who are struggling with some concept (Lee, 1988). In order to successfully integrate the assessment conversation into practice, care must be taken to do it explicitly. The project aims to be explicit in direction to students about how to approach these types of assessments and focuses on helping the teacher create quality tasks.

Implementing Assessment Conversations Digitally

Next, our attention turns to strategies for engaging with assessment through digital technology. This will involve multiple components. First, what types of technologies and methods can be used to record student thinking and/or performance. Second, how can these recorded events be assessed.

The literature points to several different technologies that can be used to record student performance. Because many of these technologies are rapidly changing in terms of their capabilities and accessibility there are a wide range of tools in terms of sophistication. Tablet-based apps have shown the ability to help with formative assessment in classrooms in a variety of ways including: rapid assessment and feedback, interactivity, and tracking (Dalby & Swan, 2019). Dalby and Swan also pointed out that the introduction of technology as a tool for formative assessment does not mean that a whole new pedagogy is needed but rather that existing teaching methods can easily be adapted to work with the new technology (Dalby & Swan, 2019). For this reason, it will be important to focus on what is generally considered effective physics pedagogy and look for ways to enhance it with available technology rather than letting the technology be the driver.

Rationale for recorded conversations. A recorded assessment conversation gives a teacher an opportunity to engage with and understand a student's thinking is a way that a written task does not. This type of recording is particularly useful in disciplines where performance is an important aspect that cannot be assessed in a traditional examination session (Williams & Penney, 2011). A recorded conversation can also be done outside of the limited class time that exists for certain teachers (Karlsson, Ivarsson, & Lindstrom, 2013). Assessed recordings give teachers the time to engage with student thinking in a way that avoids labeling the thinking as simply right or wrong (von Aufschnaiter & Alonzo, 2018). The ability to argue and reason in science is vitally important and a recorded conversation gives science students a chance to practice and demonstrate these skills (Russ, Coffey, Hammer, & Hutchison, 2009). Practically, a recorded conversation or performance also has the advantage of being easily shared. Digital files can be sent easily around the world and offer better opportunities to standardize and moderate assessment (Williams & Penney, 2011).

Tools for recording conversations. The tools available for recording assessment conversations are varied and present many ways to capture the thinking of a student. One of the most basic and straightforward is a simple audio recording of a conversation that takes place between teacher and student. This type of recording can also be used for delivering feedback (Auld, Ridgway, & Williams, 2013). Some more sophisticated strategies involve computer programs that interact with students through a virtual text-based conversation. Though these tools do not allow for as much deep understanding of student thinking, they do provide very valuable immediate formative feedback (Benotti, Martinez, & Schapachnik, 2018; Karlsson et al., 2013).

In science classes, the use of a virtual laboratory has provided teachers with options for exposure to practical activities that they would not otherwise be able to do. These virtual laboratories involve students making choices about data collection and analyzing and explaining results all in a computer-simulated laboratory environment. These programs can also direct and record student responses in another type of automated virtual conversation (Karlsson et al., 2013).

Newer, tablet-based, interactive whiteboard applications provide a multitude of ways for students to interact with material and record their thinking while they do it. Ranga (2018) pointed out that using the app Explain Everything in a chemistry course allows for on-the-fly adjustments to recorded slideshow presentations, presents the ability to import images and documents for marking up, and can have audio recorded over the top of any of this. The use of a stylus on a touchscreen gives the student and/or teacher the ability to write directly onto an interactive whiteboard while simultaneously recording an explanation of the work (Ranga, 2018).

Possibly the most basic and practical way for a problem solving session to be recorded is by pointing an iPad or cellphone video camera at a piece of paper and recording the written and oral solution simultaneously. A picture of one low-cost setup for doing this is shown in Figure 1.

Figure 1

Using a cellphone to record problem solving.

Where recorded conversations come up short. Though recorded and virtual conversations present an opportunity to better understand student thinking and understanding, there are some shortcomings. Some students might be uneasy with the idea that they are being recorded and not feel as free to speak as they would otherwise (Auld et al., 2013). Though the recorded conversations can free up valuable class time for teachers they could at the same time increase the time it takes to evaluate the responses, missing out on the important immediate feedback that is so valuable in formative conversation (Benotti et al., 2018).

Overall, the technological possibilities presented for implementing and recording an assessment conversation or performance are numerous and varied. Teachers are able to select the best method based on its fit with the learning goals of the class. These methods offer great ways to delve deep into student thinking and understanding but bring with them some practical limitations. For my own project, the choice of technology will be based on what is available to me and what is easiest as a method for demonstrating to other teachers. It will be important to demonstrate it in a way that is most accessible for others in order to more easily share the strategies.

Conclusion

In this chapter, we see the purpose of problem solving in physics as a way to elicit student responses that demonstrate a deep understanding of both conceptual and procedural physics knowledge. The assessment conversation presents a way to engage with students solving problems in order to get a better understanding of their understanding and thinking during a problem solution and various technologies allow for these conversations and problem solutions to be recorded and assessed in multiple ways. This will help as I try to answer the following: *How can the use of digital recordings of a student's thinking during physics problem solving help the teacher in assessing the student's work?*

These ideas will be used in the following chapter to develop a method for assessing student physics problem solving through a conversation/problem solving mix where students will record themselves as they talk through and work through their problem solutions.

CHAPTER THREE

Project Description

My capstone project aims to answer the question, *How can the use of digital recordings of a student's thinking during physics problem solving help the teacher in assessing the student's work?* This project represents an attempt to assess student problem-solving skills along with conceptual understanding at the same time. Solving physics problems is an important part of many physics courses but the static written solution can often leave much about the student's understanding of physics hidden. The aim here is to add another layer of student engagement and response in order to fill in any gaps in assessment that might exist.

What the Project Will Look Like

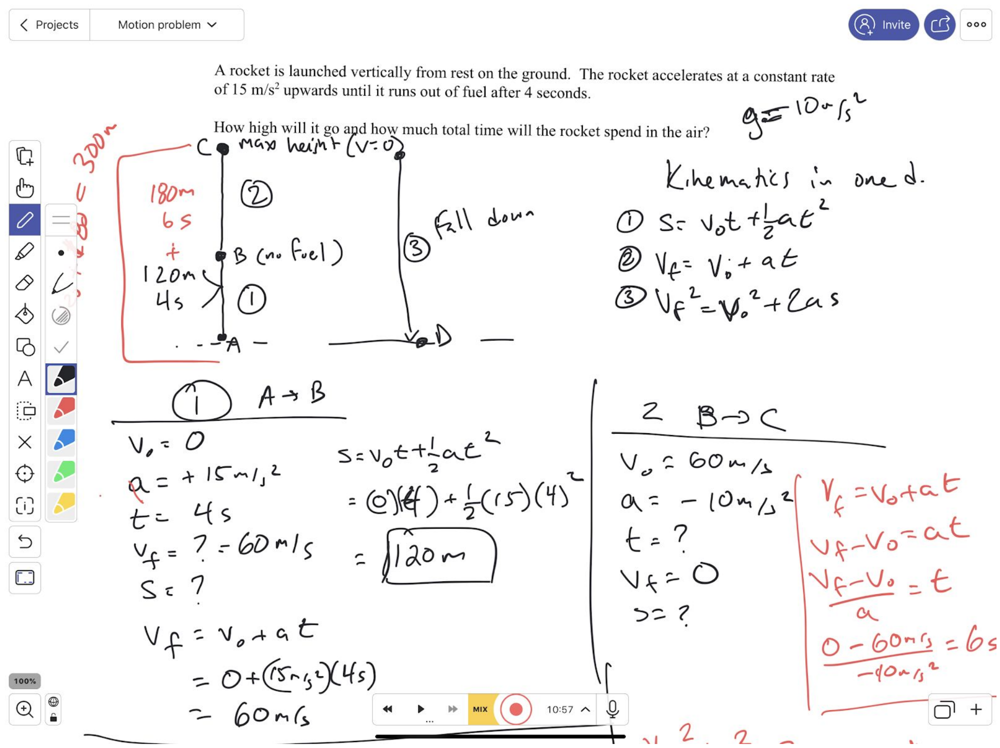
This project will consist of four main parts. First, a set of 8 physics problems, each from a different topic in introductory physics, will be presented. For each, examples will be given for how the question can be modified for level of difficulty and degree of open-endedness. Second, it will include detailed instructions for how to carry out the simultaneous written and oral problem solving using a tablet-based whiteboard app and a low-tech homemade recording device. The 8 sample problems will be solved using this recording method. Third, a rubric for the written/oral solution will be presented and its use will be demonstrated in assessing the 8 solved problems. Fourth, this information will be packaged for presentation in two ways. One completely digital with electronic copies of all resources and videos of the recorded solutions as well as videos demonstrating the application of the rubrics. Another presentation will be a slide show intended for a professional development workshop.

The main tool used to implement this project will be one that allows the recording of a student's solution to a physics problem in multiple ways simultaneously. There will be a visual recording of what the student is writing and/or drawing and at the same time an audio recording allowing for the student to explain their thinking during the solution. There are many types of digital learning tools that can reach these goals and my project will use the following two as examples.

Explain Everything (Ranga, 2018) is a virtual whiteboard application for use on computers and tablets. While being used on a tablet a student can write directly on the tablet with a stylus and record audio at the same time. This type of whiteboard has many good points. The student can easily change colors of "ink" in order to more effectively show the flow of the solution and to make clear diagrams of the problem situation. A screenshot of an example of this type of solution is shown in Figure 2.

Figure 2

Problem solution using Explain Everything for iPad.



For schools and districts that might not have the need for or means of obtaining the Explain Everything application, there is a more rudimentary way of recording the problem solving. With the aid of a smartphone or tablet stand, students can take a video recording of their written solution as they explain their thinking out loud and then share this recording with the teacher. A photo of this type of setup is shown in Figure 3.

Figure 3

Using a cellphone to record problem solving.

The project will include 8 example problems from a wide range of physics topics and will be presented as a video tutorial that teachers could use to model their own assessments after. The problem topics will be based on national and Idaho state standards. These tutorials will be in the form of videos that can be shared easily at workshops or PD sessions and will show how to approach these problems and use these technologies from both a teacher and student perspective. Four of the examples will be done using the Explain Everything App on an iPad and the other 4 examples using a basic video recording device and homemade stand. Alongside examples of how to implement the strategy will be a general assessment rubric detailing how to mark and give feedback on this type of work. There will also be several examples of physics problems that are appropriate for this type of assessment.

Theoretical Grounding of the Project

The project will be grounded in two different theoretical frameworks that deal separately with physics problem solving and assessment as conversation.

In terms of physics problem solving the project will be based on the work of Huffmann (1997) on developing context-rich physics problems and Docktor et. al (2016) for developing rubrics for assessing student work.

The research of Furtak and Ruiz-Primo (2008) on conversational formative assessment will be the basis for that part of the project. This work supports the idea that conversations and qualitative discussions about science need to be included with the quantitative aspects in order for students to really learn about the discipline.

Setting, Participants, Timeline, and Assessment

This project is one that will be developed outside of a classroom with the intention of being implemented in a classroom in the near future. I will be using national and Idaho state science standards as a basis for physics standards to be met but the tools developed will be intended for use by any physics teacher in late high school or early post-secondary physics education where problem solving plays a role.

The project will be developed and finished throughout the month of February, 2020. My aim is to share my strategies and examples with teaching colleagues through sharing of video tutorials and through district level professional development workshops.

The project will be assessed based on the ability first, to implement this type of problem solving in my own classroom, second, to get other physics teachers to try the strategy and third, to collect feedback from teachers who have gone through workshops and have used the strategy.

Conclusion

In this chapter I have detailed what the project will look like, its theoretical grounding and the logistics related to setting, participants, and timeline. After the project is complete I will reflect on the whole process in the next chapter.

CHAPTER FOUR

Conclusion

Introduction

My capstone project aimed to answer the question: *How can the use of digital recordings of a student's thinking during physics problem solving help the teacher in assessing the student's work?* In order to do this I developed a strategy for teachers to have their students record their thinking while simultaneously solving the problem. There are many ways that this can take place but the two I highlight are using a homemade camera stand to video record your solution process and using an iPad based app that allows the use of a stylus on a virtual whiteboard while recording audio. Both of these methods allow a teacher to see and hear a student's thinking in real time as choices are made in the problem solving process. This, combined with a general rubric for physics problem solving, provides a way for physics teachers to identify mistakes, misconceptions, and inconsistencies in the thinking and logic of the problem solution.

This chapter is a reflection on the project and looks at what was learned in developing the project. I reflect on the literature that proved useful for the project. Then I look at how the project will be communicated with people that would benefit from it and what the project might mean for policy or future research projects.

Major Learnings

Three things stick out to me when I think about my major learnings from this capstone project.

First, it is important in physics class to get at students' qualitative and quantitative understandings of a topic and is great if that can be done in the same problem or exercise. Often physics teachers will treat a problem as one or the other but the idea of recorded problem solution gives more ways for teachers to assess both at the same time.

Second, the introduction of recording technology as a tool for assessment does not fundamentally change the types of assessment that you should be doing in a physics class. The idea of having students communicate their understanding and thinking orally is good practice whether or not it is recorded. As teachers, we sometimes focus our teaching to model the ways that students will be assessed. This can mean that if we are not assessing students oral explanations of their thinking, we will not be teaching them to do this. The move towards recording problem solutions opens the door to using this as a form of assessment which in turn should lead to more teaching about talking through your physics.

And third, in order to best advocate for this type of assessment strategy, it is best to look at the simplest way to implement it. Certain technological tools might offer very sophisticated ways of achieving these goals but those technologies might be cost-prohibitive for some schools and/or districts and the learning curve for some of those applications might seem too steep in order to get a large number of teachers to take up the challenge. Individual schools or districts might try to incorporate more sophisticated technological tools that allow for even more types of interaction but in order to introduce the strategy broadly it is likely best to stick to a method that can work for anyone relatively easily.

Revisiting the Literature

Going back to chapter two and the literature review, I find there are a few parts that stand out as most important in my project.

First, the work of Huffmann (1997) and Docktor et. al.(2016) provided the base for what type of things should be involved in crafting and assessing physics problems. Huffman's clear description of the key aspects of a good problem were helpful in developing goals for writing good physics problems. I did find that the goals that Huffman advocates for a good physics problem are not ones that you can, or even want to, always be using. Teaching introductory physics still involves asking some one-step, non-context rich questions in order to quickly assess student knowledge.

Docktor et. al's (2016) rubric for problem solving was clear and focused while at the same time being open-ended enough to apply to any type of physics problem. This rubric provides a great base for assessing both written and spoken work.

The works of Furtak (2008) and Ruiz-Primo (2008, 2011) were very useful in emphasizing the importance of conversation in science classes in general and Hattie and Timperley's (2007) work on formative assessment was of course important in showing the value of providing various types of feedback to students. One thing that still did not show up and that might be part of future research is the idea of using conversations in physics classes as a way to do summative assessment. I am hoping that my work on recorded problem solving conversations might be a step towards this though.

Implications

It was interesting to be finishing this project in a time when most of the country's children were learning from home because of the COVID-19 pandemic. This push towards at-home learning put into the light the inequities that students face in regards to access to computers and internet connection at home. The implementation of my project depends on some access to computing/recording technology and internet connectivity and my belief is that it should become a federal priority to get every student in the country access to a computer and internet at home. As we prepare students to go out into a school and work world that depends so heavily on technology literacy, I believe we are doing them a great disservice if we do not make sure that they can all regularly access these important tools.

From an assessment perspective I would expect that more school districts will move towards assessing students in more varied ways. My focus on giving students the ability to add an explanation to their problem solution is a small step in this direction but I would aim to try to integrate this as much as possible so students would start to feel comfortable using it in some way during summative assessment tasks.

Limitations

The biggest limitation I faced in doing this project has only to do with my own timing of completing the project. I am currently in my first sabbatical from teaching which provided the time to work on the project but at the same time meant that I did not have students I could be practicing some of the strategies with. I look forward to getting back into the classroom in the fall and having students work through problems using this strategy.

Future Research/Projects

The first step from here with this project is to get it out into schools and get high school physics teachers using it. This would help in generating feedback for how much the strategy gets used and how it can be improved. At this point the recorded problem is intended for use as a formative assessment in order to give better feedback to the student but a future project might look at ways that students could provide oral explanation during a summative feedback task.

A more quantitative research project might involve collecting the written and written/oral work of several classes of students. This work could then be marked by a range of physics teachers both with and without the recorded explanation included. This type of research might help show how useful or not useful the recorded conversation is in illuminating inconsistencies in written and oral work.

This project could also be expanded for use in other subject areas where written problem solving is often used as a teaching and assessment tool. I could see these same strategies being used in middle and high school math and chemistry classes very easily.

Communicating Results

The slideshow presentation that I have put together, along with all of the documents and videos that it links to, can be easily shared both virtually, as a recorded presentation, and in person. The first step, for me, will be to gather with the science and math teachers in my own school building in order to share the results of my project. From there I will work towards giving the same presentation to all of the physics teachers in my school district and then to present at a statewide science teachers' conference.

Beyond delivering the presentation in person, the slideshow can be shared virtually. I could easily present it remotely to a range of participants in a range of locations. The presentation can also be recorded so that someone can access it and go through it on their own.

Benefit to Profession

My project aims to provide physics teachers with another tool in their attempts to diagnose and help correct the mistakes that students make in solving physics problems and understanding physics. It also provides students with an outlet to show their understanding that is different from traditional written-only methods.

By adding ways for students to explain their thinking I hope to make the physics problem-solving process more dynamic and less dependent on just writing down mathematical steps. Overall, my hope is that this project will help teachers to vary the ways that students show their thinking through problem solving and to use this to better assess and develop student understanding in physics classes.

REFERENCES

Anderson, K. T., Zuiker, S. J., Taasoobshirazi, G., & Hickey, D. T. (2007). Classroom discourse as a tool to enhance formative assessment and practise in science. *International Journal of Science Education, 29*(14), 1721-1744.

Auld, G., Ridgway, A., & Williams, J. (2013). Digital oral feedback on written assignments as professional learning for teacher educators: a collaborative self-study. *Studying Teacher Education, 9*(1), 31-44.

Benotti, L., Martinez, M. C., & Schapachnik, F. (2018). A tool for introducing computer science with automatic formative assessment. *IEEE transactions on learning technologies, 11*(2), 179-192. doi:http://dx.doi.org/10.1109/TLT.2017.2682084

Dalby, D., & Swan, M. (2019). Using Digital Technology to Enhance Formative Assessment in Mathematics Classrooms. *British Journal of Educational Technology, 50*(2), 832-845.

Docktor, J. L., Dornfeld, J., Frodermann, E., Heller, K., Hsu, L., Jackson, K. A., . . . Yang, J. (2016). Assessing student written problem solutions: a problem-solving rubric with application to introductory physics. *Physical Review Physics Education Research, 12*(1), 010130-010131. doi:http://dx.doi.org/10.1103/PhysRevPhysEducRes.12.010130

Duschl, R. A., & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment, 4*(1), 37-73. doi:10.1207/s15326977ea0401_2

Furtak, E. M., & Ruiz-Primo, M. A. (2008). Making students' thinking explicit in writing and discussion: an analysis of formative assessment prompts. *Science Education, 92*(5), 799-824. doi:http://dx.doi.org/10.1002/sce.20270

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

Huffman, D. (1997). Effect of explicit problem solving instruction on high school students' problem-solving performance and conceptual understanding of physics. *Journal of Research in Science Teaching, 34*(6), 551-570.

Karlsson, G., Ivarsson, J., & Lindstrom, B. (2013). Agreed discoveries: students' negotiations in a virtual laboratory experiment. *Instructional Science: An International Journal of the Learning Sciences, 41*(3), 455-480.

Lee, K. (1988). The development of oral assessment. *Mathematics in School, 17*(3), 12-13.

Mansyur, J. (2015). Teachers' and students' preliminary stages in physics problem solving. *International Education Studies, 8*(9), 1-13.

Ogilvie, C. A. (2009). Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems. *Physical Review Special Topics - Physics Education Research, 5*(2), 020102-020101. doi:http://dx.doi.org/10.1103/PhysRevSTPER.5.020102

Ontario. Ministry of Education. (2010). *Growing success: Assessment, evaluation, and reporting in Ontario schools*. [Toronto]: Queen's Printer for Ontario.

Ranga, J. S. (2018). Multipurpose use of explain everything iPad app for teaching chemistry courses. *Journal of Chemical Education, 95*(5), 895-898. doi:http://dx.doi.org/10.1021/acs.jchemed.7b00676

Reinholz, D. (2017). Peer conferences in calculus: the impact of systematic training. *Assessment & Evaluation in Higher Education, 42*(1), 1-17.

Ruiz-Primo, M. A. (2011). Informal formative assessment: the role of instructional dialogues in assessing students' learning. *Studies in Educational Evaluation, 37*(1), 15-24. doi:http://dx.doi.org/10.1016/j.stueduc.2011.04.003

Ruiz-Primo, M. A., & Furtak, E. M. (2006). Informal formative assessment and scientific inquiry: exploring teachers' practices and student learning. *Educational Assessment, 11*(3-4), 237-263. doi:http://dx.doi.org/10.1207/s15326977ea1103&4_4

Russ, R. S., Coffey, J. E., Hammer, D., & Hutchison, P. (2009). Making classroom assessment more accountable to scientific reasoning: a case for attending to mechanistic thinking. *Science Education, 93*(5), 875-891.

Saputri, A. A., & Wilujeng, I. (2017). Developing physics e-scaffolding teaching media to increase the eleventh-grade students' problem solving ability and scientific attitude. *International Journal of Environmental and Science Education, 12*(4), 729-745.

Toraman, Ç., & Karadag, E. (2018). Analyzing process of problem solving with group via statistical discourse analysis. *Educational Sciences: Theory and Practice, 18*(2), 229-252.

von Aufschnaiter, C., & Alonzo, A. C. (2018). Foundations of formative assessment: introducing a learning progression to guide preservice physics teachers' video-based interpretation of student thinking. *Applied Measurement in Education, 31*(2), 113-127.

Williams, M. (2018). The missing curriculum in physics problem-solving education. *Science & Education, 27*(3-4), 299-319. doi:http://dx.doi.org/10.1007/s11191-018-9970-2

Williams, P. J., & Penney, D. (2011). Authentic assessment in performance based subjects. *Teachers and Curriculum, 12*(1), 31-39.

Yavuz, A. (2015). Do students trust in mathematics or intuition during physics problem solving? An epistemic game perspective. *EURASIA Journal of Mathematics, Science & Technology Education, 11*(3), 633-646. doi:http://dx.doi.org/10.12973/eurasia.2014.1205a