CREATIVE PROBJECT DESCRIPTION

CREATIVE THESIS PROJECT: Inverted-Classroom Problem-Solving Methodology and Video Recorded Materials

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The Problem

Many learners today struggle with modern textbooks and their motionless depictions of information. As a response, schools and classrooms are becoming more digital to reach those learners who learn best in dynamic ways. Using technological tools an instructor can reach children in new and energizing instruction that uses the text but is not reliant on it for full instruction.

One popular technological platform is a video hosting website called YouTube (www.youtube.com) where videos can be uploaded and replayed as needed. It is the purpose of this creative project to create YouTube videos introducing concepts and solving problems for topics in physics in a more dynamic way. In these videos, careful consideration will be given when detailing and explaining the problem. Problem-solving strategies will also be exemplified
in these videos. Using this re-watchable medium of digital videos could prove to help learners who otherwise struggle to find success in less dynamic circumstances in physics.
Dedicated to my family, including my wife, my dad, and my mother-in-law, who are always there for me.
# Table of Contents

Chapter 1: Introduction .................................................................................................................. 1  
1.1 Traditional vs Inverted ........................................................................................................... 1  
1.2 Inverted-classroom Origins ................................................................................................. 2  
1.3 Inverted-classroom Application .......................................................................................... 3  

Chapter 2: Literature Review ....................................................................................................... 6  
2.1 Problem-solving .................................................................................................................... 7  
2.2 Orchestrations of Learning .................................................................................................. 11  
2.4 Memory ............................................................................................................................... 13  
   2.4.1 Memory reconstruction. ................................................................................................. 14  
   2.4.2 Working memory. ........................................................................................................ 15  

Chapter 3: The Inverted-Classroom ........................................................................................... 19  
3.1 Video Problem-Solving ....................................................................................................... 19  
3.2 Inverted-classroom and beyond ......................................................................................... 23  

References ................................................................................................................................... 24  

APPENDIX ................................................................................................................................... 26
Chapter 1: Introduction

1.1 Traditional vs Inverted

Problem-solving, as a topic, is a massive field of study within the field of physics Education and similar content areas. There are many different aspects of a learner’s engagement to a problem that can greatly affect their ability to solve it correctly and transfer that knowledge to similar problems in the future. A key aspect of problem-solving is often addressed in a physics classroom using example problems that are meant to transfer to practice problems in the form of homework. The purpose of this is to give an instructor a chance to exemplify the internal justifications he or she uses during problem-solving, such as strategies and methods, and to engage learners in that process by acting as a role model in problem-solving.

In traditional classrooms, this exemplification can leave very little time in the class to address questions and may not help correct poorly executed problem-solving techniques or fill gaps in concept knowledge. However, since the internet has become a nationwide resource that more and more learners have access to it is possible that more instruction can be done outside of the classroom. This would leave more time in the classroom to answer questions, help learners correct mistakes, and have more targeted instruction.

Most households today either already have internet or learners can go to local libraries or local businesses, which offer publicly free internet access. There has been a recent move toward using multi-media tools and platforms online that learners can access outside of class time to help them get the extra time with school materials outside of school. By not relying solely on in-class time instruction to navigate classroom content, learners not only have more exposure to the material they need but they also have control over how they use it. The internet, so widely
offered in the modern world, may be the key to helping learners access more materials outside of class.

This is especially important to learners who either do not have the money or availability to access tutoring or to join study groups. Such outside instruction can also be essential for learners who need more time with material for learning or linguistic reasons and can catch learners up who are absent from school. As an answer to this need and using the internet and other technological innovations available to both learners and instructors, the idea of implementing an ‘inverted’ or ‘flipped’ classroom arose.

1.2 Inverted-classroom Origins

Inverted-classrooms were first explored by Lage, Platt, & Treglia (2000) when discussing ways to incorporate the World Wide Web as a tool in the classroom. An inverted-classroom is one in which a classroom’s time spent on the topic material is inverted from a traditional classroom’s format (Lage, Platt, & Treglia, 2000). This format means that activities generally completed during class time in traditional classrooms, such as lectures, were provided online for independent viewing and note taking (Lage, Platt, & Treglia, 2000).

Such inverted materials could take the form of video recordings of lectures or PowerPoint presentation with voice over dictations (Lage, Platt, & Treglia, 2000). Since classroom lectures are handled outside of the classroom, classroom time itself is now more free to more informal aspects of education, such as answering questions, abridged lectures discussing difficult talking points, and group work time (Lage, Platt, & Treglia, 2000). This group work in physics can take place in several different ways.
The goal of the inverted-classroom was to address the “mismatch between an instructor’s teaching style and a learner’s learning style” that had been seen to negatively affect learner gains in the classroom (Lage, Platt, & Treglia, 2000, p. 30). Lage, Platt, & Treglia (2000) suggested using technology as a learning platform and add more options for learners to choose from in-order-to complete assigned work and directly interact with the teacher and the material. By doing this, different learners with different learning techniques were able to engage with the material in ways that benefited them and this method also allowed for time in class to ask questions that traditional classrooms do not have an abundance of (Lage, Platt, & Treglia, 2000).

1.3 Inverted-classroom Application

Application of an inverted-classroom to a physics course could be done in a similar fashion as seen in Lage, Platt, & Treglia (2000)’s economic classroom. Physics is primarily a three-component classroom: (1) Lecture, (2) Lab, and (3) Problem-Solving. Of course, other elements work their way in and out of a physics classroom such as demonstrations, hands-on activities separate from labs, and group work. However, for the purposes of discussing an inverted-classroom, these are the primary elements being focused on to be inverted.

Lectures can easily be transitioned to an online setting. This can be seen across the United States of America where partially or completely online physics courses and/or materials are available online. Such places include a homeschooling platform Khan Academy and in Indiana two universities, Purdue University and Ball State University, offer online physics materials and either partially or completely online physics courses (Khan Academy, 2019; Purdue University, 2019; Ball State University, 2019). Lectures and lecture quizzes, in some of these settings, are done by using online educational platforms such as Google Classroom or
Blackboard which allow for episodic, module based learning for online courses (Purdue University, 2019; Ball State University, 2019).

Labs themselves have also had some success outside of the classroom where schools have converted simple experiments or inexpensive demonstrations into material accessible to at home completion. Such experiments or demonstrations are typically completed using at home supplies or they can involve lab kits (Purdue University, 2019). More technologically sophisticated lab kits can involve gadgets which include a multitude of sensors for various company provided labs, all of which can be rented for set amounts of time or purchased (iOLab, 2019). Either way, in an online classroom, labs can be completed, recorded, and discussed using worksheets provided with the lab manuals and accessible and deliverable all online (Purdue University, 2019).

Since both the lecture and some or all the labs can be completed outside of the classroom time, such online courses become powerful ways to educate non-traditional or distance learners. In an inverted-classroom setting, giving more time to the instructor during meeting hours can be equally powerful. Having lectures online and covered outside of class gives both the learners more time with the material and the instructor can do more with the learners in class. Additionally, having an option to do some lab work outside of class time gives instructors a better opportunity to dive into the rest of the process of experimentation, such as analysis and more complex data interpretations, which otherwise would not be able to be completed in limited lab time. This format also allows a more extensive lab work experience, giving more time in class to dedicate to the lab materials (Lage, Platt, & Treglia, 2000).

In a physics classroom, problem-solving is arguably the primary avenue for understanding and being able to use concepts taught, both as part of the lecture and the lab. This
can either be accomplished in a homework or classroom example format. To reach a level of understanding that can be applied in a lab or test, one must use the concept, like a tool, through problem-solving to develop stronger comprehension of that concept in the language of mathematics.

As such, utilizing the inverted-classroom method to help learners with this crucial part of the material covered in the physics classroom may be beneficial. While the classroom time may be used for answering questions directly and allowing for group work or guided problem-solving, the inverted-classroom gives yet another avenue to reaching learners to aid them in developing the problem-solving skills necessary to navigate a physics course. As stated previously by Lage, Platt, & Treglia (2000), there is an observed mismatch in teaching styles of modern-day lecture/lab formatted classrooms and the diverse learning styles of the learners.

In this paper, the literature will be explored on the validity of inverted instruction in terms of working memory, cognitive load, and problem-solving as it applies to the physics classroom and videos produced for inverting that classroom.
Chapter 2: Literature Review

Before inverting a classroom can be argued to be beneficial to learners, there first needs to be an understanding of how a learner’s brain processes information, gains comprehension, and uses this comprehension to enact responses in a classroom. This can be done by understanding how a learner experiences learning and, more specifically concerning physics, how a learner’s developed mental strategies are used in problem-solving. Additionally, by using the most effective mediums to reach learners both cognitively and engagingly, a general understanding of both learning orchestrations and working memory as it applies to problem-solving can help instructors develop a path of learning useful to multiple different learners.

In a book by the National Academies of Sciences, Engineering, and Medicine (NASEM)’s book, *How People Learn II: Learners, Contexts, and Cultures* (2018), the learner’s experience both externally and mentally is examined. By understanding the orchestrations of learning and memory and how they play a role in a learner’s learning in general, NASEM (2018) argues that insights gained by this knowledge will lead to more effective educational strategies. As previously discussed, inverted-classrooms utilize classroom strategy that effects the learners, the instructor, and the classroom dynamic in a unique way. Whether or not an inverted-classroom is not only a useful change to a classroom but also not a detrimental one is an important question to consider.

By understanding the aspects of learning orchestrations, memory, and specific struggles in physics classrooms, instructors in physics will be more able to equip learners with the tools necessary to overcome challenges they may encounter in the classroom. Not only can learners come closer toward a deeper understanding of the material if such aspects of learning are
understood, it may enable learners to apply what they have learned more effectively, more quickly, and with less incorrect responses.

Let’s first explore problem-solving, as it applies to the subject of physics, and then explore out students learn and use what they learn to navigate problem-solving experiences through their orchestrations of learning and working memory.

2.1 Problem-solving

Problem solving in physics is likely one of the most important aspects to learning and using the concepts learned in the subject. Much of what is physics deals with taking what is understood and applying it to different situations. This can come in multiple forms in physics, such as laboratory exploration and hypothetical situations that have both known and unknown variables.

In physics education, learners can have varying degrees of success when it comes to successfully understanding and strategically solving problems. Such variations can have a huge impact on the learner’s success not only in physics but in problem-solving outside of the classroom. Being both a scientifically literate adult and developing universal problem-solving skills are important aspects of education which a physics classroom is uniquely capable of addressing.

When a problem-solver engages with a problem, they may process the information and strategize through their solution differently based on some important factors, including prior experience and prior knowledge. Chiefly, if a learner has experience working with physics problems and has a well-established grasp of concepts, they may navigate a problem completely
differently than someone unfamiliar with one or both of those factors. In physics educational research, some refer to these two types of learner as expert and novice.

The idea of experts and novices comes from a long-held belief in education that experienced learners will “solve complex problems considerably faster and more accurately than novices do,” (Larkin, McDermott, Simon, & Simon, 1980, p. 1335). Expert problem-solvers therefore must interact with information differently than newer, more novice problem-solvers. Perhaps expert problem-solvers see a problem differently and are able to strategize and solve problems in more effective, efficient, and experienced ways.

This idea has formulated into what is called the Expert and Novice Theory, a framework in education that attempts to explain the differences in behavior between how experts and novices interact with content or challenges. In a study done by Ali, et al. (2014), not only were their participants, who were categorized as experts, effective at navigating challenging situations in problem-solving, but they were also self-aware of their status. Expert problem-solvers were not only able to self-correct when problem-solving, but they were also capable of articulating justifications in detailed, content rich ways (Ali, Ibrahim, Abdullah, Surif, & Saim, 2014).

In a similar study by Chasteen, et al. (2012), expert problem-solvers were also aware of their conceptual fallacies and were more likely to self-correct than counterpart novice problem-solvers. Conversely, novices who may have been capable of choosing the right answer in problem-solving were rarely capable of justifying why their answer was correct beyond superficial or conceptually simplified reasonings (Chasteen, Pepper, Caballero, Pollock, & Perkins, 2012). In fact, in the Chasteen, et al. (2012) study, some of the novices were able to achieve correct answers but used incorrect assumptions or misconceptions as reasoning in their justifications.
It was this lack of self-awareness that lead Chasteen, et al. (2012)’s researchers to the conclusion that novices are not lacking in knowledge of concepts in order to develop cogent justifications. Despite the knowledge of concepts likely being present, Chasteen, et al. (2012) suggest that novices are not considering why their justifications may be wrong or they are misunderstanding the problem, leading them down a path of incorrect uses of concepts. This may be due to novice learners’ inexperience with identifying central features of a problem and using them to form strategies along with recently learned concepts in class (Chasteen, Pepper, Caballero, Pollock, & Perkins, 2012).

Other research in physics education problem-solving more explicitly looks at all aspects of novice and expert interactions with problems, not just the end results and justifications. This includes considering where learners focus on a problem the most, what concepts or strategies do they use, and how long it takes for certain phases of problem-solving to transpire (Kohl & Finkelstein, 2008). In a study of experts and novices, Kohl and Finkelstein (2008) discovered that expert problem-solvers spent significantly more time reading the problem and goal orientated activities, where their priority focus of time was spent on goal orientated activities and almost zero time spent on planning.

In the same study, novice problem-solvers, on the other hand, had priorities which seemed evenly split between goal orientated activities and aimless, less focused behavior (Kohl & Finkelstein, 2008). Such aimless, less focused behavior was indicative of option searching or experimenting with variables (Kohl & Finkelstein, 2008). Overall, Kohl and Finkelstein (2008)’s study revealed that while experts spent most of their time attempting to understand the problem first, before solving, the novice problem-solvers had less focus and neglected, in comparison, aspects important to understanding the problem. This, Kohl and Finkelstein (2008) conclude, is
perhaps a key difference between expert problem-solvers and novice problem-solvers, a lack of focus. Where expert problem-solvers did not necessarily know what steps to take next, they were still pursuing goals towards crafting a solution (Kohl & Finkelstein, 2008). Novice problem-solvers, on the other hand, did spend some time on this pursuit of goals, however, spent equal time aimless attempting to accidentally find a workable path toward a solution and did not consider in significant ways why those methods may work (Kohl & Finkelstein, 2008).

Such aimlessness is perhaps considered part of a deeper reliance on pre-solved solutions to compare and, perhaps even, to copy from in order to find a working solution (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). In a study done by Chi, et al. (1989), the research done on a similar notion of novice and expert problem-solvers, referred to as ‘good’ and ‘poor’ problem-solvers in the publication, showed ‘good’ problem-solvers were not only accurate in their own monitoring of understanding but were also not dependent on examples to guide their strategies. It was reasoned that ‘good’ problem-solvers were not dependent on examples because they had a better grasp of the content that made both examples and the current problem being solved solvable (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Comparatively, ‘poor’ problem-solvers depended heavily on outside examples to solve problems because they lacked the content knowledge or confidence to use the content knowledge necessary to craft their own solution (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Such a lack of use of content to build solutions was attributed to ‘poor’ problem-solvers lack of self-sufficient explanations and inaccurate monitoring of understanding and learning of the content (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). More specifically, inaccurate monitoring in this context was the occurrence of changes to content understanding occurring without the awareness of the learner, robbing them
of the ability to know their understanding changed or, at minimum, why it changed (Chi, Bassok, Lewis, Reimann, & Glaser, 1989).

However, despite having a more intimate knowledge of what expert problem-solvers do as their activities compare with novice problem-solvers, this does not quite answer the question of why this may be occurring. To understand this, an understanding of the human brain is necessary to access how learners process information given to them and how it is used in the future. Let’s first consider how information is processed by the brain.

2.2 Orchestrations of Learning

The human brain and the processes behind how learning occurs are interesting topics. Though there are mysteries concerning these processes, there has been a great deal of work done to understand how the human brain and its processing and abilities effect learning. According to NASEM (2018), the learning and understanding process learners experience can be discussed in terms of the three primary orchestrations of learning: (1) metacognition, (2) executive function, and (3) self-regulation.

NASEM (2018) defines metacognition as the capability of a learner to monitor and regulate their own processes. The learner’s cognitive abilities and the activities associated with cognitive function are controlled and regulated through behaviors the learner enacts during the learning process (NASEM, 2018). If a learner can become more self-aware of this process and their own epistemology concerning physics, they can become a more active participant in improving their learning (NASEM, 2018). Having this self-awareness, NASEM (2018) claim, will empower learners in their life-long learning skills as well.
Executive function is defined as a learner’s ability to consider information, navigate thought processes to avoid incorrect or incomplete solutions, and switch attention as necessary (NASEM, 2018). In problem-solving, this ability to navigate a problem’s many pieces of information to form a complete and correct solution is essential. This is because problem-solving is about finding the best solution that fits all of the given information, not a solution that fits some or most of the information given. This explains why problem-solving is considered a difficult skill to master because of the mental load it can weigh on the mind and especially if a problem requires a person to consider multiple different aspects of a problem to weave together an answer.

It is noted by NASEM (2018) that the executive function plays such a fundamental role in the human mind concerning processing of information that humans may not be capable of learning complex concepts without it. NASEM (2018) argue that learning disabilities are manifested due to impaired executive function. When a learner has difficulty either holding information or lacking the inhibition to jump to incorrect or incomplete solutions or to switch attention, this is a sign of an undeveloped or impaired executive function of the brain (NASEM, 2018). This is especially important in physics problem-solving because learners must be able to focus on information and make choices amongst competing perspectives in order to craft a solution.

These competing perspectives can manifest in interesting ways. Part of the problem-solving process is using a current understanding of content to solve a problem. However, by being self-aware, using metacognition, and the process of thinking through information, solutions, and being flexible in attention, learners must sometimes overcome what they think they know in order to solve a problem. This process of changing understanding in order to regain
a balance of sorts internally is known as equilibration (Piaget, 1964). Piaget (1964) argued a learner’s ability to recognize an imbalance between their current understanding and the contradicting evidence they must consider was key to gaining understanding.

In problem-solving, learners develop models or understandings of concepts in physics which may or may not be completely aligned with the intent of the instruction. Such misunderstandings or misconceptions often find resistance in problem-solving because the correct solution relies on accurate understandings of concepts. When learners go through equilibration, as Piaget (1964) describes it, the learners make choices on their self-aware aspects of understanding, their metacognition, and make changes in order to accommodate new information, contradictory evidence, or failed predictions produced by their executive function. Such equilibration, a learner’s self-control of how to interact with new information and how this affects future thinking, is the third orchestration of learning called self-regulation (NASEM, 2018).

Now that there is some context to how the brain orchestrates learning through metacognition, executive function, and self-regulation, skills the brain uses to process information, let’s now consider how the brain stores this information through memory.

2.4 Memory

Memory and the processes involved in information recall are still not well understood. Memories are not files on a hard drive, ready to be retrieved and replayed whenever desired (NASEM, 2018). There is a more wholistic approach to storing memories which uses global processes of the brain in order to store information for later reconstruction (NASEM, 2018). NASEM (2018) lists five processes of the human mind as it is associated with memory and each
process, though distinct from each other, are well connected in function. However, for this literature review the focus will be on (1) memory reconstruction and (2) working memory.

2.4.1 Memory reconstruction.

The first is reconstructing memory which is a process by which the brain is reproducing a memory (NASEM, 2018). Unlike the more common depiction of memory recall which employs the analogy of the brain retrieving a copy of a memory, memory reconstruction is much more complex (NASEM, 2018). Reconstruction is done by combining a current situational event, such as a cue during a learning activity, and past experiences to create a representation of a past event or experience (NASEM, 2018). This representation is not perfect, and it is largely incomplete, due to processes of the brain which will ultimately destabilize or store these memories (NASEM, 2018). Stabilization of representations, through consolidation, allows for the strengthening of these memories for later access (NASEM, 2018).

An example of how reconstruction works can be represented by solving a problem. Unified in an experience of problem-solving, the different information processes that govern the brain are using sensory inputs and cognition to handle the thinking process. While solving the problem, the brain may recall partial and related information to the current problem from previous experiences that may help strategize how to find a solution for this experience. Though a complete recall may not be necessary, the learner is still using prior knowledge through reconstruction of memories to solve the problem at hand.

However, because memories are reconstructions and not copies, degradation, alteration, and even fabricated elements may change how that memory is reconstructed in the future (NASEM, 2018). This can change how learners understand material over time and can change or prevent recall if the environment in which a learner is asked to recall a memory is different than
where the memory was first stored (NASEM, 2018). In fact, it has been suggested that learners who are asked to answer questions in environments unfamiliar and out of context associated with the topic of the questions are being removed from a significant element associated with memory reconstruction (NASEM, 2018). Learners in these situations may show a level of impedance in reconstructing relevant memories causing limited aptitude that is artificial and due to the change in environment (NASEM, 2018).

2.4.2 Working memory.

The second process of memory associated with the human mind is working memory. An analogy for working memory could perhaps be the buffering storage space for the brain since working memory is the temporary storage of information that are being used in active processes, such as learning (Jaeger, Shipley, & Reynolds, 2017). However, the working memory storage capacity is limited and can determine a lot when it comes to how much information an individual learner can process. Working memory has three components which work in tandem with sensory input and the orchestrations of learning discussed previously: phonological loop, visuospatial sketchpad, and a central executive component (Jaeger, Shipley, & Reynolds, 2017).

The first component of working memory is the phonological loop (Jaeger, Shipley, & Reynolds, 2017). This portion of the working memory is associated with sensory inputs from hearing and affect how the speech and sound-based information received by the brain is processed. Such processes also include communication information. In the phonological loop, communication is processed in both the sound of words and the word structure within working memory (Jaeger, Shipley, & Reynolds, 2017). Such information in problem-solving may involve verbal instructions or verbally constructed concepts.
The second, and possibly the most relevant to this creative project, is the visuospatial sketchpad associated with visual and spatially-based information (Jaeger, Shipley, & Reynolds, 2017). Visual, in the context of working memory, is associated with objects being seen in a specific and specified three-dimensional environment (Jaeger, Shipley, & Reynolds, 2017). In problem-solving, the visual and spatial aspects of a problem are often essential in understanding the problem and successfully crafting a solution. Not only must learners understand these aspects of a problem within their working memory, they must manipulate this information from one form to another in order to use it in different laws of physics for a solution.

An example of this would be a learner is given a problem which provides the velocity and position of an object in motion but then asks for the force causing an unspecified acceleration. In order to successfully solve the problem, the learner must use visual and spatial components of working memory and memory reconstruction to understand how the change in position can be used to find the amount of time this interaction takes. Why time is relevant then comes from yet another understanding of how the change in momentum, which is the change in velocity multiplied by mass, can be divided by time to solve for the net force of the problem.

All through that problem-solving example, visual and spatial information was necessary to understand the problem and holding that information long enough to find a strategy to a solution was working memory’s part in solving it. Learners who can use the visuospatial component of working memory effectively are able to perceive visual and spatial information in more complex and abstract ways (Jamil & Ghazali, 2018). Learners who have well-developed visuospatial reasoning can also articulate their understanding more sophisticated and relevant ways, something that Jamil and Ghazali (2018) consider a priority skill in problem-solving.
This priority is likely due to the perception by Jamil and Ghazali (2018) of the mathematical nature of problem-solving. Namely, problem-solving involves quantities and visually and spatially subject matter, all of which must be processed and articulated through symbolic representations of situations (Jamil & Ghazali, 2018). Being capable of processing all of this information using well-developed visuospatial skills allow for strategies and solutions to use content specific reasoning and therefore be more likely to be correct (Jamil & Ghazali, 2018). Such success in understanding and processing content and concepts in a visuospatial way in physics may also affect later memory reconstruction.

As study by Pals, et al. (2018) found that visuospatial working memory was a pathway for improving long-term reconstruction of memories associated with visual and spatially relevant information. Specifically, Pals, et al. (2018) found that learners who attempted to memorize a set of information in different ways resulted in having statistically significant differences in later recall and that visuospatially stimulated students had the best results in long-term memory recall. This difference was found by asking different groups of students to (1) write a concept using words and (2) draw a concept using a picture (Pals, Tolboomb, Suhre, & van Geert, 2018).

Pals, et al. (2018)’s study resulted in three reproduction test after the initial activity was concluded, the last of which was four weeks after the intervention had concluded. Students were asked to reproduce the information they were asked to memorize in the same way they had been asked to represent the information during memorization (Pals, Tolboomb, Suhre, & van Geert, 2018). The students with drawings out-scored the students who used the technique of writing out the concept in all three tests and had the least degradation in reconstruction over the four weeks after instruction (Pals, Tolboomb, Suhre, & van Geert, 2018).
The last component of working memory is the central executive component. Executive function is a skill associated with control over how information in working memory is being used (Jamil & Ghazali, 2018). Associated explicitly with the orchestration of learning’s executive function, the executive function as it applies to working memory is the decision maker, a supervisory system that decides what information to encode, how to monitor perforce, change attention as needed, or how adapt as situations change (Jamil & Ghazali, 2018; Jaeger, Shipley, & Reynolds, 2017). Such decisions can affect learning in directly unseen but very real ways and should be monitored through assessment to help students properly develop decision making when it comes to information processing (Jaeger, Shipley, & Reynolds, 2017).
Chapter 3: The Inverted-Classroom

As seen by studies previously discussed, experienced problem-solvers take both the time to understand the problem and the time to craft solutions using content orientated justifications that they can cogently articulate. It has also been shown that information processing and use of that information is complex, but in problem-solving can be aided by allowing novices the experience of working with expert problem-solvers, who can exemplify better problem-solving practices. Problem-solving can also be aided in novice problem-solvers by improving their visuospatial skills. This can be done by making them more self-aware of these elements in problems, using visuospatial prompts and aids, and exemplifying well-developed visuospatial skills in problem-solving examples.

Not only is evident that learners who are less experienced lack the focus in problem-solving to understand a problem or be able to use content relevant strategies, but that these shortfalls could be corrected by improving visuospatial skills and exemplifying the type of focus, in detail, via visual methods and aids. Such corrections could be done using methods which not only showed an expert problem-solver solving a problem, but also detailed the thought processes, the focus areas, and the content awareness necessary to solve the problems effectively, efficiently, and quickly. This is where the inverted classroom’s unique structure becomes ideal.

3.1 Video Problem-Solving

In this creative project, I have created a series of videos for an inverted-classroom covering physics topics. These videos, detailed in the Appendix at the end of this paper, take into consideration the research thus far covered and personal experiences working with students. In my 20 videos, I have unique problems that cover various topics throughout a typical semester in a high school physics classroom. Not only are these topics important for the NGSS Physics
Standards and the Indiana State Standards for physics, these topics cover key aspects of the physics field of science that are building blocks for later and more advanced courses (NGSS Lead States, 2013; Department of Education - Indiana, 2019).

In each of the videos, I begin my introduction. Not only do I read the problem, but I also underline important aspects that I’ve detected and explain why I think these may be important. Often, these important aspects I’ve underlined are variables either being given or being asked for. These aspects can also be visuospatial elements I think may affect strategies I can use. This is an important step as research has shown novice problem-solvers do not often read the problem thoroughly enough nor do they focus on important aspects of the problem right away (Kohl & Finkelstein, 2008; Chasteen, Pepper, Caballero, Pollock, & Perkins, 2012).

Then, I either add to a drawing of the problem already provided, such as in Problems 10, or, and perhaps more importantly, I draw my own depiction of the problem on a separate page. Drawing my own picture, as seen in Problems 1, 3-6, 8-9, 11-13, 16, and 18-19, was important because I could show how the words of the problem translated to visual representations directly in the video. I was also able to add my own labels, draw lines depicting motion or forces, and add anything else I felt was relevant to the problem. This exemplifies how to transfer written representations into visual representations, thus accessing and developing the visuospatial reasoning research showed was important in both problem-solving and retention. Also, as seen in previous research, having visual representations is key to making sense of a problem (Kohl & Finkelstein, 2008).

This aspect of problem solving, drawing out the visual components of a written problem, is often skipped by novice problem-solvers in my classrooms. Though I cannot say if expert problem-solvers use visual representations more often, I can say that when I have used visual
representations in teaching, novice problem-solves seem to understand more of the problem than when I teach concepts less visually present. More abstract concepts, such as electricity, are difficult to represent realistically in visual format and students tend to struggle with these concepts more, even after a good portion of the semester has already been spent on problem-solving.

Not only is adding a visual representation key to making sense of the problem, but the visuospatial part of working memory was shown in research to improve retention of content and improve the correct application of that content in future activities (Pals, Tolboomb, Suhre, & van Geert, 2018). Students who use the conservation of energy in solving one problem will likely need to use the concept of energy conservation in future problems. This future use will be more complex and perhaps even in conjunction with other concepts, making retention and accurate reconstruction of memories associated with conservation of energy all the more important. Being able to accurately reconstruct content in working memory for future problems depends, as seen by Pals, et al. (2018), on the visual representations used in previous learning activities.

Additionally, as seen by Jamil and Ghazali (2018), learners can also articulate more cogently with content rich reasoning if they had well developed visuospatial skills, skills developed by practicing using visuospatial information. Since problem-solving already has elements of visuospatial information, both in visual representations of motion and mathematical symbols, watching problem-solving and practicing problem-solving are both excellent ways to develop and strengthen visuospatial reasoning (Jamil & Ghazali, 2018). In an inverted-classroom, giving time to problem-solving and explicitly breaking down problems into visual and spatial components with applicable can therefore improve content rich justifications for solutions.
After a visual, and sometimes spatial, representation is constructed, I then begin to break down my variables I have been told and discuss the variables I am asked to find. This process is exemplifying the strategy building process and though I am already aware of the way I wish to solve this, I am showing my thought process and reasoning in conjunction with showing the strategy in real time. This will help students who can successfully do all the steps leading up to this moment and suddenly find a road block in their thinking.

One of the main ways I help them overcome road blocks like the beginning of strategizing is bringing up current content being discussed in class. If we’re solving a problem and the current discussion in class is conservation of momentum, then I reason with the students that very likely this content will be useful in some way in finding the solution. I also have students list the variables given to them and consider what content that we’ve covered uses these variables. For example, if we see masses and velocity being important variables in the problem, this could mean several different content specific strategies can be used. However, if we see a height, for example, as part of the equations, conservation of energy becomes a more likely content strategy because conservation of momentum only deals with masses and velocity.

During the solving phase of the videos, I am careful to include all units and proper notations. Consistency is important in complex mathematical representations and variations on a notation or changes in units may seem clear to myself, but they may be unexpected road blocks in sense making for my students who are unaware of the nuance between a kilogram and a gram. Keeping all units in their rightful places throughout solving a problem also allows for unit checking at the end, a procedure useful in justifying a solution. If the final answer was supposed to be a temperature, then having a final unit of kg/K, a combination of mass and temperature units, will tell me I’ve made a mistake somewhere in my solution.
3.2 Inverted-classroom and beyond

Now I have begun my collection of inverted-classroom problem-solving videos, I can add to this collection over time and build up a variety of videos I can use in my classroom. Not only can this format be useful in problem-solving physics problems as it applies to singular examples, such formatting can help make sense of inverted-lab content and inverted-demonstration content. As discussed previously, part of online classrooms at universities and in some inverted-classrooms at a high school level involve take home lab experimentations. Having a visual guide to go along with these labs could help students in similar ways it can help them with problem-solving.

Making sense of the lab instructions, understanding how the lab should look visually before, during, and after data collection, and visually watching the data analysis could help students more independently achieve understanding in a physics classroom. This would also give the instructor, myself, more time in the classroom to do more complex and time-consuming activities that, if the classroom was not inverted, would be impossible. Keeping struggling students from falling behind by giving them out of class aids like these videos and allowing for more content being covered in less class time due to the inverted-classroom format allow for exciting possibilities in physics education.
References


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Purdue University. (2019, 11 02). *Purdue University Online*. Retrieved from Purdue University: https://online.purdue.edu/
APPENDIX

In this appendix I provide a full list of the videos I created for this project. This list includes screen shots, problem details, and signifiers for reference in the main body of this paper. The videos are posted on the website YouTube.com and are part of a public profile, identifiable by my name, Ben Hook. I will be using these videos and many more in the future for my classroom in high school physics.
Problem 1: Accelerometer as found on YouTube.com at link https://youtu.be/K0yC62WQYYU.

An accelerometer is a device that measures acceleration, just like a speedometer measures speed. It’s easy to build your own accelerometer! It consists of a ball on a string hanging from the roof of your car. When the car is stopped or cruising at a constant speed, the ball hangs straight down. But, when it is accelerating as in the picture, the ball hangs down at an angle, which we’ll call q.

**Part 1:** There are two forces acting on the ball. One is gravity. Identify the other and draw a free-body diagram including both forces.

**Part 2:** Do the two forces from part 1 add up to zero? If not, in which direction is the net acceleration?
**Part 3:** Write down Newton’s 2\textsuperscript{nd} law for both the horizontal and the vertical directions. You’ll have to use sine and cosine to decompose one of the forces into its components.

**Part 4:** You now want to try out your new accelerometer, so you get in your car and hit the gas. As you accelerate, you notice the ball hanging down with an angle of $\theta = 7.0^\circ$.

How fast were you accelerating?

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**Problem 2:** Escape Velocity as found on YouTube.com at link [https://youtu.be/tWqIxisWZeU](https://youtu.be/tWqIxisWZeU).

**Part 1:** Find the escape velocity of an object being launched from Earth. Earth has a radius of 6360 km and a mass of $6.0\times10^{24}$ kg.
**Part 2:** Within a certain distance of a black hole, not even light can escape. This distance is called the “event horizon.” (This was discussed in the online question box earlier this month.) The speed of light is $3.0 \times 10^8$ m/s. Even though our equation from part 1 does not hold exactly when considering light beams, we can still use it to get a good estimate of the size of a black hole. Estimate the radius of a black hole with the same mass as our sun ($2.0 \times 10^{30}$ kg). (For comparison, our sun has a radius of about $7.0 \times 10^8$ m.)

**Problem 3:** Fighting Fire as found on YouTube.com at link [https://youtu.be/xNg9UjmgNvY](https://youtu.be/xNg9UjmgNvY).
After the recent drought in California, wildfires are commonplace. To help fight the fires, the state uses planes to drop water and fire retardants on the flames. One such plane flies horizontally over a fire at a speed of 60 m/s and drops a giant water balloon to help extinguish the fire. It flies at a height of 200 m, as shown on the picture.

**Part 1** How long does it take for its load of water to hit the ground? (Hint: as gravity pulls the balloon straight down, you can ignore the plane’s horizontal motion to solve this part! You’ll need to know the gravitational acceleration, though.)

**Part 2**: If the plane released its load when right over the flames, it would overshoot its target. It must release it a little earlier, marked by $d$ on the drawing. How far before the fire must it release the water? (Hint: just like the ball thrown straight up into the air inside the car stays above your hand, the balloon stays right under the plane when falling!)

**Part 3**: The pilot accidentally angles his plane slightly downward when releasing his water balloon, with the nose lower than the tail. He releases the water balloon from the exact same location as before. Will the balloon still hit the fire, overshoot it, or land short of it? You don’t need to do any explicit calculations, but use what you know about velocity and acceleration to justify your answer.

An exceptional standing jump would raise a person 0.80 m off the ground. To do this, a 61 kg person crouches 0.20 m and pushes off from the ground, exerting a force on it. By Newton’s third law, the ground pushes back with an equal and opposite force, which accelerates the person off the ground.

Part 1: What is the jumper’s speed just as he leaves the ground?

Part 2: What force must he exert on the ground to perform the 0.80 m jump?
Problem 5: Lever as found on YouTube.com at link https://youtu.be/_sV5KIAMhC8.

If I gave you a lever arm 10 m long, where would you have to rest it on the fulcrum to lift a 1000 kg object off the ground? (I.e., what must the ratio $L_1/L_2$ be?) (Hint: The force you can exert is probably largest if you lean on it and push down with all your weight.)

You’re driving your car towards an intersection. A Porsche is stopped at the red light. You’re traveling at 40 km/h (11.11 m/s). As you are 15 m from the light, the light turns green, and the Porsche accelerates from rest at 3 m/s². You continue at a constant speed.

**Part 1:** How far from the stop line do you pass the Porsche? At what time, measured from when the light turned green, do you pass the Porsche?

**Part 2:** As the Porsche keeps accelerating, it eventually catches up to you again. How far from the stop line does it pass you? At what time, measured from when the light turned green, does it pass you?
Part 3: If a Boston police officer happens to get you and the Porsche on a radar gun at the instant the Porsche passes you, will either of you be pulled over for speeding? Assume the speed limit is 50 km/h.

Problem 7: A Squirrel’s Displacement and Velocity as found on YouTube.com at link https://youtu.be/6ZMi0EnDkg0.
A squirrel is running along a fence. Mr. Jensen, curious about squirrel velocities, has shrewdly observed at which fence post the squirrel is located at one-second intervals. After the squirrel has run away, Mr. Jensen measures the spacing between two adjacent fence posts to be 5 ft.

<table>
<thead>
<tr>
<th>Time</th>
<th>0.0 sec</th>
<th>1.0 sec</th>
<th>2.0 sec</th>
<th>3.0 sec</th>
<th>4.0 sec</th>
<th>5.0 sec</th>
<th>6.0 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>0.0 ft</td>
<td>5.0 ft</td>
<td>15 ft</td>
<td>25 ft</td>
<td>35 ft</td>
<td>55 ft</td>
<td>60 ft</td>
</tr>
</tbody>
</table>

**Part 1:** Based on his observations, Mr. Jensen estimates the squirrel’s velocity between measurements.

**Part 2:** By taking the average of the above velocities, calculate the squirrel’s average velocity over the entire 6 seconds.

**Part 3:** Do you need all 7 measurements to determine the squirrel’s average velocity over the entire 6 seconds, or could you do it with only two? Which two would you use? Do you get the same result as in question 2?

**Part 4:** Convert your answers from questions 2 and 3 to appropriate SI units.
Problem 8: Stressed Out Swimmer as found on YouTube.com at link https://youtu.be/-4uXxhR3zXg.

A swimmer is trying to swim across a river. The river is 100 m wide. 50 m down the river from his starting point, a dangerous waterfall is threatening to drown any unsuspecting swimmers. The swimmer can swim at a speed of 1 m/s relative to the water (we’ll call this $v_{\text{swimmer}}$). The current pushes him towards the waterfall at a speed $v_{\text{water}}$.

**Part 1:** The swimmer starts out aiming himself straight for the other shore. How long will it take him to reach the shore?

**Part 2:** If he aims straight for the other shore, how fast can the current ($v_{\text{water}}$) be, if he is to survive the swim?

**Part 3:** As viewed from the shore, what is the total speed of the swimmer? (Hint: From the shore, his path will look like a diagonal line. You probably know from math class how to find the hypotenuse if you know the two catheters of a right-angled triangle.)
**Part 4:** The current in the river turns out to be 0.8 m/s, too strong for the swimmer to make the other shore if just aiming straight for the opposite shore. The swimmer changes strategy and decides to swim at an angle, so that part of his efforts cancels the current. As a result, he moves straight across the river towards the other shore, as viewed from the shore (see drawing). How long will it now take him to reach the opposite shore? (Hint: $v_{\text{swimmer}}$ is still 1 m/s)

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**Problem 9:** Tractor Pulling as found on YouTube.com at link [https://youtu.be/EgsnEAl-5kM](https://youtu.be/EgsnEAl-5kM).

A tractor of mass $m$ is connected to a trailer by a rope. The rope can carry 7,000 N before it breaks.

**Part 1:** Draw a free-body diagram of the trailer before the tractor starts pulling it. Be sure to label the different forces acting on the trailer. What is the net force?
**Part 2:** The tractor now starts pulling the trailer with a force (let’s call it $F_{\text{pull}}$). Draw a free-body diagram of this situation. (Be sure to include friction.)

**Part 3:** The trailer accelerates at 3 m/s$^2$. As it drags across the ground, a frictional force of 1,000 N acts in the direction opposite its motion. However, the rope breaks. Using the rope’s breaking strength of 7,000 N, what can you say about the mass of the trailer? (For partial credit, you can solve this without the friction present if you like.)

**Part 4:** The driver replaces the rope and tries again. Having learned his lesson, he now pulls the trailer with a resulting force of just 2,000 N. However, suddenly a gust of wind pushes him directly sideways. As this happens, the driver measures the total force to be 2,500 N. What was the force of the wind?
Problem 10: Velocity vs Time as found on YouTube.com at link https://youtu.be/F3hNWhL9bmc.

The graphs in the video above show the velocities (v) of two different people running, as a function of time (t). You will need no calculations for the questions below, only the graphs. But, be sure to show your work!
Part 1: (Answer for both graphs.) During which intervals of time is the acceleration positive? Negative?

Part 2: (Answer for both graphs.) Is the acceleration ever 0? If so, when?

Part 3: Which person runs farther during the first 10 seconds?


You’re stuck in a boat in the middle of a lake. Luckily, you brought your physics book! You decide to use your book to propel you back to the shore. You throw your 1 kg book overboard with a speed of 10 m/s to propel yourself back towards the shore. Assume the combined mass of you and the boat is 100 kg.
How long would it take you to reach the shore after throwing your book? (Ignore friction between the water and the boat.) The shore is 60 m away.

Problem 12: Mid-Air Explosion as found on YouTube.com at link


A cannon shoots a grenade into the air. The grenade is shown on the figure to the right. The grenade has a mass of 50 kg and travels to the right with a speed of 100 m/s.

Part 1: What is the initial momentum of the grenade (magnitude and direction)?
**Part 2:** The grenade explodes in mid-air and breaks into three pieces, as shown on the figure. You manage to measure the mass of all fragments, but only the velocity of two of them. Use momentum conservation to find the velocity (both direction and the magnitude) of the third fragment. (Be careful with the directions of the velocities!) (Hint: The three pieces originally “stick together.”)

**Problem 13:** Travel to the Moon as found on YouTube.com at link

[https://youtu.be/svb7mPrvSwQ](https://youtu.be/svb7mPrvSwQ).

**Part 1:** NASA is launching a rocket into space from Earth. This particular rocket burns its fuel for 5 minutes and then turns off its engines. At this point, the rocket keeps floating along
through space at a speed of 10 km/s. What is the rocket’s average acceleration during these first 5 minutes?

**Part 2:** How far did the rocket travel during the first 5 minutes?

**Part 3:** The Moon is approximately $3.8 \cdot 10^5$ km from Earth. At its final speed, how long will it take the rocket to reach the Moon?

**Part 4:** The star nearest to us, called Alpha Centauri, is $4.1 \cdot 10^{13}$ km away. Could this rocket get a man to Alpha Centauri before he dies of old age? (This is a real obstacle to NASA’s plans of exploring other solar systems than our own!)

**Part 5:** The rocket is half way to the Moon when its pilot suddenly notices he forgot his camera! He radios a second rocket crew on Earth and tells them to bring his camera and meet him on the Moon when he lands. Unfortunately, the second rocket can only accelerate at $3 \text{ m/s}^2$. Can this second rocket make it to the Moon before the first one lands?
Problem 14: Astronaut Weights as found on YouTube.com at link

https://youtu.be/QgqGGWfeZvY.

The mass of Earth is $6 \times 10^{24}$ kg and the radius of Earth is $6.4 \times 10^6$ m.

**Part 1:** Using the formula for gravity, what is the force of gravity on a 90 kg massed soon-to-be-astronaut standing on Earth’s surface?

**Part 2:** Using the formula for gravity, what is the force of gravity on a 90 kg massed astronaut on the International Space Station at an orbit around Earth approximately 400,000 m above the Earth’s surface?
In this problem, we will compare the strength of gravitational and electrical forces. Almost all stable matter in the world is composed of protons, neutrons, and electrons. Their properties are listed below. To compare electric and gravitational forces, imagine an electron and a proton separated by 1 meter.

Proton: Mass: $1.6726 \cdot 10^{-27}$ kg Charge: $+1.6022 \cdot 10^{-19}$ C

Gravitational Force:

$F_g = G \frac{m_1 m_2}{d^2}$

$F_g = (6.67 \times 10^{-11} \ \frac{Nm^2}{kg^2}) \left[ \frac{0.6726 \times 10^{-27} kg}{(1 m)^2} \right]$  

$F_g = 1.02 \times 10^{-67} N$

Electrical Force:

$F_e = k \frac{q_1 q_2}{d^2}$

$F_e = (8.99 \times 10^9 \ \frac{N m^2}{C^2}) \left[ \frac{1.6022 \times 10^{-19} C}{(1 m)^2} \right]$  

$F_e = 2.31 \times 10^{-28} N$

**Problem 15: Electric vs Gravitational Forces as found on YouTube.com at link**

Neutron: Mass: $1.6726 \times 10^{-27}$ kg Charge: 0 C

Electron: Mass: $9.1094 \times 10^{-31}$ kg Charge: $-1.6022 \times 10^{-19}$ C

**Part A:** What is the magnitude of the gravitational attraction between the two?

**Part B:** What is the magnitude of the electric attraction between the two?

**Part C:** Which one is stronger, and how many times stronger is it?

Problem 16: Resistors as found on YouTube.com at link [https://youtu.be/_xTBvSaoGsA](https://youtu.be/_xTBvSaoGsA).
Find the effective resistance of the circuit drawn above.

Problem 17: Falling Puppy as found on YouTube.com at link https://youtu.be/tKlFgID3MRs.

A 3.0 kg puppy is dropped from someone’s lap. Oh no!! It starts at rest and falls, gaining speed, until it lands safely on the floor at 2 m/s. (Whew!)
**Part a:** What is the Kinetic Energy of the puppy before it is dropped?

**Part b:** What is the Kinetic Energy of the pulley right before the landing?

**Part c:** What is the Change in Kinetic Energy of the puppy?

**Part d:** What Work was done to the puppy?

**Part e:** Knowing how much work was done, calculate how far the puppy fell if you know the force of gravity on it is 30 N.

**Part f:** Knowing how far it fell, what is the puppy’s Potential Energy before the drop?

**Part g:** What was the Puppy’s Potential energy before the landing?
Problem 18: Mystery Substance as found on YouTube.com at link

https://youtu.be/RNeGNUiOTDo.

You are given a 125 g block of a mystery substance, and your task is to figure out what it is. You heat your 0.125 kg block of mystery substance to 90 °C in an oven. You then lower it into a cup with 0.326 kg of water. The water is initially 20 °C. After leaving the block in the water a long time, you notice that the temperature of the water has increased to 22.4 °C. Find the specific heat capacity of the mystery block. What substance is it?
Problem 19: Power and Electricity as found on YouTube.com at link

https://youtu.be/amDDhX4Pg6k.

Part 1: A 3 W light bulb and a 6 W light bulb are connected in series, and then hooked up to a battery. Which one of the two will shine the brightest, and by how much?
Part 2: The same light bulbs from part 1 are now connected in parallel to a battery. Which one of the two will now shine the brightest, and by how much?

Problem 20: Sound in Air and Water as found on YouTube.com at link

https://youtu.be/Ptb8M7YMz5I.

The speed of sound in matter depends on the density of the matter, as well as how easy it is to compress it, called the bulk modulus $B$. $B$ is measured in Pa (pronounced “Pascal”), which is the standard SI unit of pressure. 1 Pa = 1 N/m. $B$ is defined as the increase in pressure ($Dp$) divided by the fractional volume change caused by this pressure increase: .
Part 1: A pressure increase of 100 kPa compresses a volume of water by 0.005%. Calculate the bulk modulus of water.

Part 2: The speed of sound in a medium is given as $v = \sqrt{\frac{\beta}{\rho}}$. And if the bulk modulus of seawater is 2100 MPa, what is the speed of sound?

Part 3: A ship emits a sound burst of frequency 40 kHz to detect a submarine in water. Using your answer to part 3, what is the wavelength of the sound wave?

Part 4: The ship’s sonar operator hears the reflected sound reach him 5 seconds later. How far away is the submarine?