The Impact of Productive Struggle Support on Student Mindset in a High School Technology and Engineering Class: A Case Study

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The goal of preparing students for life after secondary school, regardless of future student plans, will require the development of critical thinking to face complex problems in life. One potential tool in preparing students for these challenges is the use of purposeful teacher support of student productive struggle in learning new skills and concepts. As iterative failure and improvement are essential parts of the engineering design process, it is important to explore supportive productive struggle in engineering coursework.

Social skills, perseverance, and learning strategies are part of the noncognitive factors that impact academic performance. One factor affecting student behavior and thinking is student mindset. Previous literature has shown that not only can fixed or growth mindset impact learning behaviors, mindsets are also capable of being altered through interventions. One missing piece of understanding mindsets is the role that challenging classroom experiences, such as working through significant struggle, have on the way students view their own intelligence. This action research case study aims to connect the research on supportive productive struggle with that of mindset, error attribution, and academic progression through lab tasks.

The study was conducted with high school engineering students who engaged in three productive struggle lab tasks based in the context of mechanical advantage in simple machines. Throughout the lab tasks, the teacher provided support while maintaining rigor, student-aligned thinking, and student-led solution attempts, which are essential in productive struggle. Data collected through pre- and post-task mindset assessments, journals of academic work alongside reflections, and focus student interviews was utilized to answer inquiry questions about the relationship between productive struggle support and student mindset, attribution of errors, and academic progression through tasks.

Data analysis revealed a statistically significant ($p=0.05$) change in mindset after supportive productive struggle. The data showed no consistent shifts in internal versus external error attribution across the tasks. Finally, the data suggest that supportive productive struggle experiences do increase student ability to make progress through challenges, including doing so with a more positive outlook on the experience. Additional rationale and discussion explains the findings as related to existing literature, researcher observations, and future implications.

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Preface

Just a few short years ago this was a dream. Without the support, understanding, and tough love from countless individuals, this would still be nothing but a dream. First and foremost, I thank Jesus for the strength, peace, and focus throughout the most difficult times during this program. I thank God for the blessings and privileges that I have experienced to get me to this point.

None of this would have been possible without my family. You have given me so much support and sacrifice while working toward my goal. To Landry and Scarlett, never doubt yourselves and what you can accomplish. I believe and know that you will accomplish so many great things in your own time. To Pop, while Pitt may not be your first choice of school, thank you for by my side since the day after orientation and seeing this through.

So many individuals have provided time, guidance, and support through this degree program. To Marie, Adam, and Michael, you have given me renewed passion, drive, and focus. I cannot thank you enough for the humor, the check-ins, and the extra work time you have provided. Marie, from spending time coding with crayons to consoling me through challenges, you were instrumental in this accomplishment. You are next! To my committee, Dr. Warner, Dr. Kokka, and Dr. Ansell, you have guided and pushed me to more than I thought possible. When everything changed instantly, you all provided stability in times of uncertainty. Thank you.

Finally, to each of the students who have entered my classroom, you have left a mark on me that will last much longer than your time there. To those of you that have lived in the lab, spent your free time there, and made me laugh daily, I hope this inspires you to never stop dreaming and pushing yourselves for more. Most importantly, to Starrett, the inspiration for this line of research and the most impactful individual to ever enter my classroom, this is for you.

1.0 Introduction

The standards, curriculum, and tests that regulate and guide public education focus around a set of knowledge and information that can be defined as cognitive skills. Life outside of school demands that students also possess a set of skills and attributes including, but not limited to, those required to focus on goal achievement, obtaining and maintaining healthy social relationships, and using critical thinking to solve problems. These skills and abilities demanded by life have often been referred to in literature as noncognitive qualities (Duckworth & Yeager, 2015). Research has shown that these qualities, such as grit, growth mindset, emotional intelligence, and self-control contribute to academic success just as much as social and psychological health (Farrington et al., 2012). If the goal of education is to support students so that they may be successful in life, one must look at the qualities of the most successful individuals.

Studies of the difference between successful and unsuccessful business people showed that those who are most successful are not those who only experience growth. Rather, the most successful individuals experience mistakes throughout their lives and, rather than see them as failures, learn from them in order to improve (Boal, 2016). Mistakes in life occur in every area of life, they are not unique to business. Individuals face these mistakes and process them differently. Some people, those with a growth mindset, look at the mistake as a learning opportunity, a challenge that they should rise to and overcome. Other people hold a fixed mindset, these individuals view mistakes as a sign that they, as a person, are a failure. In the fixed mindset, intelligence is a set value which cannot be altered, or increased over time leading individuals to hold set views of what is attainable and avoid challenges. In the growth mindset, however, intelligence is a quality that can be changed, improved upon, and increased over time through learning opportunities (Dweck, 2006). In school, the goal would be for students to view their brain as a muscle to be grown and strengthened through exercise just as easily as their biceps. Not only does this view allow students to see the value in their learning, it also sets them up for better mental health and self-efficacy in classes.

The Science, Technology, Engineering, and Mathematics (STEM) fields, which are perceived to have more clearly defined correct or incorrect answers than other school subjects, can introduce students to a more black-and-white picture of success and perceived failure (Lannin et al., 2007). If students can look at setbacks and incorrect answers as learning opportunities rather than failures, perhaps students would be more inclined to continue and complete studies in the STEM disciplines rising to the challenge rather than resisting failure. Many of the most quickly growing and expanding jobs in America are in the STEM fields (Vasquez, 2014). Without students prepared to fill these jobs, the American workforce may be at risk.

Upon noticing this importance, it becomes essential to determine what aspects and practices STEM teachers can use to make an impact not only on student learning and academic prowess but also on the personal growth and development of the student. At times, noncognitive factors such as grit, mindset, and student identity can have just as large an impact on student learning as academic capabilities themselves (Cook et al., 2017). Classroom experiences can drastically change the way a student thinks and learns. Teachers typically try to shape, mold, and plan classroom experiences so that they will lead to positive experiences for all students. The world holds many opportunities for individuals to be exposed to negative experiences, what if teachers also purposely planned lessons and activities in such a way that teachers could support students in learning through difficulties and challenges that occur during the learning process?

1.1 Problem of Practice

As a high school technology and engineering educator, I teach students of varying backgrounds and academic abilities. In my place of practice I engage, on a daily basis, with the most gifted learners as well as those who struggle with learning. Regardless of the academic level of the student, one thing that I have observed in my daily work is a common resistance and discomfort among students when encountering struggle during the learning process. This is worrisome to me both as a teacher and as a member of society, since so much of life after high school will cause students to be faced with struggles and problems that they must think through and solve.

A major component and goal of teaching is to develop new knowledge and skills in learners. While learning and academic performance are important to success not only in the classroom but also in life in general, there are a number of factors that play a role in that success. In the school environment, cognitive factors such as study habits, organization, and preparation for class are easily visible to the teacher and also impact student learning (Farrington et al., 2012). A number of noncognitive factors also play a key role in student academic performance. In order to best guide and encourage students through classroom learning, it is important that teachers are aware of not only what these factors are but also how to best take advantage of them in ways that benefit student learning.

Within the factors that impact student mindset, a key influencer of student confidence and beliefs are their own experiences in the classroom. While it is ideal for classroom experiences to be positive, successful experiences, a natural part of the learning process is making mistakes and grappling with foreign ideas. Productive struggle tasks provide students with support in recognizing that challenging tasks are an opportunity for deeper understanding. Conversely, unproductive struggle occurs when students make no progress towards understanding or developing a solution to a problem (NCTM, 2014). Support of productive struggle in learning has been shown to lead not only to deeper understanding of the concept at hand but to better transfer to future learning as well (Kapur, 2008, 2011). Additionally, extra experience with working through struggle has been shown to develop better critical thinking and problem solving capabilities in students (Kapur, 2010). If these points of struggle are already happening within students' minds and within the classroom walls, how then can I make use of strategies and techniques to maximize the productivity of student struggle?

1.2 Inquiry Questions

The research study was designed to guide not only teaching practice in my own classroom but the larger field of technology and engineering education as well. The questions were crafted to address the problem of focus for the study which has been present in my place of practice for many years. Beyond just my own classroom, student mindset and persistence have been research topics in a variety of fields and subject areas. Through the use of productive struggle lab tasks in a hands on technology and engineering classroom, the following questions were addressed by the research study:

1. What relationship exists between student exposure to supportive productive struggle learning experiences and shifts in student mindset?
2. How does teacher productive struggle support impact student attribution of impasse points in learning?

3. How does teacher productive struggle support impact student academic progression through challenging tasks?

2.0 Review of Literature

This review of literature examined existing research performed in the areas of the noncognitive factors affecting student academic performance, student mindset, the brain's neural activity during learning, the importance of struggle in the learning process, and methods of supporting productive struggle in the classroom. The literature was searched in order to form a better understanding of the connections that may exist between student noncognitive factors (specifically academic mindset), and student learning and knowledge acquisition. Extra attention was paid to the impact that classroom experiences with struggle, errors, confusion, and failure have on student achievement and mindset. Additionally, specific strategies for supporting productive struggle in the classroom were sought out to guide and inform classroom planning and instruction.

2.1 Factors Affecting Student Performance

It is important for educators to recognize that there are other components to student achievement besides content knowledge and acquisition (Duckworth & Yeager, 2015). Considering that children spend over 16,000 hours of time in classrooms throughout their primary and secondary schooling, it is important to consider all elements of schooling as an integral part to the growth and development of the child as a whole (Farrington et al., 2012).

2.1.1 Noncognitive Factors Affecting Students

Children are significantly shaped and developed based on their surroundings including the society, adults, environment, and culture with which they interact. Each of these factors play a role in the development of noncognitive traits unique to each individual. Noncognitive factors can be categorized into five different groups: academic behaviors, perseverance, mindsets, learning strategies, and social skills (Farrington et al., 2012). As teachers spend so much time influencing students, it is important to consider how each of these factors is formed and altered to impact the learner.

Academic behaviors are those which are most easily seen through a student's school performance. While these traits can be impacted by other noncognitive factors and outside events, they are typically the traits with which the teacher is most familiar. These behaviors include organization, participation and preparation of the student for each class activity as well as arriving on time daily and completing work on time. While many of these traits, such as completing nightly homework, may impact student academic performance, they are not directly necessarily related to student intelligence or even understanding of new concepts (Kohn, 2006).

Perseverance is a noncognitive factor that has received both positive and negative attention in recent years. Academic perseverance is a student's ability to use self-discipline and self-regulation techniques towards delayed gratification in the attainment of some goal or benchmark. Grit is one term for the perseverance toward a goal, regardless of failures or setbacks along the way, through persistence and consistency of effort (Duckworth, 2016). There are limitations to when grit is a positive trait in students. Critics argue that it is an essential trait in individuals to identify situations and actions that just will not succeed regardless of effort or time. Endlessly working towards some goals or outcomes can be an exercise in unproductive persistence, ending in a lot of grit but no real tangible success (Kohn, 2014). In addition, a deficit lens is often used in determining that students need more grit rather than deeply considering the societal, socioeconomic, and other barriers that students may be facing as barriers to growth and achievement (Kohn, 2014).

Academic mindset is how a learner thinks about intelligence and learning, both in general and in themselves. Mindsets can include everything from a student's sense of fit in an academic community to their assessment of the value of what is being taught and learned. Important in failure experiences, academic mindsets can also shape whether a student believes that additional effort in learning can result in new knowledge and understanding (Farrington et al., 2012). Mindsets have a long history in research including foundational work by Dweck (1986). While classroom and life experiences can play a role in student mindset, this is not always positive. Research has shown that outside factors can negatively affect student mindset through such theories as stereotype threat, the tendency of individuals to conform to stereotypes of others, (Steele & Aronson, 1995) and learned helplessness, a feeling of extreme helplessness possibly stemming from traumatic life events (Seligman & Maier, 1967). It is important to consider and evaluate the impact that failure in learning experiences may have on a student's mindset about learning.

Learning strategies are another noncognitive factor that, while not being directly related to knowledge and academic performance, contain a strong relationship with the potential to perform well on tests of academic knowledge. Learning strategies include a student's ability to evaluate his or her own thinking, set academic goals, study, and self-regulate during learning. These factors are typically what moves learning in the classroom to a personal level based on the effort and abilities of each student (Farrington et al., 2012).

The final category of noncognitive factors is that of the social skills possessed by a student. This category deals heavily with a student's ability to work cooperatively with peers and others in order to function both in and outside of the classroom environment. A student's interpersonal skills and soft skills play a major role in their ability to learn and grow in the classroom environment. There is currently a great demand for "people skills" among workers in the twenty-first century with companies looking for individuals that are able to communicate their thoughts, work collaboratively, and manage themselves within diverse groups (Casner-Lotto et al., 2006).

In considering the ways that student noncognitive factors present themselves in the classroom to impact student classroom experience, it was important to identify the factors that are most present in my own classroom. Created while considering the related literature by prior researchers, Figure 1 presents a theoretical model for the most prevalent noncognitive factors in my own classroom and the perceived relationship they have to measureable results and classroom experience.

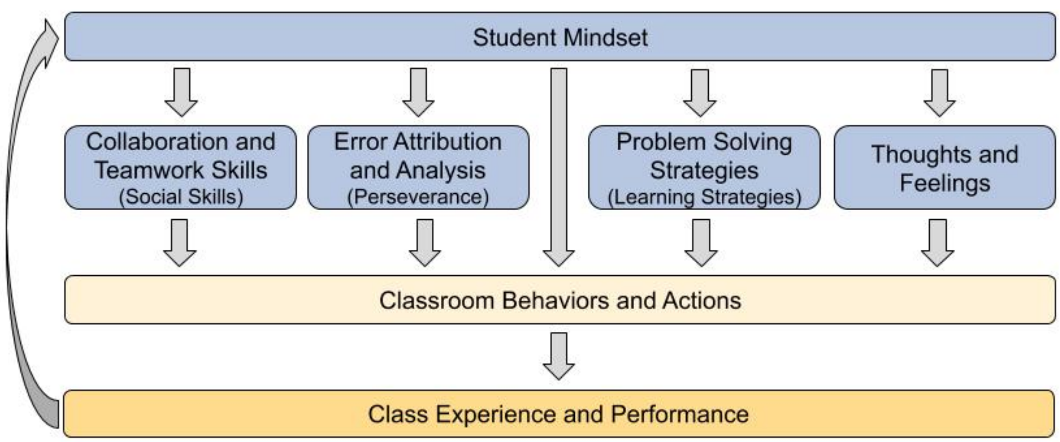

Figure 1 Impact of Noncognitive Factors on Classroom Performance

2.1.2 Learner Mindset

A significant amount of educational research has shown that learner mindset is a key element in student learning (Dweck, 1986, 2000, 2006; Kelley, 1973; Weiner, 1986). Mindsets are strongly related to the ways in which individuals experience and attribute successes and failures in life. In failure experiences, if students believe their own ability or lack thereof is the cause, they may withdraw from future struggles in order to maintain or reserve confidence (Kelley, 1973; Weiner, 1986). Other research in mindsets has found that if students attribute the struggle to a lack of their own effort, they try even harder in future endeavors (Dweck, 1975). Student mindset shows significant connections to performance on future academic tasks and activities. Mindsets may be a key factor in whether or not classroom struggle is productive or prohibitive to learning.

Carol Dweck (2006) attributed a difference between two different mindsets to an individual's ability to persevere, succeed, and fulfill their own potential. She categorized a variety of traits and thoughts about learning and intelligence into either a fixed or growth mindset. Every individual possesses core beliefs about how and why they learn. Some individuals attribute learning to innate intelligence while others believe learning comes as intelligence grows due to hard work (Boaler, 2016). Research shows that not only can mindsets impact learning, but STEM students, more specifically students in math fields hold some of the most extreme fixed mindsets of all subject areas (Leslie et al., 2015). Additionally, a high rate of fixed mindsets among girls is one factor in the STEM gender gap (Boaler, 2014). While this is likely related to stereotype bias rather than innate gender qualities, it is important to consider the impact mindsets have on student educational outcomes. What is a fixed or growth mindset, and how are they present in the thoughts and beliefs that people hold?

Individuals with a fixed mindset believe that each person possesses an innate level of intelligence that cannot be changed over time. Many people that hold a fixed mindset have thought that way from a very young age. Individuals with a fixed mindset can feel pressured to continually prove their ability by performing well on tasks or skills that they believe are within reach of their own level of intelligence and ability. These learners feel most intelligent when reflecting on flawless performance rather than while being pushed or tasked with something that may be difficult or challenging (Dweck, 2006). This means that students who hold a fixed mindset can hold back and resist new learning experiences in order to preserve and highlight the level of intelligence they possess.

Individuals with a growth mindset, alternately, hold the belief that one's efforts, strategies, and experiences can grow and develop new knowledge and higher levels of intelligence. Individuals that possess a growth mindset feel most intelligent when tackling a new or difficult task that requires true effort and persistence on their part (Dweck, 2006). The ideal learning mindset for students at almost any stage of learning is a growth mindset. Researchers have linked the beliefs of a growth mindset with higher grade point averages in college coursework (Wilson & Linville, 1982), a lower dropout rate (Wilson & Linville, 1985), and higher course grades (Hulleman & Harackiewicz, 2009). Additionally, researchers have found that mindsets are a malleable factor affecting learning. After interventions encouraging a belief that intelligence can be altered, students showed changes in mindset and better academic performance (Aronson et al., 2002; Walton & Cohen, 2007; Blackwell et al., 2007).

Accurately measuring student mindset can be a challenging task. While not the only attempt at measuring student beliefs and attitudes towards learning, Dweck's *Implicit Theories of Intelligence Scale* (ITIS) explores student beliefs in order to classify their fixed or growth mindset alignment (Dweck, 2000). The scale achieves this goal by measuring how students feel towards mastery and performance tasks. While initially only three items (Dweck et al., 1995), the ITIS was eventually expanded to eight items in order to account for a range of beliefs rather than only providing binary categorization (Dweck, 2000). Four items on the instrument deal with an individual’s beliefs about intelligence while the others relate to the ability to change beliefs, all being measured on a Likert scale. The ITIS has been used in a number of studies and validated through research (De Castella & Byrne, 2015; Cook et al., 2017).

While a variety of noncognitive factors can influence student learning and achievement in school, student mindset is one that pervades the daily life and thought processes of the individual well beyond the classroom. While research has shown that mindsets can be altered and a valid instrument exists for measuring student learning beliefs, the search for this study yielded very few studies exploring the impact of purposeful classroom struggle on student learning mindset.

2.1.3 Neuroscience Behind Academic Mindsets

The brain is one of the most intricate and complex organs of the human body. It is under constant research by scientists including focusing upon the plasticity or adaptability of the human brain. Numerous studies have shown the ability of the brain to make significant growth and changes within short periods of time (Woollett & Maguire, 2011; Maguire et al., 2006). Science shows that when we learn new things, our brains fire electric impulses which connect new areas of the brain (Abiola & Dhindsa, 2011). The hippocampus of the brain, specifically, has the ability to grow significantly when learning and studying new information (Maguire et al., 2006).

These same adjustments and growth opportunities occur in the brain when individuals encounter mistakes (Moser et al., 2011). When a mistake occurs, the brain makes one of two responses. One response is to signal conscious attention to reflect upon the mistake. The other is an unconscious raise in electrical activity when the brain identifies a conflict between the right and wrong answers. This electrical activity takes place regardless of whether the individual is aware of the mistake or not. Even if the student is not aware, the brain itself recognizes the challenge and grows through the experience. The brain's electrical response is significantly greater when individuals develop incorrect rather than correct answers. Additionally, the brain activity is far higher in individuals possessing a growth rather than fixed mindset (Moser et al., 2011).

This increased brain activity in individuals with a growth mindset also causes greater awareness of mistakes in students. Research has shown that individuals with a growth mindset pay more attention to mistakes and are more likely to go back and correct their errors due to differences in brain response (Mangels et al., 2006). This means that one's beliefs about one's own intelligence can be a self-fulfilling prophecy. The fixed mindset beliefs can influence individual behavior which will keep him or her from engaging in the growth-related activities (Mangels et al., 2006).

The power of errors in learning is undeniable in looking at the neuroscience behind everyday mistakes. Scientists and educational researchers alike stress the importance of teachers not only understanding but utilizing the power of mistakes and mindsets in teaching and learning (Boaler & Anderson, 2018). If mistakes can be so powerful in the neural growth and development, how can educational systems support students through productive struggle in learning new concepts and skills? Could classrooms that encourage students to work through confusion and mistakes harness the power of errors in the brain's learning process? Could repeated exposure to errors and struggle in learning actually change the way a student views failure and their own intelligence? Previous reviewed literature have focused upon academic mindsets and the role these mindsets have in how individuals process failure. The next section will explore ways in which failure can be incorporated in the classroom to encourage deeper learning.

2.2 Struggle as Part of the Learning Process

For many years, researchers have aimed to define the presence and importance of failure during learning. This research has shown that the learning, transfer, personal impact, and reflective power of learning through failure can transform student thought (Morgan, 1984; Piaget, 1977; VanLehn, 1988; Kapur, 2010).

2.2.1 Reflecting on Failures

Some of the top businesses in America are the same companies that urge their employees to embrace failure, reach outside of their comfort zone, and take big risks. From Amazon to Coca-Cola, corporations are striving to push the limits of what is expected and accepted in search of new and unique ideas. The business world is moving toward adoption of the belief that “there is no learning without failing, there are no successes without setbacks” (Taylor, 2017). If American industries are embracing this mentality, are our public schools preparing students, the workforce of tomorrow, to have the same thoughts toward failure?

A key difference between the way that schools and industries view failure is the size of the error. While large, all-encompassing failures really are not embraced in either arena, business and industry are much more likely to identify, support, accept, and learn from small failures that occur every day. Cannon and Edmondson (2005) suggested a three step process for learning from failure that exists in the most successful learning organizations. True learning through failure occurs when companies identify the failure, analyze their errors, and deliberately experiment with ideas accepting the possibility of being wrong in their findings. A move to this type of struggle recognition and support in schools is one that requires a culture shift among teachers and students alike. In all social systems, “being held in high regard by others is a strong fundamental human desire… people instinctively ignore or disassociate themselves from their own failures” (Cannon & Edmondson, 2005, p. 302). Traditionally, students learn from their teachers. Perhaps the most effective way for students to embrace failures is for teachers to support students through errors, confusion, and struggle, in general, as part of the learning process. While teachers can already feel stretched too thin covering content alone, it is important that content is presented and taught in ways that support students through struggle. Unfortunately, due to time and curriculum constraints “the value of learning from analyzing and discussing simple mistakes is often overlooked” (Cannon & Edmondson, 2005, p. 309). This is especially true in STEM education environments where students are so often engaging in real-world problem solving and designing. A key aspect of learning and working in the STEM disciplines is the ability to fail, learn from errors, and make appropriate adjustments in moving forward with learning and discovery. If failure is an almost unavoidable experience in the real world, should not teachers also be guiding students through failure as part of learning in schools?

Outside of business owners and CEOs, other professionals, including those situated within STEM fields recognize the value of failure in learning and developing as an individual. While the term failure is usually associated with negative experiences, many current working individuals look back upon struggles in life as turning points in both their career and personal goals. STEM employees associated their experiences with changing their own perception of failure, altering their trajectory within their STEM career, and even developing new skills (Simpson & Maltese, 2017). Most participants in a survey on failure experiences viewed failure as an intrinsic part of learning and creating new things rather than as a final judgement of worth or growth. In the survey, many respondents reflected upon how unprepared they were for failure experiences at their job. A stress was placed in the study on the fact that failure itself is not positive but rather the stages of learning that come after failure is where the growth occur. One respondent replied that, "failure is certainly not a positive thing in a work environment. Being willing to accept the risk of failure is necessary, but hardly implies that failure itself is positive" (Simpson & Maltese, 2017, p. 230). Given that so many working professionals were able to identify the byproduct of failure as a positive experience both personally and professionally, why do our school systems tend to view aspects of failure in a negative light? What do American teachers think about failure?

When elementary teachers were surveyed about their failure experiences in the classroom and reactions to failure in general, most responded that failure was more detrimental than it was constructive and an overall negative condition for students or teachers to experience (Lottero-Perdue & Perry, 2017). When asked what the underlying causes of failure may include, teachers were quick to respond with causes such as students giving up, too hard of a task, a lack of knowledge, or boredom. Teachers tended not to respond with possible causes such as trying something new or experimenting outside of comfort zones that demonstrate a belief in failure as part of any learning process. The teachers in the Lottero-Perdue & Perry (2017) study failed to recognize the smaller, seemingly insignificant failures that occur along the way.

The results of questioning shifted significantly when, rather than general elementary teachers, maker-educators were the focus of the interviews. When asked to respond with the phrase or word that comes to mind when hearing the word failure, most maker-educators responded with words like opportunity and learning rather than negative terms (Maltese et al., 2018). These educators of STEM, STEAM, and makerspaces completely shifted the definition of negative failure from being the point at which struggle occurs to the point at which a student gives up. One such teacher stated, “the real value is seeing or recognizing that it’s not an end state but just a part of the process. If youth did not experience failure, there wouldn’t be opportunity for this growth” (Maltese et al., 2018, p. 13). If embracing failure in the classroom is going to find a place in schools, it is going to need to start with teachers. How can teachers guide and support students through the entire learning process, including the failure experiences that so often accompany and predate success?

2.2.2 Learning from Errors

As long as teaching has been a profession, researchers and scholars have been interested in the best and most effective methods of teaching and training students. The skills required for tomorrow’s jobs are often referred to as 21st century skills and include the ability to think critically, solve complex problems, and work collaboratively. As suggested by educational researchers, preparing students for the work of tomorrow requires an environment that mirrors the learning processes and assessment strategies used in the real world (Conley & Darling-Hammond, 2013). Recognizing failure as a welcome part of the learning process and classroom instruction was first introduced in discussion of the natural learning that takes place through trial and error (Morgan, 1894). While many educators would consider the goal of teaching to be to eliminate student mistakes, that goal is based upon the idea that students will understand concepts better if a teacher can minimize confusion in the learning process (Dick et al., 2014). Many teachers separate instruction into smaller, more manageable segments to scaffold students toward instructional goals with as few misunderstandings as possible along the way (Kapur, 2008).

The idea of supporting rather than avoiding failure in the classroom has been revived in educational research as of late. Based on recent research, both success and failure experiences contribute to student understanding and higher-order thinking (Jonassen, 2011). As business and industry were early to fully embrace failure-based learning, much of the current research is situated with workplace learning. In workplace settings, learners have been observed to have encountered errors, and used them to identify key issues. This identification and utilization developed problem solving, critical thinking, and self-regulation techniques in employees (Lannin et al., 2007). Later, learners transferred what was learned during their initial experiences with errors in order to approach and solve new problems (Casale et al., 2012). If the goal of education is to prepare students for life after secondary school, it becomes a point of key importance that learners are able to transfer learning from one setting to another as is shown in research on supporting productive struggle in learning.

One method for leading students to and supporting them through failure in learning is through the use of ill-defined problems. Intentionally designed problems that hold multiple possible solutions can cause students to encounter multiple small failures on the way to fully solving the problem. Not only does this stress the iterative nature of solving problems, but it also exposes students to errors that can lead to concept transfer (Casale et al., 2012). Failure-based learning can provide key skills and abilities to students through high school and beyond as, "exposure to failure allows the learner to identify causal processes and employ this new knowledge to resolve the problem" (Jonassen, 1997, p. 72). Ill-defined problems in educational settings are so valuable because when students are unsure or questioning their approach, the metacognitive process is more likely to yield meaningful understanding (Bar-Anan et al., 2009). While this is one method for supporting productive struggle opportunities during the learning process, there are multiple frameworks in existence for encouraging failure in educational settings.

2.2.3 Failure-Based Learning Theories

One of the first to theorize about the role of failure in the natural learning process was Piaget. His theory of cognitive development included the state of cognitive disequilibrium in which a learner encounters events in reality that are not easily assimilated into understanding (Piaget, 1952). The state of disequilibrium is key to later understanding because it is the point at which the learner realizes that there is new knowledge that they want and need to possess (Piaget, 1977).

Another theory about the importance of failure in learning is that of impasse-driven learning (VanLehn, 1988). Impasse-driven learning builds upon Piaget through the idea that the point of cognitive disequilibrium becomes a catalyst for developing self-motivated inquiry within the learner. According to VanLehn, an impasse is classified as the point at which a learner lacks the knowledge needed to solve the task or problem. At the point of impasse, the learner engages in careful and deliberate inquiry to alter their understanding and information about a topic. While the theory encourages that teachers support these impasse moments in the classroom, it also supports swift intervention and assistance from that point forward. VanLehn (1988) goes on to say that, “if there is no impasse, there is no learning” (p. 32) as it is at the point of impasse that the learner tries to move on but does so with errors or failures. Once errors occur, the teacher must intervene to correct and instruct the learner, without such intervention, impasse-driven learning theory suggests that the student will accept and repeat their errors without notice.

A more recent theory on supporting failure experiences in educational settings is that of productive failure introduced by Kapur (2008). A key diversion point of this theory is that rather than place the focus on timely intervention, Kapur focuses on the need for frustration and struggle on the part of the learner during problem solving. The theory suggests that all learning takes place through the stages of generation and consolidation. Productive failure requires teachers to support the student by removing themselves from the learner to allow for two distinct phases of progress in the learner. The first phase, the generation phase, takes place as students develop numerous creative ideas during their problem solving. This often involves multiple solution pathways or models which develop through grappling with difficult challenges. The second phase, consolidation, occurs when students are instructed by the teacher after they have already presented their own solutions to the problem at hand. Due to prior exposure to the task and challenge, students are more readily able to organize their own thoughts and observations into the accurate information presented by the instructor. The delayed formal instruction used in productive failure provides extra time for the generation phase which leads to better transfer in later struggles (Kapur, 2011).

The final theory of focus on failure in the learning process is that of failure-driven memory. This theory posits that through regular exposure to failures, students develop a script of sorts for dealing with errors that helps to guide them through future issues and challenges (Schmidt & Rikers, 2007). This theory was born out of the case-based reasoning of the medical field, which suggests that when encountering a problem, a learner first tries to apply solutions they know, then reaches for the higher-order learning that they do not possess but must learn in order to solve the problem. Case-based reasoning and failure-driven memory are common terms in the medical field but have very little research backing in other learning environments.

While each of these theories shares some of the same concepts and build upon the prior theories, each has its own principles and intricacies. Productive failure shares aspects such as the disequilibrium concept of Piaget while also sharing the eventual teacher support of impasse-driven learning. Each theory agrees that while failure is a part of the natural learning process that all learners progress through, teachers should be doing their best to support and encourage students to grapple with difficult concepts when learning.

2.2.4 Impacts of Productive Struggle

Productive struggle occurs when students grapple with challenges during the exploration and solving of novel topics and problems. Manu Kapur, one of the foundational researchers and theorists about productive struggle, specifically productive failure, defines its use in instruction as "engaging students in solving complex, ill-structured problems without the provision of support structures" (Kapur, 2008, p. 379). It is important to note that the topic of productive struggle is also referred to as productive failure. The key goal of productive struggle in the classroom is to make the failure that students experience more productive in learning new concepts and skills. For the purpose of this study, outside of direct discussion of Kapur's work, the term productive struggle will be used to encompass both concepts.

While productive struggle is a natural step in the process of learning new information, it is the unique level and type of support provided in productive struggle that maximizes its potential for classroom use. Kapur has completed a number of experiments dealing with the impacts of productive failure support in the classroom, primarily in Singapore high schools. In one such study, students were randomly assigned to either ill-structured or well-structured problems dealing with kinematics. Kapur (2008) found that those students that had worked with ill-structured problems scored higher on a well-structured problem both immediately following and delayed after their experience. Separately, seventh grade mathematics students were put through a similar separation of either traditional lecture or productive failure teaching methods on rate and speed, and were tested after instruction. Despite more struggles in the initial task, the students from the productive failure group scored higher on both well-structured and ill-structured post-test problems. They also went on to outperform their peers in unrelated concepts later in the course (Kapur, 2010).

Another study into teachers supporting productive failure in mathematics placed seventh grade mathematics students into either traditional lecture, productive failure, or facilitated complex problem-solving instructional groups. Again, despite significant struggles in initial problem-solving efforts, students from the productive failure group outperformed students in both of the other teaching groups on both well-structured and ill-structured post-test problems. Traditional lecture and facilitated complex problem-solving students performed similarly on both measures (Kapur, 2010). This research seems to suggest that it is the student's own grappling with the problem that is meaningful in changing academic understanding. Teaching potential misconceptions or errors is simply not enough to make the leap to deep, transferable understanding for students. These same findings have also held true across grades and ability levels of students (Kapur & Bielaczyc, 2012).

Other studies evaluated the difference between failure experiences, separating productive from vicarious failure. Productive failure students from an eighth-grade math class dealt first-hand with ill-defined problems while their vicarious failure counterparts simply looked at their wrong solutions and heard about their difficulties. In tests of conceptual understanding and transfer, productive failure students outperformed their peers showing that students learn better from first-hand failure rather than simply looking at incorrect solutions (Kapur, 2014).

STEM education has the potential to be a foundational method for teaching students critical thinking and problem-solving skills. With those goals, STEM classrooms become a natural partner for supporting productive struggle in learning experiences. Another study of the effects of productive struggle in STEM education dealt with college science students in a General Ecology class. The students were asked to complete an ill-structured problem dealing with a local river. After the activity, while students stated they were not very confident in the instruments that they used, ill-structured task students scored significantly higher than their peers on transfer tasks (Trueman, 2013).

It is important to consider the subject of study in the research. STEM education can cover a wide breadth of information and skills. While Kapur focused his research on mathematics, Yanjie Song focuses on science education, specifically. In one such study (when learning about plant adaptations) students in a class in which the teacher supported productive struggle as part of learning went on to better understand and apply the concepts than did their traditionally taught counterparts (Song, 2018). The same students also faced future challenges with a more positive outlook. These findings held true even in more progressive styles of education, including the flipped classroom design. In a collaborative effort in 2017, Song and Kapur studied the differences between classes that learned in traditional flipped classroom situations and those in flipped classroom designs where the teacher also intentionally planned and supported the student through productive struggle. The results showed that while both student groups showed improvement, students in the productive struggle group had deeper conceptual knowledge understanding than those in the other group (Song & Kapur, 2017).

Productive struggle fits squarely within the constructivist viewpoint of education in which it is believed that students must experience different situations and make sense of their own observations in order to form new knowledge. An example of students benefitting from productive struggle support was seen in a study by Schwartz et al. (2011) in which students were either instructed on density before experimenting or after. Not only did those that explored before receiving instruction perform better on post-test measures but they were also able to reason and discuss density more adequately than their counterparts. It is this deeper understanding that allows students to transfer their understanding to other concepts or problems (Schwartz et al., 2011).

2.2.5 Four Types of Problem-Solving Experiences

Regardless of the failure-based learning theory, each agree that supporting productive struggle can be a productive method of teaching and learning. What exactly is it that defines some failure as productive and others as simply an unfruitful error? According to Kapur and Rummel (2012) and Kapur (2016), there are four possible outcomes in classroom instruction: productive success, unproductive success, unproductive failure, and productive failure.

Productive success occurs when a task or performance presents a challenge yet teacher support and instruction take place at a level and pacing that ensure student success. This is the typical classroom goal which includes scaffolding of tasks and the sequencing of activities from relatively simple to more challenging in order to build learner understanding and confidence along the way. Confusion and struggle are typically avoided in this type of learning. Activities in productive success instruction are typically heavily guided toward successful solutions (Kapur & Rummel, 2012). One example of productive success is Problem-Based Learning (PBL) in which students are experiencing productive learning opportunities but are typically doing so with ample support and instruction throughout the process.

In contrast to productive success, unproductive success also focuses on removing confusion or difficulty from the students but does so through activities or instruction methods that do not lead to lasting learning or knowledge acquisition. These are often very short learning experiences without the cognitive demand or rigor required for acquisition of new information. Samples of unproductive success in the classroom include skill drills and rote memorization in tasks.

Unproductive failure may challenge or confuse students urging them to reach a moment of impasse but again, that impasse fails to lead to deeper understanding or meaning for the student (Kapur, 2016). Unproductive failure occurs simply when errors, problems, and mistakes are encountered that do not lead to meaning-making or development of any kind. Depending on the assessment strategies and methodologies of the instructor, some researchers posit that direct instruction could fall into these unproductive learning outcomes. Simple lecture or call and repeat teaching styles may underperform in studies because simply hearing the information does not lead the student to complete and enduring understanding of new concepts (Kapur & Rummel, 2012). In addition, poorly supported discovery learning or open research could lead to unproductive failure in students. Without structure or guidance, students could squander and fail to develop meaningful new skills or knowledge from the activity.

Productive failure is a method in which short-term struggles do lead to long term understanding. Most productive failure strategies call upon students to work through vague problems prior to receiving teacher instruction on new concepts (Kapur, 2008). The problem solving phase of learning meets Kapur's generation phase requirement while the delayed instruction becomes the consolidation phase, an opportunity for students to make sense of their prior experiences in problem solving (Kapur & Bielaczyc, 2012). The main topic of this research, productive failure occurs when students are encouraged to grapple with struggle during the exploration of new concepts. The productive nature of this learning style occurs when students receive delayed instruction on the concepts and are able to fit their own observations and findings among the accurate information presented by the teacher.

2.3 Strategies for Supporting Productive Struggle

If failure is, and should be recognized as an important part of the learning process, how and why should teachers support productive struggle to lead to a meaningful and prolific event? One influential educational group to recognize the importance of, and encourage teachers to support productive struggle or impasse moments in learning, was the National Council of Teachers of Mathematics (NCTM), who named productive struggle as one of the methods for effective teaching in their *Principles to Actions* (2014) publication geared at improving mathematics education. NCTM urges that "effective teaching of mathematics consistently provides students, individually and collectively, with opportunities and supports to engage in productive struggle as they grapple with mathematical ideas and relationships" (NCTM, 2014, p. 48). As researchers have demonstrated the effectiveness of productive struggle in some STEM subjects, it is important to define what strategies teachers can employ to make these experiences meaningful and successful.

There are a wide variety of viewpoints as to how to best support productive struggle in the classroom. In order to best ensure the struggle is a productive learning experience, teachers must be intentional during planning, delivery, and debriefing of student activities. During lesson planning, teachers must design activities and learning environments that bring students to the impasse point in which their understanding is simply not enough to solve the problem at hand

(Tawfik et al., 2015). This means the teacher needs to have a deep understanding of student knowledge while also anticipating what students may struggle with during the lesson, and how to support students through those struggles without simply providing answers (NCTM, 2014). Teachers must be ready not only to provide the proper challenges but also to ask questions that guide students towards metacognition and the identification of the source of their struggle (Warshauer, 2015). Most often, productive struggle supported lessons are planned in such a way that students take part in a problem solving or critical thinking activity prior to receiving any type of instruction on the new concept (Lai et al., 2017). This sequencing of instruction allows students to use their own inquiry and generation methods to become aware of their knowledge gaps. It also leads to the delayed instruction being more meaningful and beneficial to students as they immediately understand its importance as related to the previous task (Loibl & Rummel, 2014).

Next, during the activities and ill-defined tasks, teachers must be attentive and available to students while not simply giving students answers to progress past the point of impasse. Teachers must allow students time to struggle and develop questions in order to allow the student to realize that struggle and confusion are a part of the learning process rather than the opposite of learning. Teachers should also be available in order to praise students for their efforts as necessary to ensure students persist through the challenge moments (NCTM, 2014). The National Council for Teachers of Mathematics laid forth a series of behaviors on the part of both the teacher and students that indicate support of productive struggle in the learning process. Their recommendations included teachers anticipating student errors, providing time for struggle, and encouraging students with praise and reminders that struggle is a natural part of learning new things. During productive struggle students should be asking questions related to the source of their struggle, realizing that it is okay to have a hard time but not okay to quit, and helping one another toward a solution without providing answers (NCTM, 2014).

Productive failure can easily become unproductive failure if students cannot identify the issue at hand or knowledge gaps that exist in their learning activities. Students should be familiar with common signs of success and failure in learning and be given the opportunity to reflect on them regularly (Tawfik et al., 2015). It is also during this active stage that teachers should support students by again pushing students towards metacognition in order to reflect on their actions and thoughts during struggle (Warshauer, 2015).

One key component to supporting productive struggle during the learning process is the teacher being aware and intentional about the dialogue that they have with students. There is a big difference between a teacher saying that a student “is so smart” compared to saying a student “really thought through that problem”. One is more directed toward a fixed mindset with no room for errors while the other is more growth-minded and acknowledges the struggle that a student worked through in solving a problem (Dweck, 2006). Teachers can even use their dialogue to ensure that students see failure as part of the process rather than the opposite of learning. In a simple or easy task, a teacher can share “Whoops! I guess that was too easy. I apologize for wasting your time. Let’s do something you can really learn from!” (Dweck, 2006, p. 173). This statement alerts students to the fact that challenges are really the opportunities for deep and meaningful learning to occur, rather than a condition to avoid.

Dialogue is also important not only to the student but also in what the teacher requests back from the students. There is a key difference between asking students, “What is the right answer?” and “Can you think of any other possible solutions?”. The first question follows the very basic and traditional viewpoint of teaching and learning in which there is one right answer and once it is achieved a student is done. The second question asks students to dig deeper into their understanding, to theorize about what they observed, and to explore other possibilities (Boston et al., 2017). Effective support of productive struggle creates dialogue between the participants in the learning environment that encourages students to reflect on and reconsider their own understanding of the concept and problem at hand. The goal is not to take over the thought process for the student, but rather to guide the student by asking meaningful questions, providing time to grapple with concepts, and acknowledging student effort along the way (Boston et al., 2017).

Warshauer (2015) identified four distinct teacher responses to student questions and concerns in productive struggle situations. Two of these types, telling and directed guidance, provide very limited to no positive support for students in working through struggles and errors. Telling consists of supplying solutions in order for students to continue progress, this avoids rather than grapples with the struggle. Directed guidance redirects students towards a solution but does so in the teacher's method of thinking toward a solution rather than aligning with the student's own thought process. Probing guidance is supportive of productive struggle in that the teacher identifies the student line of thinking and works to encourage self-reflection and determination of next steps that are congruent with the student's own thought process. Lastly, affordance is a teacher productive struggle support strategy in which the teacher works to have the student reiterate what has already been done and considered so that the student can identify their own best next course of action. Affordance is usually followed by allowing the student additional time to grapple with and work through the struggle at hand. Affordance and probing guidance are effective productive struggle supports in that they do not reassign a line of thinking, but rather work towards metacognition and deeper analysis of the impasse point (Warshauer, 2015).

Finally, teachers can support productive struggle by providing students the time necessary to debrief from learning activities. After formal instruction, students should be guided to fit the newly learned information into the gaps that existed during problem solving. Teachers should support students in later solution generation toward the initial problem in order to revisit failures with deeper and more connected understanding (Kapur, 2008). Allowing students to reenter the problem-solving process in order to resolve the source of failures is key to developing transferable new skills and ideas (Tawfik et al., 2015).

Productive struggle is being supported so long as three conditions, as set forth by Warshauer (2015) are being met: cognitive demand and end goals of the challenge remain unchanged, individual thinking is supported rather than changed, and the student is able to move forward through his or her own actions or attempts. While supporting productive struggle can be an extremely powerful tool in students reaching lasting learning, it is a teaching method that requires attention of the teacher before, during, and after instruction. Thoughtful and attentive behaviors on behalf of the teacher help to ensure that students not only reach a moment of impasse but also that the struggles of the student result in productive learning experiences.

2.4 Gap in Literature

A significant gap exists in the literature required to make a connection between student mindset and experience with teacher support of productive struggle. Most research on these fields specializes in either the role of productive struggle or student mindset on learning outcomes. One study to attempt to bridge both research fields dealt with the impact of short videos incorporated in an online course on student mindset and perceptions of mathematics as a creative subject. The researchers found that incorporating the videos, which included one focused on the brain development and learning that occurs during struggle, had a significant impact on student perceptions, student growth mindset, and student fear toward mathematics (Boaler et al., 2018). While this study helps to explore relationships between productive struggle and mindset, the focus of the study was on mindset and achievement in mathematics as impacted by a variety of fields. The other videos incorporated in the middle school online course included the ability for everyone to learn math, thought process over speed, the creative nature of mathematics, strategies for solving mathematics problems, and the authentic applications of mathematics. There was no specific attempt by the teacher of the course to respond to student struggles or provide individualized support through struggle during problem engagement (Boaler et al., 2018).

The review in literature exposes a gap in understanding in the connection between teacher support of productive struggle and student mindset. Much of the current research focuses on only one of those two areas with little connection existing between the two fields. This research study seeks to explore the interrelated nature of the two areas and fill an essential gap in understanding for teachers and learners alike.

2.5 Summary

If the goal of education is to enhance student learning and understanding, to train the next generation of problem solvers and critical thinkers, or even to prepare students for whatever phase of life comes after graduation, it is absolutely vital that teachers encourage students to develop habits of persevering through failures in learning new information and skills. Doing so requires that teachers create classroom climates that are growth-minded and provide ample opportunities for students to interact with and respond to their own errors (Kapur, 2012).

Beyond preparing for the future, the literature leads to the belief that learning through supportive productive struggle experiences has ample support that it may be a superior method for learning. Not only does the experience of making mistakes cause significant brain responses (Moser et al., 2011), it also can lead to deeper and more transferable knowledge gains for the students (Kapur, 2008). Seeing that student academic mindsets can make a large impact on the brain's neural responses and the student's learning process, it is essential to explore supportive productive struggle teaching methods for the possibility of shifting student beliefs from those of a fixed to a growth mindset.

Through a review of the available literature on failure-based learning experiences, noncognitive factors impacting academic performance, and the neuroscience involved in learning, key connections exist between concepts that should be explored through further research. A significant gap in the literature exists in the exploration of any possible connection between productive struggle support and student mindset. While these two topics both exist in the noncognitive realm of student factors affecting achievement, and while both topics have been studied in a variety of fields and levels by researchers, little to no research has sought to establish a connection between the two. More investigation is needed on how teacher support of productive struggle in the classroom may or may not impact student error processing and learning mindset and therefore student brain responses in learning. This research would benefit teachers, parents, and students alike in attaining meaningful growth and development toward future goals.

3.0 Methodology

Based on both reviewed literature from the field and reflection upon the problem of practice, three inquiry questions were developed to be addressed through the study. Two questions refer to the impacts of productive struggle on students. The first inquiry question was meant to form a bridge between the literature that exists on productive struggle and that which exists on student academic mindset. These two fields of research, while seemingly similar, have little to no overlap in current research. The case study was organized around the following inquiry questions:

1. What relationship exists between student exposure to supportive productive struggle learning experiences and shifts in student mindset?
2. How does teacher productive struggle support impact student attribution of impasse points in learning?
3. How does teacher productive struggle support impact student academic progression through challenging tasks?

First, what relationship exists between student exposure to supportive productive struggle learning environments and possible shifts in student mindset? As shown in research (Farrington et al., 2012) there are a number of factors that affect the learning process, including noncognitive factors, specifically student mindset toward learning. It is beneficial to consider the learner as a whole in looking for changes in student mindset over the short-term timeframe of learning through productive struggle in a course. Does a student's experience with and development of learning strategies during struggle and failure change the way that he or she views their own intelligence and their ability to grow their own skills and knowledge? While this is important information to consider and analyze, it is important to consider that changes in student mindset may be in the short-term and do not necessarily imply long-term changes.

Next, how does teacher productive struggle support impact student attribution of impasse points in learning? While research (Kapur, 2008, 2010, 2011) has shown the impact of productive struggle learning experiences in course achievement, little research exists about its impact on a student's own reflection toward learning and attribution for errors or difficulties. The reason students give for success or failure has been shown to be a key piece to learning new skills. Attribution theory shows that these identified causes for failure or success can be either internal or external, and have lasting effects on student learning, persistence, and motivation (Weiner, 1972, 2010).

Lastly, how does teacher productive struggle support impact student academic progression through challenging tasks? As a director and facilitator of learning in the classroom, the power of the teacher in the learning process is paramount. While suggestions for strategies for student support exist (Smith, 2000), it is unclear which strategies specifically are most effective and how their impact would be observed by the teacher. The National Council of Teachers of Mathematics defined teacher actions during productive struggle tasks as being categorized as either telling, directed guidance, probing guidance, or affordance depending on the level of guidance and direction provided to students (Boston et al., 2017). Seeing as to how busy and regimented teacher schedules and planning time can be, it is important to maximize the teacher impact through strategies and actions that are shown to be meaningful.

3.1 Inquiry Design

The proposed problem of practice inquiry sought to investigate the teacher's current practices and improve the impact that it has on students in a specific setting. Building upon research on productive struggle in other STEM disciplines, the research was expanded into the realm of technology and engineering education. The goal of the research was to determine whether teacher support of productive struggle experiences in technology and engineering classes leads to any noticeable difference in student work and thoughts toward their own learning. Data was collected through the form of through-task student journals and one-on-one interviews of focus students. Student mindset was measured using the ITIS survey before the first and after the final iteration of the productive struggle cycles. Collected data was then analyzed to look for patterns in student processing of errors, progression through struggle, and changes in mindset and achievement.

The inquiry was explored through an action research design with three separate iterations of a cycle through planning, action, and reflection on teacher support of productive struggle through lab tasks. Each iteration of data collection included student engagement with a lab task dealing with mechanical advantage of simple machines. An action research model best fit inquiry in that it allowed for each cycle to be altered based on observations and findings in the previous iteration. It allowed for practice and support strategies to be refined through the process to reach the best possible set of behaviors informed by student responses, learning measures, and reactions.

The design of the research is also a case study based in a particular setting with specific participants and context. The study is a case that explores how student noncognitive outcomes may change when the teacher instruction and support changes to that of a productive struggle support approach. The results and findings of the study are focused in the setting of the study and the implications they hold for future teaching and learning in that setting. While the content and standards covered in the study were not unique, the real inquiry was based on the changes present when teacher support was changed to align with student thinking, maintain rigor through challenging tasks, and allow students time necessary to grapple with points of impasse in learning.

3.2 Inquiry Setting

My current place of practice is a high school within a district that spans 113 square miles of land in Pennsylvania. The district serves a diverse set of individuals from rural farming-based students to urban students. The district also comes right up to the edge of the closest city. The total population served by the district is about 42,000 people. The high school graduates approximately 400 students each spring with about 40 percent of the student population receiving free or reduced lunch, and over 70 percent of graduates going on to higher education. Within the high school, I work as a technology and engineering teacher offering courses at a variety of levels and topics. On a regular basis, I teach Advanced Placement (AP) Computer Science, Honors-level Engineering Principles, career-level Applied Science and Technology, and a Freshmen Experiencing Technology introductory course. One thing that I see regardless of topic or academic level, is a resistance in students to problem solve on their own when faced with struggles. In teaching design and technology, it is essential that I work to develop critical thinking in students as well as the ability to think through and solve problems that they encounter in learning and in life.

Technology and engineering education has strong roots in authentic inquiry and assessment. National standards for teaching engineering include defining and delimiting engineering problems (HS-ETS1-1) and breaking problems and solutions down into simpler issues that can be solved (HS-ETS1-2) (National Research Council, 2012). In this authentic classroom environment, the teaching, learning, and student engagement process is typically less prescribed and structured. This type of learning environment regularly exposes students to problems and failures as an integral part of design and engineering. Additionally, technology and engineering education tends to push students to analyze, evaluate, and synthesize information, which are defined by educational researchers as requiring high cognitive demand (Bloom et al., 1956). Because technology and engineering coursework pushes for higher cognitive engagement from students, it is important to determine if productive struggle as a teaching and learning method impacts a student's ability to reflect on his or her own mistakes and revise their work accordingly.

The specific setting for the study was the Honors Engineering Principles course. The content, flexibility, and curriculum of this course best fit a study of this design. This course consists of a curriculum developed by a team of educators within the district, including myself. The curriculum is geared toward preparing students to decide if they want to pursue engineering post-secondary school and, if so, what branch of engineering might be closest to their interests. Course units of instruction include mechanical advantage in simple machines, static and dynamic loads, trajectory motion, energy, and basic chemistry. Specific productive struggle lab tasks used in the study took place during the mechanical advantage of simple machines unit of instruction. After learning about a variety of fields of engineering and the theories that guide them, the lab tasks forced students to think and behave like engineers by using observations, calculations, and predictions to set forth theories and findings of their own. Each of the lab tasks was completed in small work groups. Students worked in the same work group for each of the lab tasks which covered mechanical advantage of inclined planes, levers, and wedges. These lab tasks caused students to look at these simple machines in new ways by trying to determine what mechanical advantage is gained through utilizing each simple machine and how this can be calculated. Each lab task prompt is included in Appendix C.

In preparing for each lab task, I laid out specific teacher productive struggle support actions using pre-lesson planning and strategizing documentation from Smith et al., (2008) which are provided for each lab task in Appendix D, E, and F. Each pre-lesson plan was completed prior to the lab activity so that I could reflect on prior task successes and struggles using my observations and journals to inform changes to be made in the action research cycle. These planning documents were instrumental in guiding my actions as they dictated prior thought given to the knowledge students would bring to the lab task, the evidence that would suggest student attainment of learning goals, as well as anticipated solutions presented by student work groups. Each of these components plays a key role in student progression through struggle. Lastly, the format of the plan included specific teacher actions and supports that I planned to use during the learning experience, a key component in creating meaningful learning experiences during productive struggle.

3.3 Stakeholders

Key stakeholders in the matter of maximizing the learning potential of productive struggle in the classroom include both the students and the teacher. In my particular case, the students are those in STEM courses. Statistically, STEM students, specifically those with interest in mathematics, are already more likely to have a fixed mindset toward their own intelligence and its ability to grow and develop (Leslie et al., 2015). Important factors that students value include the ability to learn from the teacher, the ability to get help or assistance when necessary, and, in my particular case, the ability to do those things while using hands-on and engaging methods. In my own observation I have found that the students in my classroom are quick to become frustrated or outright quit when faced with a challenge that they believe is beyond their ability.

As a teacher, I am also a stakeholder in the teaching and learning that occurs in my classroom. I, as well as the organization for which I work, hold beliefs and ideas about the types of activities that should take place in the classroom environment. I am expected to teach content and curriculum that is matched to standards, as well as to assess student abilities and knowledge in both formal and informal ways. I personally value the ability to teach students through real-world, authentic problems which I do often in my place of practice.

An additional stakeholder in students developing critical thinking and problem solving skills would be the local society including potential future employers. The skills and knowledge gained by students in school also benefit the wider community as well as the students in the course. If the goal of school is to prepare students for life after high school, then the teaching and learning that occurs within schools impacts much more than a student's grade or abilities. The local society and economy demand that students graduate school prepared to enter the workforce and the world around them.

3.4 Researcher Positionality

A major piece of learning about the culture and outcomes of any classroom is understanding more about the teacher leading the instruction and activities. As the teacher-researcher, it is important to acknowledge the biases, perspective, and beliefs that I bring to my own classroom. I am a white female teaching in the predominantly male dominated technology and engineering subject area within a conservative district and town. While I did not personally attend the school district in which I teach, my own alma mater closely matched the demographics and characteristics of the studied district. I taught within the district involved in the study for all seven years of my teaching career. Throughout that time, I taught technology and engineering coursework including electronics, materials, engineering, and computer science. I was an influential part of proposing the course involved in the study for school board approval including writing much of the enacted curriculum.

I am a firm believer in teaching through the role of a supportive facilitator rather than authoritative source of information. I consider experiential learning to be the most powerful way for providing meaningful and lasting learning in students. I also try to impart on students that the process of thinking critically, challenging norms, and taking risks is more important than the end result of their designs. This is important to me as I feel that developing the skills necessary to solve problems and work through challenging experiences is the biggest life skill that I could help students to develop. These expectations and beliefs hold true for all students in my classroom as I believe that STEM literacy and understanding is essential for all students and all future pathways. Integrative hands-on learning dominates my classroom. Lastly, I strive to create a classroom that is inviting and comfortable to all students regardless of identity, background, or demographics.

3.5 Participants

Participants in the research study consisted of all 16 students currently enrolled in the Honors Engineering Principles course. As teacher-researcher, I formed student productive struggle work groups that remained unchanged for all three lab tasks. Based on the results of the initial mindset assessment, I worked to ensure that work groups represented a variety of mindsets while also considering student prior physics course experience and grade level.

Within the whole class of involved students, a subset of four focus students were selected to take part in individual structured interviews. From the full class (4 work groups of 4), two work groups were randomly selected. Within those two groups, I selected two (of 4) members from each work group to take part in one-on-one interviews. Selection of individual interview members from within work groups was determined by student mindset and student lunch schedule. To the best of my ability, the selected interview participants represented a variety of student mindsets as reported on the student mindset assessment. A participant breakdown can be seen graphically in Figure 2.

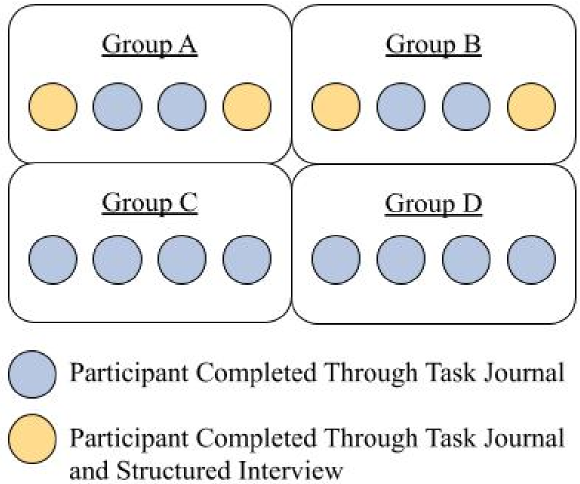

Figure 2 Organization of Participants

Student lunch schedule was a factor in the sampling of the students to ensure, as much as possible, that all interviews would take place on the same day or the next day after lab tasks While the interviews allowed me to get a deeper look into work group happenings and student processing of the experience, this sampling method ensured that the interviews captured a variety of group actions from multiple viewpoints of what occurred within each work group.

3.6 Data Collection

The data collection for the research study consisted of three main student self-report sources: the pre- and post-administration of the Implicit Theories of Intelligence (ITIS) scale to every student, entries in the side-by-side individual student work journals, and the individual student interviews. Data from each source contributed to answering inquiry questions as seen in Table 1.

Table 1 Data Collection Instruments by Inquiry Question

	ITIS Assessment	Through-Task Journaling	Post-Task Student Interviews
Inquiry Question 1: What relationship exists between student exposure to supportive productive struggle learning environments and possible shifts in student mindset?	X		
Inquiry Question 2: How does teacher support of productive struggle impact student attribution of impasse pointes in learning?		X	X
Inquiry Question 3: How does teacher support of productive struggle impact student academic progression through challenging tasks?		X	X

Dweck's Implicit Theories of Intelligence Scale (ITIS) (1975) was used to collect both baseline and post-productive struggle lab task measures of student viewpoints toward learning and intelligence. During productive struggle lab tasks, students were directed to complete all academic work and calculations on a provided organizer side-by-side with error- and struggle-based responses. The goal in using this organizer was to make visible some of the inner thoughts and processes of the student during the actual completion of the lab task. Finally, individual structured interviews were conducted with a pre-selected subset of students based on work group assignment and whether the student held a fixed or growth mindset as indicated by the student mindset pre-assessment. These interviews asked students to explain their perspective of the lab task, walk through their struggles, and reflect upon their own reactions to the difficulties encountered. One key insight gained in the interviews was the role that the teacher played in reaching the final solution or making progress during struggle. The intent in the design and administration of the interviews was to gather a more detailed understanding of what occurred in lab tasks within the work group of focused students. While student journals address the same general information, these were only brief snapshots compared to the depth that is targeted in interviews.

One additional source of information was a teaching journal which was used during instruction as a monitoring tool. The teaching journal was used to record teacher decisions, interaction with student work groups, and track student impasses and interventions. This journal was used to inform and track changes made during the action research planning phases between lab tasks. It was also used to inform questions and probing used in the structured interviews to elicit clear and useful reflection.

All data was collected over a one month period occurring during the regularly scheduled class meeting time for the course and lunch meetings, as needed, for one-one-one interviews. Figure 3 shows how all data collection instruments were used in relationship to one another to obtain a clearer picture of the full impact of productive struggle lab tasks. The entire data collection period occurred over a three week period leading up to the end of the semester. During non-task work days, students continued work on a self-directed engineering design challenge.

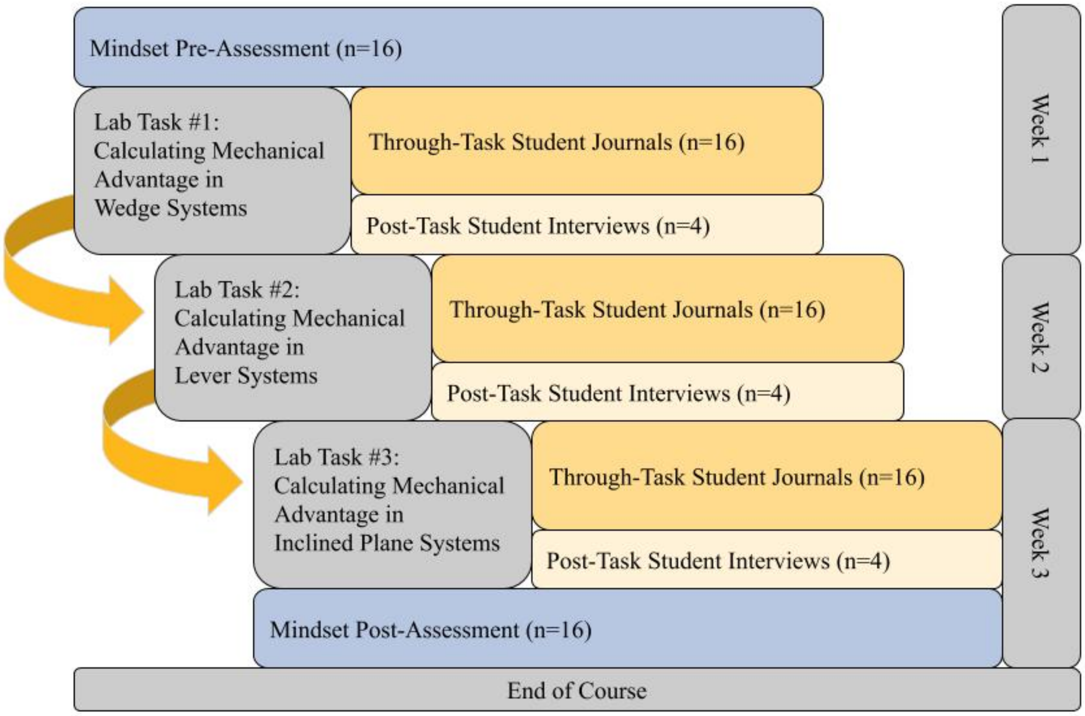

Figure 3 Data Collection Instruments in Use Through Study

3.6.1 Data Collection Instruments

3.6.1.1 Implicit Theories of Intelligence Scale (ITIS)

Prior to student engagement in any of the productive struggle supported lab tasks, the ITIS was administered to all students in order to gain a baseline starting value for student mindset. Students were provided a paper copy of the scale and asked to complete the items as honestly as possible. They were reminded their responses would not be shared with anyone nor would responses have any impact on their grade. There was no limit on time provided to students for the scale but most students finished within ten minutes. The instrument, provided in Appendix A, consisted of six distinct statements about changing intelligence that participants score based on a 6-point Likert scale. The scales range from Strongly Agree to Strongly Disagree with no neutral option. Resulting scores on the ITIS rank student mindsets based on numerical scores; scores lower than a three are indicative of a fixed mindset and those of four or higher are indicative of a growth mindset. For the purpose of this study, scores of three or more but less than four were considered a mid-range mindset.

This same instrument was used upon completion of the final lab task to explore if changes in student mindset occurred. This instrument has been widely used in research on mindset and student thoughts towards intelligence with both reliability and validity being established and reported (Blackwell et al., 2007). This data source was used as the sole measure of student mindset. The two separate administrations of the assessments were used to measure the change in student thinking over time before and after the productive struggle support experiences. The ITIS scores were used to address whether a relationship exists between teacher support of classroom productive struggle and shifts in student mindset.

3.6.1.2 Through-Task Student Journaling

During in-class lab tasks, all students were prompted to record both academic calculations and reflection on difficulties through the use of a journaling template shown in Figure 4. This template also asked students to reflect on how confident they were in their final solution. These journals were used to make student thinking more visible for use in coding error attribution and academic progression, as well as to promote reflection and metacognition.

Task-Related Work and Calculations	What are your thoughts and feelings about this task?
How confident are you in your solution? Why?	

Figure 4 Student Through-Task Journaling Template

This journaling method was piloted in a different class of similar content and size to determine how to best encourage reflection and recording of student thoughts throughout lab tasks. This process showed that introducing reflection as part of the process was most useful in collecting student thoughts and feelings. This method worked best as the timed prompting often did not align with each iteration of work group exploration or findings. Student work groups were asked to engage with the prompt through a process of brainstorming a solution, modeling and testing their solution, analyzing and evaluating the attempt, then recording their reflections in the right column of their journal after their evaluation. This cycle was repeated throughout each productive struggle lab task as many times as was necessary for students to formulate their final solution.

The student through-task work journals were used to gain insight into student thinking while engaged with the lab task. Rather than waiting for students to reflect on the experience afterwards, the academic and reflective journals allow for students to share a more seamless set of thoughts between academic calculations, error attributions, emotional responses, and more. In addition, because these journals were used during the lab task and could be coded fairly quickly, the through-task journals could be collected from every participant rather than only a select few students.

3.6.1.3 Post-Task Student Interviews

After each of the three lab tasks, during later blocks of the same school day, students representing two separate work groups were interviewed separately for a deeper understanding of student thought and processing during lab tasks. These interviews were done one-on-one so that all insights gained were unique to that single student and no pressures from peers existed. Choosing two students from the same work group ensured that individual student insight was being garnered from the same occurrences in the lab as well as from separate work group experiences. All 12 student interviews (four for each of the three lab tasks) were audio recorded and transcribed for later analysis.

The interview was comprised of five different categories: experience, struggle, techniques, teacher supports, and a live application problem. These categories were created based on information from a review of the literature and an analysis of what information would yield new insight necessary to address the inquiry questions of the study. Experience questions asked the student to describe their reactions and level of confidence in their solution which often lead to emotional cues from the participant's processing of the lab task. The struggle section of the interview asked the student to talk through issues that they encountered in the lab task collecting both emotional cues and error attribution indicators from interviewees. The techniques section explored the strategies used by the student work groups in developing a solution. This gave insight to the attribution of progress through the productive struggle lab task. One of the most insightful and important sections of the interview protocol was the teacher support section. This gave insight to the role of the teacher in the solution of the lab task as well as informing the teacher as to whether too much or too little guidance was provided to students. This was important because student work journals did not address this vein of reflection. Finally, the live application section of the interview was meant to gain perspective on the student's ability to utilize and truly understand their solution. It also revealed whether students could use what their work group presented or not.

Interview data was used to longitudinally analyze individual student reflection across the lab tasks, and to see if changes occurred in how individuals responded to the productive struggle experiences. The interview responses were also used to reflect on task implementation in planning for the next lab task implementation. These interviews were essential in obtaining additional deep thought and context from the student regarding their work during the lab tasks. The detail gained in the journals could not be achieved in the through-task journals as the time was not available for deep reflection and long-winded sharing of thoughts during the actual lab tasks. Interview coded data was not used explicitly in quantitative analysis as with such a small sampling of students the intent was not to use interviews to represent the whole group. Rather, the interviews were meant to gain further insight, richer detail, and deeper understanding to student experience during the lab tasks. These focus student interviews also gave the unique opportunity to see the differences in student thought processing of events from within the same work group.

3.6.1.4 Teaching Journal

Throughout the student lab tasks, I kept a record of observed points of student impasses, teacher suggested interventions, and work group observations. With four work groups working out of one lab space, I tried to observe all groups and identify those that were at points of impasse. These work groups were prioritized for teacher check-ins and journal recording as these moments and group discussions were the focus of the research. Beyond this, I attempted to check in and record observations from all work groups as evenly as possible. Notes made during the class period included key errors that I observed, new attempts in solving the challenge, and direct quotes from students that I found to be significant. These quotes were those that demonstrated student emotion response to the lab task as well as student reasoning for errors.

This journal provided clear and specific examples of lab occurrences to utilize during the individual student interviews. This teacher journal also helped to inform changes that should occur between lab tasks during the planning phases of action research. Additionally, immediately after the Honors Engineering Course was a full-block teacher preparatory period that was used to elaborate on the field notes collected during class with further reflection and detail.

3.7 Data Coding and Analysis

Data coding and analysis was planned and organized around addressing the three inquiry questions presented as the aim of the study. Each of the data collection instruments were analyzed in order to provide evidence-based answers to the research questions.

The Implicit Theories of Intelligence Scale (ITIS) results were analyzed to address what relationship might exist between student exposure to supportive productive struggle learning environments and possible shifts in student mindset. The results of the ITIS were analyzed through the use of statistics to examine what differences exists between student pre- and post-task academic mindset. Key informative measures of central tendency include mean, median, and mode of the class data changes between pre- and post- test measures. Changes in student scores, rather than actual scores were used in the analysis as the research shows that mindset scores can be compared over time within the same individual but are not a valid measurement of differing range of mindsets between students (Cook et al., 2017).

Data from all participating students was used to determine if a change exists, either toward or away from a growth mindset, in student mindset toward intelligence. These analyses were performed on the class as a whole as well as separately on student work groups. Additionally, the whole class set of data was analyzed using tests of statistical significance. After ensuring that the class data set fit was normally distributed through a Kolmogorov-Smirnov test, a t-test was performed to determine the significance of the change in data sets. The two-tailed t-test looks for changes in either direction as well as ensuring that the change is actually statistically significant rather than simply a chance occurrence. This analysis was only performed at the whole class level as individual work groups presented count values too low to offer significance on statistical measures.

In addressing the second inquiry question dealing with student attribution of error, both through-task journals were analyzed for student reasoning for their errors and progress during lab tasks. Student structured interviews were also coded in order to further understand student reflection and provide contextualized examples of progression through error attributions. A list of codes was developed based on prior literature on struggle and progress in challenging learning environments. These codes were further refined by analyzing the data collection instruments and deliberating with a second coder as will be explained later. A section of the final codebook, shown in Figure 5, assigned codes based upon student responses toward struggle and progress in data collection instruments.

Topic Codes	Definition	Example
Attribution of Struggle (Dweck, 1975; Loibl & Rummel, 2014)		
External Factors	Errors attributed to prompt, including too difficult, unclear, vague or limited lab task timing, conflict within the work group or team	"The problem was dumb because it didn't make sense"
Internal Factors	Errors attributed to a lack of knowledge or understanding needed to proceed	"It was hard because I don't know how to get rid of friction"
Attribution of Progress (Kapur, 2014; Warshauer, 2015)		
Student-Aligned Strategy	Progress or thinking attributed to student or peer strategies towards problem solving including progress from prior knowledge, other learning experiences	"One of my group mates suggested that we try to simulate a steeper angle"
Teacher-Aligned Strategy	Progress or thinking attributed to teacher directed problem solving methods	"Mrs. Miller asked us where we have seen this in similar situations"

Figure 5 Inquiry Question 2 Codebook

The collected through-task journal codes were then analyzed through a calculation of the percentage of student attribution of error to internal versus external factors and progress to either student- or teacher-aligned strategies. These percentages were organized in a table to look for trends in student responses over the course of the productive struggle lab tasks. Signs of shift in attribution for errors from those out of student control, termed external factors, to student identification of key impasse moment knowledge gaps, termed as internal factors, are signs of the development of strategies to make struggle more productive and deeper learning and understanding (Weiner, 1972). These trends were analyzed at the whole class and student work group levels. This data was used to address the inquiry question of whether productive struggle support impacts student attribution of impasse moments.

The final inquiry question dealt with the relationship between teacher support of productive struggle and student academic attribution through challenging tasks. This question was analyzed through use of student journals and further contextualized using student structured interviews. A partial codebook was developed using prior literature and student responses to categorize student emotional cues presented in the data collection instruments. These codes are explained in Figure 6.

Topic Codes	**Definition**	**Example**
Emotional Response (Bar-Anan et al., 2009; Weiner, 1986)		
Negative Cues	Frustration, Anger, Hopelessness, Lack of Confidence, unresolved tension/disagreement, etc.	"Initially, I knew I wouldn't get it…"
Positive Cues	Excitement, Embracing Challenge, Confidence, etc.	"I really like the topic, so I was ready to tackle the problem"

Figure 6 Inquiry Question 3 Codebook

The coded student journal data was then placed in a spreadsheet to calculate the percentage of positive versus negative emotional reactions during lab tasks. The organized data was then analyzed to look for trends in percentages over the course of the three lab tasks.

The third inquiry question was also addressed through an analysis of final solutions presented by student work groups in the through-task journals. Final solutions were coded as being either correct, incorrect, or partially correct if students included constants to describe what they were observing as friction in the lab that would not be present in ideal calculations. Incorrect coded solutions included both those that were wrong and groups that provided no solution. This distinction was chosen as both a wrong and non-existent solution would receive no credit in grading so both were coded to be incorrect. This coded data was used to analyze whether students developed more accurate solutions over continued experience in supportive productive struggle.

Additionally, in the action research design, student journals and individual student interviews were used to inform changes to teacher behaviors and support strategies in the following cycles of productive struggle lab tasks. Student journals showed the teacher the incorrect solutions that were attempted by work groups. These early attempts at the problem were used to plan for possible student responses in future prompts. Student journals were also used as an indicator of work groups that were in need of additional support or guidance through the number of iterations work groups were completing before making progress as well as the types of emotions and thoughts that were shared. Detailed conversations, including what techniques are most helpful, and deeper understanding of student thoughts and feelings during lab tasks were used to inform teacher practice. Student interview responses to teacher impact questioning revealed what behaviors were most influential to their work group and which seemed not to be effective with the students.

3.7.1 Use of Second Coder on Student Journals and Interviews

A graduate student in the field of technology and engineering education was used as a second coder during data analysis. The codebook provided above in Figures 5 and 6 was used in coding data, along with discussion between coders, and consideration of inter-coder reliability. When codes were combined or expanded, both coders revisited previously analyzed student data to ensure that the new code did not also apply to prior data.

In order to train the second coder and ensure reliability in coding, the second coder was trained on the use of the codebook and distinguishing between codes. Both the teacher-researcher and the second coder had access to all student journals and transcribed student interviews. Both data measures had no identifying information pertaining to the student. In the event of disagreements regarding assigned codes, discussions took place in order to decide the codes by consensus. At the conclusion of analysis of all student journals for one lab task (33% of journals) and student interviews through two lab tasks (67% of interviews), confidence in the evaluations reached a level (consistently above 85%) that no longer necessitated a second coder for validity. All data measures collected, including those coded with and without the second coder, were included in later data analysis and discussion. Table 2 presents the coder agreement values through the sections of data analyzed by both coders.

Table 2 Second Coder Agreement

Data Category	Percent Double Coded	Codebook Category	Average Percent Agreement
Through-Task Journals	33%	Emotional Response	89%
		Attribution of Struggle	92%
		Attribution of Progress	97%
Student Interviews	67%	Emotional Response	88%
		Attribution of Struggle	91%
		Attribution of Progress	96%

3.8 Formation of Student Work Groups

The week prior to the first productive struggle lab task, the ITIS was administered to each of the 16 students enrolled in the Honors Engineering Principles course. The distribution of individual student data is displayed through raw scores in Table 3.

Table 3 Individual Student Initial ITIS Scores

Student Number	Initial ITIS Score	Mindset Category Grouping (ITIS Score Range)
1	2.83	Fixed n=5 (1.00-2.99)
2	2.83	
3	2.83	
4	2.83	
5	2.83	
6	3.00	Mid-Range n=4 (3.00-3.99)
7	3.67	
8	3.83	
9	3.83	
10	4.00	Growth n=7 (4.00-6.00)
11	4.50	
12	4.50	
13	4.67	
14	4.83	
15	5.00	
16	6.00	
Class Mean	3.88	n=16

Next, student individual scores were categorized using RAND Education and Labor's cutoff values for fixed and growth mindset scores on the ITIS instrument. Through this classification, scores of less than 3 were considered a fixed mindset while scores greater than or equal to 4 indicated a growth mindset. Any score that fell between fixed and growth was considered a mid-range score for the purposes of this study.

Initial student assessment scores from the ITIS instrument were used to form lab work groups for all productive struggle lab tasks. Following the protocol set forth in the previous chapter, students were distributed across the work groups in such a way that each group had relatively equal representation from all types of mindsets. Other than mindset, key factors in the thoughtful grouping of students included grade level of students and prior class experience in order to remain close to equal work groups with similar backgrounds and prior knowledge. Each work group had a similar breakdown of upper to lower classmen and students that had taken a physics course and students that had not. Experience in physics was identified as an important characteristic to consider in students as the high school's honors and advanced level physics curriculum often includes mechanical advantage, a concept used in the productive struggle lab tasks.

Additional attention was paid to student free block and lunch schedule to try to equally distribute students with strong growth or fixed mindsets to allow for interviews to be easily coordinated and conducted. As the class was fairly well split between fixed, mid-range, and growth minded students, the sixteen participants were placed into work groups by distributing students as equally as possible. Table 4 shows the distribution of mindsets across each student work group.

Table 4 Lab Task Student Work Group Breakdown

Work Group	Mindset Category n			Mean ITIS Score	Students with Physics Experience	Mean Grade Level
	Fixed	Mid-Range	Growth			
A	1	1	2	3.67	2	10.25
B	2	1	1	3.87	2	10.75
C	1	1	2	3.96	1	10.33
D	1	1	2	4.00	2	10.25
Class	5	4	7	3.88	7/16	10.5

While an effort was made to keep all work groups as equivalent as possible, it is important to note that this could not be achieved perfectly. Three of the four work group means fell into the mid-range category while the fourth group fell just on the threshold of a growth minded category. With one extra fixed minded individual to be placed in a group and one too few growth minded individuals to be equally distributed, the work groups were arranged as closely as possible. The working dynamics and identifying characteristics will be discussed in the next section.

3.8.1 Work Group Collaboration Dynamics

While observing student lab performance as well as while coding student journals and interviews, it became evident that each group worked under very different relationships and dynamics. A clearer picture of how each work group progressed through the productive struggle lab tasks becomes important in analyzing later data results. The following sections characterize the work habits and function of each student work group.

3.8.1.1 Work Group A: Conflict

Work group A demonstrated significant group cooperation issues on the very first productive struggle lab task dealing with wedge systems. In that lab task, the group split and submitted two separate final solutions. Student lab journals mention this issue at a variety of levels and from various viewpoints. Student 1 told of conflict from the very onset of the lab task in mentioning that, “The hardest part about this is finding a starting point we all feel confident working from.” Student 14, who eventually split from working with Student 1 on this lab task, provided an explanation for the split in sharing that, “I think that our group is thinking too much about unimportant factors. I went on a different track.”

In the student work journals and focus student interviews alike, this work group was the only one to attribute failure and struggle to group dynamics specifically. When split, the group did split based on grade level with underclassmen working collaboratively apart from the upperclassmen. Interestingly, this split kept students from differing mindset categories together. When asked about the work group divide during the post-task interview, Student 14 shared that, “the other two people in my group were focused on their own things. Like, I don’t know, we kind of went in separate directions and just kept working from there.” After this first lab task division, the group collaborated progressively better on each lab task in succession. While the only work group split occurred in the first lab task, group conflict comments in general continued to decrease with each lab task. As will be discussed in data analysis later, this work group was the only group to show a downward trend in mindset shift with three of the four student members reporting a lower final ITIS score than initial.

3.8.1.2 Work Group B: Trust

During the lab tasks, work group B seemed to be the most trusting of their fellow group members and the most hierarchical in idea presentation and acceptance. Student journals and interviews reflected on sections of the lab tasks where individual members were unsure of what to do but leaned into the discomfort by following the lead of their peers. With each lab task, the work group identified a new leader of ideas and trials who worked to move the entire group forward toward a presented solution. Many work group members also based their own confidence and understanding in comparison to the perceived confidence and understanding of their teammates. Student 3 reflected on the final presented solution in saying that, “I’m confident that it works, but I don’t understand it. Although, they don’t get it more than I do, so I understand it enough.” On the same lab task, student 16 reflected on the same solution in sharing that “then I realized even though I didn’t exactly understand how it was, I was kind of at the same point they were.” It is not that either student, on very different ends of the mindset spectrum, was fully confident in their answer, but rather they each found more understanding and confidence in a shared experience and communication with their group mates.

This level of trust during challenging lab tasks was also displayed through often dueling emotional statements reflecting on the good and bad feelings encountered throughout the lab task. During the final lab task interview, student 2 shared that “It was hard, so that’s why I didn’t like it, but I mean, that's supposed to be that way, but it was a good challenge." While the student shared discomfort in the lab task they trusted the process of learning through experience and struggle and in the end found positive in the challenge overall. This work group also contained the greatest spread in ITIS score with both the maximum ITIS score and one of the scores tied for minimum.

3.8.1.3 Work Group C: Leadership

Work group C contained a distribution of leadership categories that was identical to groups A and D. Despite these similar characteristics, this work group seemed to set itself apart through the clear development of a group leader, chosen because of his apparent intelligence. This work group gave the most reflections on their own level of intelligence in comparison to their leader. It is of note that the leader of this particular group takes very advanced coursework including college dual-enrollment and has skipped multiple grades over his educational career. This student held the median ITIS score for the work group, a mid-range category mindset. While others saw the student as the leader and a key source for progress, Student 9, himself, reflected on his lack of consistent confidence and understanding as well in sharing that "I don't know physics as well as I thought." immediately before reflecting that the solution "is consistent with different objects."

A perceived byproduct of the development of a clear group leader seems to have been the lack of confidence and positive feelings in the team mates that were not the identified leader. Student 13 reflected in his lab task journal that, "I feel like we're very reliant on [Student 9] because [Student 12] and I do not have any background in physics." Similarly, Student 12 shared that "I've also never taken a physics or chemistry class yet, so I feel like I'm no help." Surprisingly, both of the students who felt that they were less useful in the lab tasks fell into the growth mindset category based on initial ITIS assessment while the work group leader was in the mid-range group.

The impact of this leadership and collaboration will be discussed later when final ITIS scores are considered.

3.8.1.4 Work Group D: Lightheartedness

Work group D held the highest mean ITIS score and was the only student work group to represent a growth mindset category score, albeit containing a student tied for the lowest possible growth mindset score. This work group seemed to be the most lighthearted and accepting of challenge despite still acknowledging the issues and challenges that they encountered in the lab tasks. The work group often presented both the problem as observed as well as their reasoning behind why this was an issue. Student 7 demonstrates this in sharing that, “This is going to be challenging. I’m confused why our first number is more than the second number because the first calculation should have less weight because it is a smaller angle.” On each of the three lab tasks, at least half of the group provided statements explaining a problem and providing a basis for why this was expected or not.

While being very thoughtful in their reasoning, this work group used the most humor in their student work journals. Student 11 shared in one such instance that, “my thinker is starting to hurt. Also, [Student 15] is scared of tape measures.” The jokes, off topic statements, and good-humored responses occurred in more than half of the group journals regardless of the surrounding statements considering progress or struggle. In spite of this evidence of good teamwork, thinking, and learning, this work group also demonstrated the least lab task persistence as they failed to present a final solution on two of the three lab tasks. While this group was not the most successful in task solution nor the most positive in personal emotional reflection, members were the most positive in their social interactions during the lab task struggle and challenge.

4.0 Results

The data analysis presented in this section supplies the supporting evidence used to answer the inquiry questions of the research. Each of the following sections will address one of the primary inquiry questions presented earlier. The data will be analyzed at various levels and comparisons including individual, work group, and whole class-level analyses. Section 4.1 focuses upon the overall relationship between productive struggle support in classroom environments and possible shifts in student mindset. This section will primarily use data collected through use of the Implicit Theories of Intelligence Scale (ITIS) to look for changes in student thoughts toward their own intelligence. Section 4.2 analyzes teacher productive struggle support through the lens of student attribution of errors and struggles in completing the lab task at hand. This involves analysis of the internal and external reasons students provide for encountering challenges. Finally, section 4.3 addresses the ways that teacher support through productive struggle classroom experiences impacted student academic progression through lab tasks. This analysis will include student emotional progression through productive struggle lab tasks and the final solution provided by the work groups.

4.1 Relationship between Productive Struggle and Student Mindset

The first inquiry question of the research asked, “What relationship exists between student exposure to supportive productive struggle learning environments and possible shifts in student mindset?” In order to address a possible relationship between the two variables, a quantitative statistical analysis was performed of whole-class pre- and post-task assessments of student mindset using the ITIS. Additionally, descriptive analysis of mindset changes by initial student mindset groupings and student work groups were considered. Descriptive statistics were used in subgroup data analysis as the student population size was not adequate to perform full quantitative statistical analyses.

4.1.1 Mindset Changes in Whole Class Set

The pre and post-task ITIS scores and shift for all sixteen participants are displayed in Table 5 as well as displayed graphically in Figure 7.

Table 5 Comparison of Change in Individual ITIS Scores

Student Number	ITIS Score		
	Pre	Post	Change
1	2.83	2.17	-0.66
2	2.83	3.67	+0.84
3	2.83	3.33	+0.50
4	2.83	3.17	+0.34
5	2.83	4.33	+1.50
6	3.00	3.17	+0.17
7	3.67	4.17	+0.50
8	3.83	4.00	+0.17
9	3.83	4.50	+0.67
10	4.00	3.50	-0.50
11	4.50	5.33	+0.83
12	4.50	4.50	0.00
13	4.67	5.00	+0.33
14	4.83	4.50	-0.33
15	5.00	5.50	+0.50
16	6.00	6.00	0.00
Class Mean	3.88	4.18	+0.30

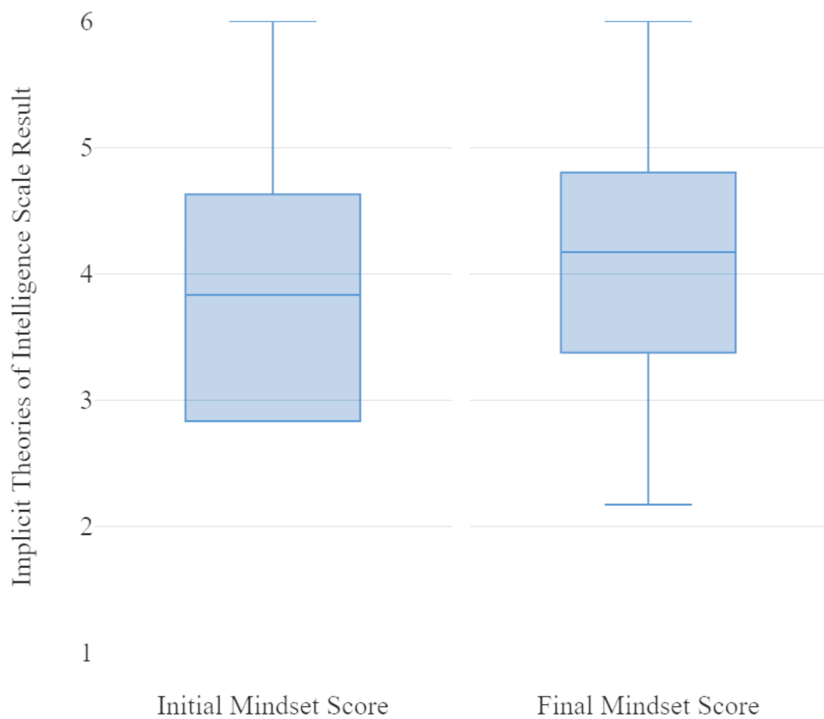

Figure 7 Box Plot of Initial and Final Student ITIS Scores

As can be seen in the Figure 7 box plot above, which presents pre-task above post-task scores, student scores increase in range after the productive struggle experiences but the general trend is toward a more growth mindset approach. While the minimum decreases, all other quartile values increase. While the range of overall data values increases, more scores shift in a positive rather than negative direction. The maximum remains the same as it was already at the maximum score possible on the ITIS. Additionally, the increase is smaller at higher score levels than it is at lower ranges. The first and second inter-quartile ranges shift much greater than the third or fourth inter-quartile ranges shift.

Analysis was performed at the student work group level as well as the individual-student level based on pre-assessment mindset. This analysis was further deepened and contextualized through supporting details gained through focus interviews with four students. The ITIS data indicates a shift in the positive direction after exposure to supportive productive struggle. As will be discussed in detail in the following sections, the data does provide evidence of a relationship between continued teacher support through productive struggle experiences and positive shifts in student mindset toward intelligence.

Table 6 contains a comparison of the measures of central tendency of ITIS scores before and after teacher support of productive struggle in lab tasks.

Table 6 Comparison of Class ITIS Score Measures of Central Tendency

	Pre-Productive Struggle	Post-Productive Struggle
n	16	16
Mean (sd)	3.88 (.98)	4.18 (1.00)
Median	3.83	4.25
Minimum	2.83	2.17
Maximum	6	6

Through first taking a descriptive approach to data analysis, initial data suggest that a change in student mindset did occur through comparing ITIS score measures of central tendency before and after the productive struggle lab tasks. Not only did overall work group mean and median increase but the standard deviation between periods remained relatively unchanged. In order to determine if the change that occurred is meaningful and establish confidence in that finding, the shift was made from analysis through descriptive statistics to inferential statistics and tests of statistical significance.

A t-test was calculated for the 2 dependent means considering a two-tailed hypothesis at the $p=0.05$ level. For the whole class set, the t-value for the test between pre-and post-task ITIS measures was 2.23 with a p-value of 0.04. This statistical test shows that the difference in ITIS mindset scores before and after continued teacher support through classroom productive struggle lab tasks is statistically significant at the .05 level.

Once determining a statistically significant change in student mindset, the size of the change was considered through calculating the t-test effect size. Based on the pre- and post-task ITIS score means and standard deviations, Cohen's *d* was determined to be 0.31. This value suggests a small to medium effect on the overall population (Cohen, 1988). While this means that differences may not be noticed in passing, even a small to medium size effect on something as impactful as student mindset is significant in impacting their view towards themselves as a thinker and learner.

4.1.2 Mindset Changes by Initial Mindset Category

The next level of data analysis dealt with the changes in student mindset after in-class productive struggle support based upon student groupings by initial mindset assessment scores. Due to the whole class set of 16 participants being split into three different subgroups, each subset of data points was too small to test for significance using inferential statistics. Using descriptive statistics and analysis of the measures of central tendency, it is evident that each mindset grouping did show a positive trend after the productive struggle lab task engagement. Table 7 presents the measures of central tendency for student ITIS scores based on initial student mindset prior to the productive struggle lab tasks.

Table 7 Comparison of ITIS Scores by Mindset Category

Initial Mindset Category	n	Measure	Initial	Final	Change
Fixed	5	Mean	2.83	3.33	+0.45
		Median	2.83	3.33	+0.42
		Min	2.83	2.17	-
		Max	2.83	4.33	-
Mid-Range	4	Mean	3.58	3.96	+0.38
		Median	3.25	4.09	+0.84
		Min	3.00	3.17	-
		Max	3.83	4.50	-
Growth	7	Mean	4.79	4.90	+0.12
		Median	4.67	5.00	+0.33
		Min	4.00	3.50	-
		Max	6.00	6.00	-

All three initial mindset groupings show positive shifts in measures of central tendency including mean and median. This change is greater in the fixed mindset group (mean shift of 0.45) than in the growth mindset group (mean shift of 0.12) which may be due to the growth mindset individuals having less possible increase as they were already toward the top of the instrument scale. It is important to note that no group shifted in a negative direction in any of the statistical measures. It is also important to note that while these patterns and shifts are consistent for all three initial mindset groupings, the same does not hold true for each and every student. As seen at the whole class and individual group level analyses, some individual students did show negative shifts in mindset scores. Of the 16 participants, 3 scored lower on their post-task than pre-task assessment. Table 8 shows the shifts in mindset scores as related to the overall category ranking of students prior to the productive struggle lab tasks.

Table 8 ITIS Mindset Category Shifts

Initial Mindset Category	Pre-Task ITIS n	Post-Task Score Category	Post-Task ITIS n
Fixed	5	Fixed	1
		Mid-Range	3
		Growth	1
Mid-Range	4	Fixed	0
		Mid-Range	1
		Growth	3
Growth	7	Fixed	0
		Mid-Range	1
		Growth	6

Pre-task and post-task scores were also analyzed to look for shifts that had occurred in student grouping categories. Beyond shifts in individual scores or means, it is notable to consider the number of students that shifted mindset categories after teacher support during productive struggle lab tasks. Only 1 of the 16 participants displayed a negative shift in mindset category after the productive struggle lab task work. Half of the participants moved up one category in mindset scores including one participant that made the leap from a fixed directly to a growth range mindset score. Six of the seven students that remained in the same category did so after having begun the study in the growth mindset category.

4.1.3 Mindset Changes by Student Work Group

The final analysis category for student pre- and post-task mindset scores considered student work group during the lab tasks. The productive struggle lab tasks were highly collaborative in nature and forced students to interact at all stages of problem-solving. Due to this collaboration, my hypothesis was that trends may exist in mindset shifts based on student work group. Table 9 represents the change in mean mindset scores by work group before and after teacher support of productive struggle.

Table 9 Comparison of ITIS Scores by Work Group

Work Group	Group ITIS Score Mean		
	Initial	Final	Change
A	3.67	3.33	-0.33
B	3.88	4.25	+0.38
C	3.96	4.29	+0.33
D	4.00	4.83	+0.83

Three of the four work groups showed a positive mean shift in student mindset scores. In analyzing similarities present in student journal academic work and final presented solutions, it was evident that students worked in close collaboration and discussion with their group mates. This was also evident in my own observation of student work time during tasks. While groups B, C, and D all had each of the four student members shift positively in their initial to finial ITIS score, work group A did not show that same result. The breakdown of Group A individual student ITIS scores is shown in Table 10.

Table 10 Shift in ITIS Scores by Work Group A Students

Work Group A Student Number	ITIS Score		
	Initial	Final	Change
1	2.83	2.17	-0.67
6	3.00	3.17	+0.17
10	4.00	3.50	-0.50
14	4.83	3.67	-0.33

Three of the four students in work group A showed a downward pattern in ITIS scores with the lone positive shift student showing the smallest incremental increase in mindset of any of the 16 participants in the class.

In considering the shifts in mindset by work group, it is important to consider the working dynamics of each group. While a more detailed narrative of work group dynamics is presented in Chapter 3, Table 11 provides a summary of difference between work group supported by student quotes from interviews and student journals that are representative of the group as a whole.

Table 11 Work Group Dynamics Presented Through Student Quotations

Work Group A **Conflict**	**Work Group B** **Trust**
• Characterized by the group conflict that caused split in one task and lesser problems in later tasks • "The hardest part about this is finding a starting point we all feel confident working from." • "I think that our group is thinking too much about unimportant factors. I went on a different track."	• Characterized by trust in group mates in developing different lead for each task • "I'm confident that it works, but I don't understand it. Although, they don't get it more than I do, so I understand it enough." • "Then I realized even though I didn't exactly understand how it was, I was kind of at the same point they were."
Work Group C **Leadership**	**Work Group D** **Lightheartedness**
• Characterized by mutual agreement on one leader for all three tasks based on perceived intelligence and ability • "I feel like we're very reliant on [Student 9] because [Student 12] and I do not have any background in physics." • "I've also never taken a physics or chemistry class yet, so I feel like I'm no help."	• Characterized by positive and humor-based social interactions in the face of difficulty and struggle in tasks • "My thinker is starting to hurt. Also, [Student 15] is scared of tape measures." • "This is going to be challenging. I'm confused why our first number is more than the second number because the first calculation should have less weight because it is a smaller angle."

As discussed in the methods section and revisited in the table above, work group A was the only one to split during any of the lab tasks due to group dynamic conflict. The group members felt as though a divide existed in where to start and how to solve the problem which resulted in the group dividing into two sub-groups. Each subgroup presented their own solution to the first lab task. Beyond the first lab task, the work group worked together on each successive lab task. It is important to note that this was the only work group to contain journal segments that attributed error or struggle to group or peer conflict while working on the lab task. The work group was also the only group to have group members present differing solutions on any of the lab tasks.

In addition, individual interviews provided further insight into the thoughts and decision-making of these students beyond the student conflict. During the final interview with Student 1, she reflected on the biggest difficulty encountered in the challenge in sharing that "we focused less on what we could have been doing and more on what we thought we should have been doing which was just not helpful to us. But it was really just the fear of being wrong that barricaded us a little bit." This thought is echoed in the interview with Student 14 sharing similar avoidance of taking too much time on unsuccessful or incorrect attempts. While it is unclear which, if either, of these factors impacted the results of this work group in particular, it is likely that either avoidance or teamwork conflict could have impacted the student experience during the productive struggle challenges.

The first inquiry question dealt with the impact that supportive productive struggle experiences may have on student mindset. Through analysis of pre-and post-tasks administration of the ITIS, there is data to support the conclusion of a relationship between the two variables. Analysis at the work group level showed movement toward a growth mindset in all but one student work group. The data suggests that the negative shift in mindset of work group A was due to the conflict that occurred between group members while solving the task problems. Rather than collaborating and engaging in productive struggle, students split their work group and became focused on an end solution rather than learning from their moments of impasse. Additionally, a statistically significant ($p=0.05$) change in mindset occurred at the whole class level after continued support through productive struggle lab tasks.

4.2 Attribution of Struggle

The second inquiry question asked, "How does teacher productive struggle support impact student attribution of impasse points in learning?" This question was determined through a qualitative analysis of differences in external as opposed to internal blame for student struggle in achieving the assigned lab task as demonstrated by students in their through-task journals. Analysis was performed at the student work group level as well as the individual-student level based on pre-assessment mindset. The student journal data analysis was further contextualized with supporting details gained through focus interviews on four students.

As will be discussed in detail at both analysis levels, the data does not support the conclusion of a relationship between teacher support of productive struggle and a shift in student attribution of struggle and errors in the problem solving process. While minor changes occur in error attribution, there is insufficient data to suggest a clear connection between the two elements.

4.2.1 Internal Versus External Attributions by Student Work Group

When analyzing the data for shifts in student attribution for error or struggle in completing the assigned productive struggle lab tasks, the first level of analysis occurred based on student work group. As stated earlier, it was important to consider trends in data based on grouping since so much of the learning and classroom experience was collaborative and tied to the other members of the work group.

Each student-supplied reason for failures or struggle in the assigned lab task was coded as either being an internal or external contributing factor. The literature review suggests that students that possess growth mindsets will also be able to attribute their issues to intrinsic factors such as a lack of knowledge or understanding. This aligns with prior research regarding the theory of impasse points being the most powerful part of learning through struggle as students are identifying the key information needed before progressing through new learning and skills. Table 12 presents the percentage of student error attributed to internal factors through the lab task journals collected.

Table 12 Percent of Internal Error Attribution by Work Group

Work Group	Percentage of Internal Error Attribution			
	Lab Task 1	Lab Task 2	Lab Task 3	Overall
A	33%	47%	42%	41%
B	67%	78%	57%	68%
C	80%	81%	57%	76%
D	100%	71%	33%	67%
Class	70%	72%	48%	65%

With the exception of group D, all work groups started with a lower percentage of internal rather than external error attribution in lab task 1 and increased in lab task 2. After the increase in lab task 2, however, the percentage of internal attribution for struggle either stayed the same or decreased during the final lab task. Even though each student submitted an individual work journal from the lab tasks, academic work and final solutions were nearly identical across members of the same work group. In work group C, for example, student 4 shared the feeling that, "the wording is distracting from the actual problem. I don't understand what we're supposed to solve." In the same work group and lab task, student 13 stated, "I wish it was less vague than 'efficient and effective'." Both of these students reflect on errors caused by an external factor, the lab task prompt. Rather than blaming their struggle on a lack of prior knowledge or understanding of the concept, both students reflected on issues in the vagueness of the prompt.

Many students within a variety of work groups blamed a lack of progress on a lack of prior knowledge, specifically a lack of experience in other course areas. As previously stated, experience with physics, specifically, was taken into account when forming student work groups. Student reflections of error often cited experience or a lack of physics knowledge for struggle and challenges that arose during the lab task. Student 14, for example, shared in the focus interview, "I'm assuming neither of them has taken physics or if they are past geo-trig or algebra 2. So, just from me taking more classes, I think we should have used sine and cosine more." In a similar vein, many students showed more internal attribution of error in the second lab task, the lever problem, due to a perceived higher understanding of the lab task context of levers. One participant, Student 11, even reflected on the problem after reading the prompt by simply saying, "Yay, levers!" When less confusion existed around the lab task context and description, students showed a much higher focus on internal factors that led to errors rather than blaming the lab task or their work group.

In analyzing student comments at the work group level, it seems more likely that the internal versus external attribution for error was based on student prior knowledge, experience, and awareness with the principles involved than a change in mindset caused by support across the productive struggle lab tasks. Student internal attribution comments were often based on recalling knowledge from other areas or recognizing value in a course that they needed to solve the lab task.

4.2.2 Internal Versus External Attributions by Initial Mindset

The second phase of analysis for inquiry question 2 involved grouping the students by initial ITIS score rather than by student work groups. Table 13 presents the percentage of student error attributed to internal factors sorted by initial student mindset.

Table 13 Percentage of Internal Error Attribution by Mindset Category

Initial Mindset Category	Percentage of Internal Error Attribution			
	Lab Task 1	Lab Task 2	Lab Task 3	Overall
Fixed	40%	53%	38%	44%
Mid-Range	60%	67%	67%	65%
Growth	92%	79%	54%	75%

Similar to the first analysis by work groups, no clear patterns emerged over progression through the productive struggle lab tasks. When looking at the overall attribution by mindset, the growth minded students were more likely to internalize errors while fixed mindset students were more likely to blame external factors for their challenges. Table 14 presents quotes from student interviews that reflect differences in error attribution.

Table 14 Student Error Attribution Interview Responses by Mindset

Students were asked to reflect on the most difficult aspect of the first productive struggle task.	
Student 1 Fixed Mindset Group A	Student 16 Growth Mindset Group B
"Probably just the overall feeling if there was no way that any of this can be right because it's set up for it not to be right to be a new thing that you have to struggle through."	"I struggled to combine all of the different variables like the force, the angle, the length of the knife or just the size of it. How to combine all of those and get just one equation."

This finding becomes even more evident when contrasting specific student reflections about errors. The fixed mindset student was so narrow minded in the lab task that she felt as though she were being set up to fail from the start. All of her errors reflected back on being part of a trap in a lack of possibility to solve the problem in the first place. On the opposite end of the mindset spectrum, the growth mindset student's attribution is vastly different as it first lays out all of the information that he does hold about the lab task and problem at hand. He then states where his knowledge is no longer sufficient to make progress in that he knows he is trying to form one final equation but is not yet sure how the variables interact to form one relationship.

At both the mindset and work group levels, error reflections shifted between internal and external attributions at different times across tasks. This can also be seen by following the attributions of one particular student across tasks. Table 15 outlines attributions provided by Student 6 in work group A across all three lab tasks.

Table 15 Student Error Attribution Shift Across Through-Task Journals

Student 6 Mid-Range Mindset Group A	
Task 1	"I think one of the hardest parts about this is finding a starting point we all feel confident working from. We don't have time to deliberate and still finish"
Task 2	"The focus seems right, and we have measurements, but we need to make sure our lever stops flexing under the weight because that will mess up our numbers."
Task 3	"The task should be less vague than 'efficient and effective', that is not a tangible goal."

As can be seen in Table 15, Student 6 begins by reflecting on two external factors including group conflict and time limits placed on the tasks. On the next task, the error attribution shifts to positive, internal factors with the focus moving toward the specific flex in the materials used in the student-created model. This shows the student making clear connections to specific issues in their own design and construction that need resolved before moving forward. However, in the third and final task of the study, Student 6 reverts back to external attribution of error in placing blame in the wording of the task rather than specific pieces of knowledge needed to succeed. Similar shifts to and away from internal attributions occurred at both the group and mindset level analyses.

In conclusion, while student attribution of error and struggle appears to be connected to student mindset, it is not clear what effect, if any, teacher support in productive struggle situations may have on changing error attributions. There are a number of reasons why these results may have occurred. One possible reason for a lack of clear trends in the data is the matter of students reflecting on errors individually without communicating with the group. This means that student prior experiences and noncognitive factors of individual students would have had an even greater impact on their attribution of error than that of teacher support. An additional possibility for the lack of pattern in data could be that students reflected specifically on the context of the tasks rather than the overall difficulty that was experienced during the struggle. Reflecting only on errors caused by the specific task context naturally would have caused more external task-related attributions than internal knowledge-based reflections. These possibilities and the research findings will be further explored and connected to the prior literature during later discussion. Overall, the lack of consistent shifts in internal versus external error attribution across the tasks does not support the existence of a relationship between continued teacher support of productive struggle and more positive, internal attribution of error in students.

4.3 Academic Progression through Lab Tasks

The third inquiry question was, "How does teacher productive struggle support impact student academic progression through challenging tasks?" The answer to this question was determined through a qualitative analysis of student emotional responses in through-task journals as well as through teacher assessment of each student's final presented solution. This analysis is further described through the use of student quotes and examples from both the journals and student interviews conducted.

4.3.1 Emotional Cues Presented Through Lab Tasks

One key component of coding the data from the through-task journals completed while solving the problems was considering the emotional cues presented from students. These cues included both positive and negative feelings toward completing the assigned lab task. While reviewing student journals and interviews, emotional responses to the progression through problems were coded as either positive or negative. Positive emotions included student expressions of excitement, confidence, and embracing of the lab task challenge. Negative student emotions included frustration, anger, desperation, or conflict. The emotional reactions presented in through-task journals were then tallied to determine whether students expressed more positive or negative emotions while completing the lab tasks. Table 16 presents the percent of student positive emotions that were presented in student journals by lab work group.

Table 16 Percentage of Positive Emotional Cues by Work Group

Work Group	Percentage of Positive Emotional Cues			
	Lab Task 1	Lab Task 2	Lab Task 3	Overall
A	22%	30%	54%	33%
B	57%	58%	50%	56%
C	0%	53%	47%	38%
D	20%	17%	69%	36%
Class	22%	37%	55%	39%

The collected data at the class level showed some progression across the lab tasks toward more positive emotional reactions to productive struggle lab task work. While engaging in the first task, only 22% of student emotional responses focused on positive reactions. One of the student groups exclusively reflected on negative emotions experienced in the task. This ratio shifted toward more positive emotions in each lab task thereon with reported emotions being 37% and 55% positive in the second and third lab tasks respectively. It is not until the final productive struggle task that the majority of emotion responses becomes positive. While this statement holds true when looking at the class as a whole, not every work group showed the same clear pattern of shift in student emotional focus. Six out of the eight members in groups A and D did show individual sizable shifts toward more positive emotional response during the third task. The final student in each group remained fairly consistent throughout all tasks. This mirrors what will be discussed later at the mindset category level analysis. Group C shared similar results where during the second task, every group member's positive response shifted greatly before remaining consistent in the third task. The final group, B, stayed fairly consistent in their emotional response across all three tasks.

The next level of analysis, presented in Table 17, considered the percent of positive emotional reaction to the productive struggle experiences based on initial mindset grouping.

Table 17 Percentage of Positive Emotional Cues by Mindset Category

Initial Mindset Category (number of students)	Percentage of Positive Emotional Cues			
	Lab Task 1	Lab Task 2	Lab Task 3	Overall
Fixed (n=5)	21%	40%	58%	42%
Mid-Range (n=4)	20%	64%	67%	56%
Growth (n=7)	24%	26%	48%	32%

The 16 students involved in the study were broken into subcategories of 7 growth mindset, 5 fixed mindset, and 4 mid-range mindset individuals. While all three mindset categories showed changes in emotional responses that shifted progressively toward positive thoughts and feelings, the five students that began the study with a fixed mindset showed a more consistent shift in response from that of negative to more positive emotions over the course of the lab tasks with teacher productive struggle support. For mid-range and growth mindset groups, it seems that each group made the shift in embracing the experience as positive at different points in the overall study. The mid-range group shows the largest shift during the second task while the growth mindset students make that shift during the third and final task. This may have occurred in this way as students in the fixed mindset collaborated with more growth mined students, the shift occurred earlier while the growth mindset students took longer to experience the shift in emotions on their own. It is possible the perceived shifts in emotion occurred because of the collaboration with other work group members rather than productive struggle support from the teacher.

Analysis of individual student comments on lab task journals and interviews does mirror the findings that emerge from the data coding. At the individual level, progression toward more positive emotional reflection between the first and third lab tasks occurred for 13 of the 16 student participants. Student 3, specifically, who tied for lowest ITIS score shows improvement over time as seen in Table 18.

Table 18 Student Emotional Response Shift Across Student Through-Task Journals

Student 12 Fixed Mindset Group C	
Task 1	"I feel even more dumb doing this task."
Task 2	"This just frustrates me because I have no clue what to do and I feel angry."
Task 3	"It turns out I have good ideas sometimes, I am excited that our idea works even if it might not be the most efficient."

On the first lab task, the student reflected with negative cues on an overall assessment of her own intelligence and ability. Not only does this show negative self-talk from the start, she shares the common fixed belief that only certain lab tasks or behaviors will showcase student intelligence while others will highlight inabilities and shortcomings. Later, in the second lab task, she again shares a negative emotional response, but her self-dialogue has shifted from her feeling as though she is not smart to feeling frustration about a lack of progress. It is a small forward step but one that is even more amplified in her final lab task journal. During the third lab task, towards the end of her journal, Student 3 shows a drastic emotional shift toward excitement in the task and her own ability. She even takes partial ownership of the final solution, one that is the correct answer to the lab task problem.

One important finding in both student journals and interviews is the amount of reflections that included both positive emotions and acknowledgement of the challenge and rigor of the lab task. Table 19 provides examples of these mixed emotional responses to the tasks.

Table 19 Student Mixed Emotional Responses to Task Difficulty

Fixed Mindset Group C	"This is fun. I think we did it. This is hard."
Growth Mindset Group D	"This is fun but kind of annoying. This is a hard challenge."
Growth Mindset Group B	"I kind of liked how, I mean I didn't but it was kind of good that we had to like really figure out how to get started, because, I mean that's how you kind of have to solve a lot of problems in life."
Fixed Mindset Group B	"I was kind of confused and frustrated, but I figured that it wouldn't be that bad because we had like everywhere in the world we could have gone with it. So I was kind of like confused but I started to think through and got mostly optimistic about what we could do."

This duality outlined in Table 19 was seen both through-task journals and post-task interviews. These mixed emotional reflections occurred in five of the seven growth mindset students as well as two of the four fixed minded individuals, including one tied for lowest ITIS score, also shared similar views. While frustration and confusion were coded as negative emotions in the coding framework, they are relatively healthy reaction to the when combined with student recognition of the rigor of the challenge and determination to solve the problem.

The data collected in the study does show a more positive student reaction to challenge and struggle as a result of continued teacher support during productive struggle lab tasks. While solving the complex, ill-structured problems, each and every student involved reflected on both positive and negative feelings used in completion of their group work during at least one of the three lab tasks. Both the whole class, and individual mindset-based groupings showed progress in each lab task toward more positive emotional response while progressing through the lab task.

4.3.2 Presentation of a Final Solution

Another important aspect of determining student academic learning through the lab tasks is considering whether or not student work groups were able to present a final solution. Not only does this lend itself to understanding if students had a base level of understanding what they were observing and modeling, it also shows student perseverance through the lab task toward a final solution rather than giving up when the lab task got challenging or difficult. This comparison of confidence-based emotional cue data and interview reflection on final solutions looks to analyze the ability of the work groups to continue through the challenge toward development of a final solution.

For each work group and each lab task, with the exception of one work group in one lab task, final solutions were identical across individual group members. Final solutions and the overall success of the problem solving strategies of work groups during the lab tasks varied from one activity to the next. On the first task, no work groups presented a correct solution to the lab task, quitting before reaching a final solution either due to frustration, time constraints, or a feeling of hopelessness towards reaching a conclusion.

During the first lab task, a student in Group C reflected that, “I don’t see how this is solved and I stopped caring. I feel dumb because I have no more ideas and can’t seem to find an equation.” During the same lab task, a student in Group A shared, “We just threw numbers and letters together. I’m not confident at all because it is completely made up.” Persistence through challenge was not evident through the first lab task in which only one work group presented a final solution to the problem.

In the second lab task, all four student work groups came to a conclusion on an equation to solve the problem. Student reflections on their final solutions shifted drastically after the first wedge-based lab task. A student in Group B shared skepticism toward the simplicity of the solution in the second lab task in sharing that, "I'm not very confident because it is very low level math. It seems too easy." This student shared their perspective that a challenging task must also have a complex solution rather than a relatively simple one. The student began to question their own assumptions while engaging in the second task.

On the third and final lab task, one work group quit before reaching a conclusion while the other three work groups provided final solutions. Student thoughts toward their own solutions became increasingly more confident as well as more based on observations and findings. A student in Group D shared that, "I am somewhat confident but it still bothers me that we couldn't get the equation to work for the last situation." Another student in Group D shared that, "I am fairly confident because it worked perfectly across almost every trial that we set up." The solutions were based on clear observations and began to hold confidence rather than quitting or guesswork.

In situations where work groups or individuals were unable to form a conclusion or solution to the problem, significant shifts occurred in student emotional reflection over the course of the productive struggle lab tasks. In the first lab task, 10 students were unable to present a final solution to the problem. Of those 10 students, 8 reflected only on feeling negative emotions during the class period. Later, in the final lab task, four students were unable to present a final solution. All four of these students were also unable to do so in the first lab task. However, during the final lab task, all of the students reflected on at least one point of positive emotion including one of the eight students who failed to do so in the first lab task. Moreover, one of those four unsuccessful students reflected only on positive emotions rather than sharing mixed or negative. While it is not conclusive that student emotions during new learning experiences are altered by teacher support of productive struggle, these findings may suggest that student outlook and reflection on the value of the learning may be changed through this teaching and learning approach.

4.3.3 Accuracy of Presented Solution

The final piece to understanding whether or not students learned new skills and concepts through the teacher support during productive struggle lab tasks is considering whether the final solution presented by students was an accurate solution for solving the problem. It is important to consider that answer accuracy is only one method of measuring student learning of new skills and information. While there are a variety of methods of assessment, including focusing upon process rather than end result, the final solution was chosen as a useful assessment in this research to determine student learning as a result of the productive struggle process that had been supported and analyzed. While most engineering curricula will present one formula for calculating mechanical advantage in different simple machine configurations, it is important to also recognize the value in a variety of formulas and equations that will also solve the problem at hand through alternate approaches. Table 20 displays the accuracy of the final solution presented for each lab task by the student work group.

Table 20 Accuracy of Final Solutions by Work Group

Work Group	Lab Task 1	Lab Task 2	Lab Task 3
A	Incorrect	Correct	Partially Correct
B	Incorrect	Correct	Correct
C	Incorrect	Correct	Partially Correct
D	Incorrect	Incorrect	Incorrect

During the first productive struggle lab task, none of the work groups presented a correct solution to the problem. As outlined in the methodology section, an incorrect code was assigned to both incorrect solutions and incomplete solutions. The second lab task, the lever problem, was the most successful for all work groups. One group provided an incorrect equation to the problem while all three other work groups presented accurate solutions to the lab task. Finally, on the third lab task which dealt with inclined plane systems, one group provided an incorrect solution, one group provided the accurate equation, and two other work groups provided partially correct solutions. The two partially correct solutions set up an accurate equation but added an efficiency constant to match their observations and measurements recorded from their model. While these constants are not part of the actual equations for mechanical advantage of a simple machine, they are accurate in calculating the actual rather than ideal mechanical advantage of the systems in the word problems provided.

An important piece of overall data analysis regarding student academic progression is that success on the lab tasks did not necessarily correlate to higher changes in student mindset. Group D, the student work group that never came to an accurate conclusion for any of the lab tasks, also represented the highest individual student change in mindset as well as reporting all four student mindset scores shifting positively and the overall group mean shifting by more than any other student work group. Group A, a work group that correctly solved one lab task completely and one lab task partially, represented changes in student mindset that were inconsistent from student to student with three of the group members mindset scores shifting negatively and was the only work group to show a negative shift in mean mindset. This finding suggests that success or immediate gratification during the lab task may not be the driving factor in shifting student mindset through productive struggle experiences.

The final inquiry question dealt with the impact that supportive productive struggle experiences may have on student progression through lab tasks. Through analysis of student through-task journals and structured interview responses, no clear relationship was found between a series of productive struggle lab tasks and student persistence through lab tasks or an increase student success in solving complex problems in the lab tasks. Data analysis did reveal that shifts toward a more positive outlook on classroom experiences and shifts in mindset occurred regardless of student success in presenting a final solution.

4.4 Teacher Role in Productive Struggle Lab Tasks

Upon data analysis determining that changes occurred in some student noncognitive factors after the supported productive struggle lab tasks, it was essential to remain clear on the focus of the study. While the lab tasks are important and meaningful by themselves, the goal was to determine the importance, value, and impact of teacher guidance and support through challenging lab tasks. In order to accomplish this, lab tasks were adjusted using the action research cycle (plan, enact, reflect) not only in student-facing materials but also in the plan of action that would be used by the teacher. Additionally, while the role of the teacher and the role of the lab task is difficult to separate in student work journals, more attention was paid to the impact of the teacher on student outcomes through student focus interviews.

4.4.1 Action Research Planning and Reflection

The teacher journal completed throughout the lab tasks served as a key collection of observations, noticings, and additional student quotes collected while in the act of teaching and supporting students through challenging activities. In addition, this journal served as a key piece in making changes as part of the action research design. Not only were student data collection instruments, but also teacher observations and reflections were used in determining improvements to make between each productive struggle lab task. For example, when observations on the first lab task included students becoming fixated on the material provided and unsure what other materials were available, I made effort to organize and make the most usable materials more readily available to students in accessible lab areas. On later lab tasks, material-based distractions were not seen in journals or interviews.

While some error and difficulty was expected, it seemed as though students struggled more with the lab task and materials than they did with content or problem solving. One student reflected that, "I had no idea where to start because it was like cutting cheese. Like I don't know where you start to make an equation for that." Another student shared that, "I didn't know what factors we needed to include or like what different things we needed to focus on to make an equation for cutting cheese." While the piece of string cheese was provided as part of the context for the wedge mechanical advantage problem, many students got overly focused on the mechanics of cutting the string cheese itself rather than observing and calculating the mechanical advantage gained. 12 of the 16 students directly referenced the string cheese in a struggle-based statement in their journals rather than discussing the wedge system as a whole. Based on my own observations during the task, much of the work group conversations focused upon ways to cut string cheese rather than shapes, devices, and mechanisms that utilize a wedge system at some point in problem solving.

The decision to provide the string cheese to student work groups was made in order to maintain context and real life application to the productive struggle lab task. Seemingly, rather than make the problem more approachable, the material became a barrier that students needed to overcome in observing the work performed by the wedge. This may have occurred because the use of the string cheese in measuring mechanical advantage of a wedge was aligned with the teacher's thought processing rather than that of the students. In order to combat this misalignment of approaches, in future tasks I stopped providing students with specific context-based materials. Instead, I allowed students to utilize any materials in the laboratory environment to create their own models or visualizations of their solution.

In addition, when students reflected on specific teacher tips and ideas as being the reason for progress on the lab task, I shifted support toward more probing guidance and questioning techniques. This was done in reflection on the Warshauer (2015) study which highlighted the importance of aligning with student thought processes and minimizing the insertion of the teacher's own ideas. In work group B specifically, both interviewed students reflected on teacher input as a key reason for progression through the lab task. Student 2 shared that the teacher "suggested using the tare thing for the wedge and the cheese. We didn't know what to do next." Student 16 also reflected on the same issue in stating that the teacher "helped us out when trying to show that the weight might not have affected the overall force needed so you helped us by showing that we should be taring the weight of both the cheese stick and the weight of the wedge." While this was presented as a suggested tip for moving forward with measurements and modeling, both student responses point toward the guidance as a key moment in their progress rather than student ownership of solving the problem on their own which would be the ultimate goal of productive struggle. On the second productive struggle lab task, I made a more conscious effort to provide probing question-based guidance rather than direct suggestions or problem identification.

After the second lab task, my own teacher responses and student journals both focused much more on student-aligned solution strategies and problem solving attempts. Additionally, each work group's individual model of the problem varied much more than the first lab task. Students were no longer focusing on provided materials and supports and rather thinking in more open terms and lab task prompts that led to multiple approaches to the same problem. Student reflection of the lab tasks also mirrored the goal of less teacher-aligned thinking and directing. When asked if he was directly supported by the teacher, Student 16 shared that "You helped us but you kind of let us try to figure it out as well. You said there was more than one solution, so it made us look for something that worked instead of like the single solution." This acknowledgement of many possible solutions supports the belief that students no longer saw a single approach to a solution as well. Without the observation of student disconnect to the support provided or student reflection on key moments of teacher input, very little adjustment was made to the teacher support strategy between the second and third productive struggle lab tasks.

The main focus entering the third productive struggle lab task was to provide students the time necessary to grapple with their group's issues as well as to provide the questioning of their thoughts, processes, and confidence moving forward. I also made sure to constantly reflect back on the three conditions, as set forth by Warshauer (2015) that are necessary for good support of productive struggle: cognitive demand remain unchanged, individual thinking is supported rather than changed, and the student is able to move forward through his or her own actions. This led to the most questions and least traditional support on the third productive struggle lab task. Student 4 took note of this in their final focus interview in sharing that "I felt that you were constantly there to question what we would do next, or what might we have missed. It got to the point that our group started thinking up answers to your questions before you even came over." This statement shows that the support in the final lab task shifted the thinking and planning in this work group even without the direct support being there in the moment. This group began to engage in deeper metacognitive analysis prior to being prompted by me as their teacher. Rather than checking in with students only when struggle was sensed, I made a point to also check in on work groups that seemed to be encountering success in order to question their thinking, progress, and reservations that remained in solving the problem.

4.4.2 Teacher Support Versus Lab Task Influence on Measures

While both the curriculum and the teacher are important factors in student outcomes in any course, the true focus of this study was on the role of teacher support on student progression, error attribution, and mindset. In order to differentiate between the lab task and the teacher, student responses were analyzed for attributions of progress through the lab task. In addition, special attention was paid to student mentions of task novelty in comparison to past experiences and coursework. Throughout the lab task journals, many students compared the lab tasks, including the content or problem, to experiences that they had encountered in other classes including both my own current Honors Engineering course and other non-department coursework. If the format of the lab task itself was not new to students, it is not likely that changes would have been seen in student mindset and emotion by encountering similar problems again.

During an interview with Student 2, he spoke about the lab task in explaining that "it helped to understand some of the inclined plane stuff just from when we had designed other things to solve problems before in class." While he saw the parallel in solving problems and designing unique solutions, he went on to say that, “While we were doing the actual work, it didn’t seem to me that you helped very much at all besides asking us more questions and telling us to explain things which I think was intentional.” Other students shared similar reflections on teacher support as being minimal or non-existent while still talking about the unusual level of questioning and clarifying performed through the lab tasks. Students identified teacher support if the teacher presented a new idea or strategy that was not developed by the work group. Any questioning or dialogue with the teacher was typically reflected as being conversation rather than assistance or help in solving the lab task. Student 14 stated that, “I don’t think you played a role in it other than like telling us what the prompt was and encouraging us to test it.” His work group was encouraged to test a solution when they told me that it was a final solution and I asked how they knew that it worked. When they couldn’t provide an answer, I asked how they might be able to prove to me that they were right. Most of the students interviewed defined teacher assistance or help as providing direct answers to questions or realigning student thinking to teacher thought processing, both of which are very different from the type of support encouraged in productive struggle situations.

As shared previously, the main goal in teacher support through the lab tasks was to provide questioning and probing guidance rather than direct assistance or redirection of student thought. A few student interviewees picked up on these things specifically in reflecting on the teacher support specifically during their lab tasks. Student 1 reflected on the third and final lab task’s support during her individual interview in saying:

> I mean you kind of like hinted us towards maybe finding a solution but nothing like extremely direct. Um, I think we might have honestly gotten there whether you had pointed us there or not because we were already sort of working with them, and like asking, what

> can we do with them, what can we play around with? And you said something about whether they should all be changing or if anything was and I think we might've gone there anyway, but I think we just starting asking the questions much faster.

This student shares that the general feeling of the teacher support is to lessen the unproductive time spent struggling and take a faster track toward productive solution development. It is not that I put new ideas or unique solutions into the group but rather sped up the process toward the work group's own thoughts and ideas. Looking at the same lab task but from a growth mindset perspective, Student 16 shared that:

> All you really did was really asked us, did we really know what we're doing? Then you'd prowl and you would challenge what I said and then I'd be like, 'Oh, I didn't think about that.' That was the biggest help in the entire thing was when you challenged it. When you did, we'd probably, we would realize at that point that we were wrong and then we knew that we had to do, we had to fix something.

Students at a variety of mindsets and success levels in the lab tasks identified that the probing, questioning, and problem affordance strategies that I used during the lab tasks were influential in their processing of the problem and development of a final solution. None of the students reflected on the impact of the lab task, prompt, or teammate influence as often as that of questioning, challenging, and probing that was performed by their teacher.

5.0 Discussion

Upon conclusion of the research study, it is important to review the results of the research and the meaning of those findings to future practice in education. This section will summarize the results of the study, contextualize the results both in the literature and the class setting, discuss limitations, and lay out implications for future practice and research.

5.1 Summary of Results

The research study was designed to explore the relationships that may exist between teacher support of productive struggle experiences and student mindset, error attribution, and academic progression. Through the use of data collected before, during, and after productive struggle lab tasks in a technology and engineering classroom, the inquiry questions were investigated and answered through the research. Each of the inquiry questions will be presented and summarized through the use of data analysis findings. Reasoning for the data analysis conclusions will be further explored in section 5.2 which revisits prior relevant literature.

5.1.1 Inquiry Question 1: Productive Struggle and Student Mindset

The first question that the study sought to explore was whether a relationship exists between student exposure to supportive productive struggle learning experiences and shifts in student mindset. In order to explore this possible relationship, the Implicit Theories of Intelligence

Scale (ITIS) was administered to students immediately before and after students received teacher guidance, questioning, and support through three productive struggle lab tasks. The score shifts for students on the ITIS were then analyzed at the whole class level through the use of a t-test. The statistical analysis showed a significant change in student mindset after the productive struggle support. Further descriptive statistical analysis of the change in scores at the work group and initial mindset category levels also led to a similar conclusion. Only one work group, A, resulted in three members with decreases and one member with an increase in ITIS score. This group is also the only to encounter significant group conflict during the tasks.

To summarize, the data analyzed in the study demonstrates a statistically significant ($p=0.05$) positive relationship between teacher support during productive struggle experiences and shift toward a growth mindset.

5.1.2 Inquiry Question 2: Productive Struggle and Attribution of Error

The next potential relationship explored through the study was whether teacher productive struggle support impacts student attribution of impasse points in learning. In order to address this inquiry question, student lab task journals were coded for indicators of error attribution. These indicators were coded as either external factors (such as prompt clarity and time constraints) or internal factors (such as a lack of prior knowledge or a specific concept yet to be learned. The through-task student journal coded data was tracked for each student within work groups to look for trends in error attribution over the three productive struggle lab tasks.

No linear trend existed across the three lab tasks between increased supportive productive struggle experiences and increased positive, internal reasoning for errors. The belief that a relationship exists between these two factors is not supported through the data collected and analyzed in this study.

5.1.3 Inquiry Question 3: Productive Struggle and Academic Progression

The final question to guide the study was whether or not teacher productive struggle support impacts student academic progression through challenging lab tasks. This investigation was completed through coding student through-task journals and focus student interviews for emotional cues presented through the lab task as well as an analysis of the final solution presented by each work group. The emotional cues presented in the through-task journals were tracked and analyzed for trends in presented thoughts and feelings while engaged in lab task struggle. Emotional response to challenges during the lab task became increasingly positive over the course of the lab tasks at each of the whole class, work group, and mindset category grouping. In addition, both student persistence and accuracy in the lab task increased after the first experience with supportive productive struggle.

Overall, the data collection and analysis suggest that supportive productive struggle experiences do increase student ability to academically progress through challenging lab tasks. The conclusion that a relationship exists between increased experience with struggle and development of student persistence and academic progression is supported through the data.

5.2 Comparison of In-Context Study Findings to Literature

5.2.1 Observed Changes in Learner Mindset

Dweck defines mindsets as a perception that people hold about themselves. In education, these views most often present themselves in the way that students view their own intelligence as being either a set value (fixed mindset) or a point on a continuum that can be altered (growth mindset). Research shows that academic mindsets are capable of being changed through interventions that encourage a growth mindset (Aronson et al., 2002; Walton & Cohen, 2007; Blackwell et al., 2007). These academic mindsets hold a strong connection to the way that individuals process their own failures and successes during the learning process (Dweck, 1986, 2000, 2006). During failure experiences, fixed mindset students may withdraw from a task in order to maintain dignity and self-confidence (Kelley, 1973; Weiner, 1986). The literature on productive struggle has shown that the use of productive struggle support in the classroom can help students to become more comfortable with future struggles in learning (Kapur, 2014).

My research supported prior research in showing that the intervention of teacher support throughout productive struggle experiences in an engineering course can make shifts in student mindset. Overall, there was a statistically significant ($p=0.05$) change in student mindset scores after the productive struggle lab tasks. Thirteen of sixteen student mindset scores increased over the three-week study. The decreased student scores may be explained through consideration of existing student mindset research and its relationship to the research on noncognitive factors.

Figure 8 outlines the theoretical mapping of noncognitive factors that impact classroom performance in my own place of practice as informed by a review of prior literature.

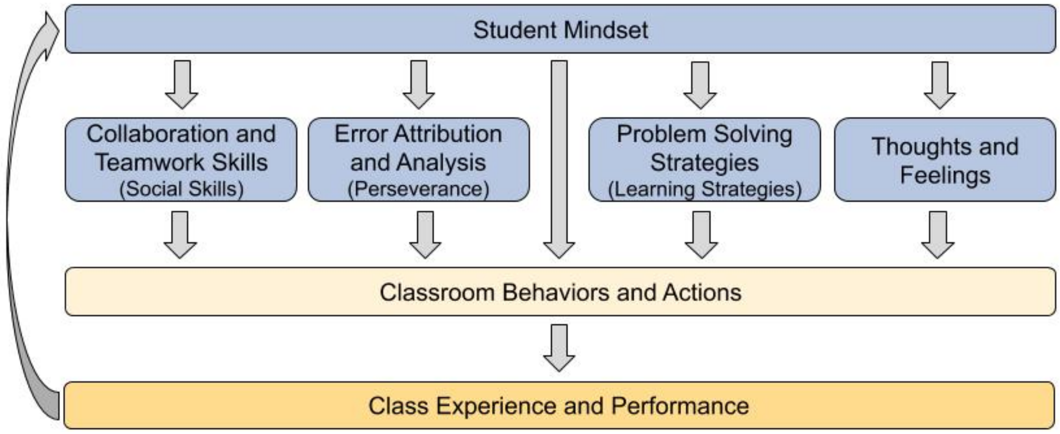

Figure 8 Impact of Noncognitive Factors on Classroom Performance

Farrington et al. (2012) suggest that academic mindsets are one student characteristic that impacts many other factors of student behavior and work. While this may be true, it is important to note that many other factors impact classroom behaviors, and therefore the class experience and performance of students.

As supported by Figure 8, the collaboration and teamwork of the students in group A became a barrier to academic behaviors and end performance which, in turn, affected the shift in student mindset within that group. The only work group to reflect on social skill conflict within the group also contains all of students to have shown a decrease in mindset score. Figure 8 also provides theoretical support for this finding in that if the work group's social skills impacted their performance, it could cause additional impacts on student mindset. The negative shift in mindset could have been due to the impact of the collaborative issues on their performance resulting in a difference in self-feedback and shift in behaviors and actions moreso than a lack of support from the teacher. The gap in collaboration and teamwork skills present in group A may have impacted student experience and performance and therefore the student mindset.

5.2.2 Learning from Errors

Research has shown that all learning, both successful and failure ridden, contribute to student knowledge attainment (Jonassen, 2011). Identification of specific errors encountered during moments of struggle develop higher problem solving, critical thinking, and self-regulation techniques in individuals (Lannin et al., 2007). Later, these learners are also more able to transfer their new problem solving skills when approaching new issues (Casale et al., 2012). Identifying specific, knowledge-based errors in understanding has been shown to lead to better concept transfer in learners (Casale et al., 2012). It is through the identification of specific gaps in knowledge that learners develop the diagnostic skills used in moving more efficiently and effectively through future experiences with struggle (Jonassen, 1997).

The data collected and analyzed in this investigation did not support the expectation of a relationship between teacher support during struggle and more internal, specific attribution of error. One possible explanation for this disconnect is the short time frame used in the study and the few lab tasks used to initiate student changes. While these design decisions were driven by the needs of the classroom curriculum and time frame, it may have been an insufficient time period to cause or measure adequate change in error attribution. Other error attribution studies have taken place over longer periods of time including entire semester-long coursework (Lannin et al., 2007). This seems an unlikely reason however as the three-week time frame was sufficient to show shifts in student mindset. The final possibility that I considered after seeing the lack of expected relationship connects back to the research which discusses the idea that while error-based learning takes more time, we should use caution as “learners may spend time fruitlessly on incorrect solution paths and therefore may fail to acquire good models of solutions” (Jonassen, 1997, p.76). Because student journals are not timestamped, it is unclear how long students spent dealing with each error. While more error codes exist for external error attributions, the codes may relate to less actual lab task time. It is also possible that students spent too much time in unproductive error leading to a lack of development of better problem solving strategies and focused pinpointing of failures.

5.2.3 Emotional Response to Lab Tasks

Considering that productive struggle increases the time that students are grappling with complex tasks and failures in problem solving, it is important to consider student emotion during this teaching and learning style. One research study that specifically considered student emotional approach during productive struggle found that students better understood and applied the concepts in future applications. Importantly, students also displayed a more positive outlook than traditionally-taught peers when encountering future tasks and challenges (Song, 2018). Additionally, through supportive productive struggle teaching and learning used in a flipped classroom, researchers found that students reported both a more positive experience and a deeper understanding of the new information taught (Song & Kapur, 2017).

The study data further supported prior research on the impact of difficult productive struggle experiences on student emotional progression through lab tasks. Student emotional cues presented in student through-task journals trended in an overall positive direction through the lab tasks. As seen specifically in work group D, regardless of student success in developing one final solution to the lab task, students began to look at their experiences as more positive as their academic mindsets also increased. All starting mindset categories reported progressively higher percentages of positive emotional cues through each successive productive struggle lab task.

5.2.4 Strategies for Support of Productive Struggle

While productive struggle is a natural occurrence in most learning processes, the key role in classroom productive struggle is that of the teacher in supporting of students. Teachers can provide feedback and assistance to students in four possible categories: telling, directed guidance, probing guidance, and affordance (Warshauer, 2015). Telling and directed guidance are not effective in supporting productive struggle as they provide too many answers and too few opportunities for students to continue to explore their own paths of problem solving. Alternately, probing guidance and affordance tend to be more successful in maintaining the key components of productive struggle in learning. Rather than providing a new line of teacher-aligned thinking, these support structures work toward student metacognition and analysis of their own failures (Warshauer, 2015).

According to research, in order to support productive struggle, the teacher must maintain three conditions: cognitive demand of the challenge remains unchanged, student thinking must be supported, and students must be able to move forward through their own actions (Warshauer, 2015). These three principles guided teacher support throughout the lab tasks. At the conclusion of each class session, student journals and interview responses were searched for evidence of any of these three conditions being breached through inadequate or excessive teacher support. For example, when the first lab task seemed to align with teacher rather than student thinking through provided material of the string cheese, materials and supports in future lab tasks were reevaluated to ensure student thinking was the driver of work group progress. This shift in strategies was essential as the meaningful learning is heightened when students are able to grapple with the problem rather than receiving teacher instruction or redirection during impasse points (Kapur, 2010).

5.3 Discussion Summary

Success in the STEM fields, specifically technology and engineering careers requires persistence through challenging situations and the acceptance of failure as part of the process rather than a final destination. As such, it is important that students in STEM disciplines develop a resilience in the face of struggle as characterized through a growth mindset towards their own intelligence. A growth mindset belief is one that suggests that a person can grow and develop new skills and abilities, becoming more intelligent in the process, through practice and experience.

In this investigation, an action research cycle was used to explore the relationship between teacher support of students in productive struggle environments and student noncognitive factors, specifically student mindset, progression through the task, and attribution of errors. It was not surprising to find that as students received support toward success in challenging lab tasks, their beliefs about growing intelligence through difficult tasks and struggle also increased. As the support shifted through each lab task based on observations and student feedback, no consistently progressive shift was seen in student attribution of error. While the content involved in each lab task shifted, student positive emotional cues increased through each challenge. Following the observations and data analysis of the study, it is possible to make changes in student noncognitive factors by providing students with probing guidance and affordance support during challenging learning opportunities.

5.4 Limitations

The study, as planned and enacted, presents limitations natural to its design and interpretation. As a case study, the true intent of the research was to gain insight on the outcomes in the specific place of practice and to shift my own understandings and actions as an educator. The practice-bound research occurring in one real-world classroom with an enrollment of 16 students in this specific case is not meant to be generalized to larger groups as each participant can greatly swing the statistical analyses.

In addition, because the research was done in a real class bound to one 18-week semester, the length of the study and related lab tasks was relatively short. Using only three hands-on lab tasks during which students were supported through productive struggle can only provide a small glance into the possibilities if the entire curriculum was shifted to be taught and learned in this fashion. This limitation, however, also points to a major strength in the study. If such results were found in such a short period of time, it is hopeful that even a small effect size could be increased in a larger study period.

The data used in the study were collected from one class of students in one course at one school district. This limitation impacts the generalization of the data to other classrooms, teachers, or students. The site of the study was a suburban school district in the northeastern United States. It is unclear if similar effects would occur in rural or urban districts in other areas. Each classroom and course works under its own conditions, norms, and nuances as created mutually by the students and teacher. The impact of supportive productive struggle in one situation does not necessarily imply similar findings in all classrooms and schools. As a great deal of classroom culture comes from the teacher, the impact of that teacher on the outcomes of the study cannot be ignored. The impact of the teacher relationship with students, rapport, and interaction style may have an underlying impact on the findings of the study. As the support during productive struggle often looks like challenging student thoughts and ideas, the relationship each student has with that teacher may impact the student response to questioning techniques.

Collected data used in this research is based on work group lab efforts rather than the work of individual students. This leads to data that is highly impacted by the collective work of students rather than truly separate data by student, mindset, or intelligence. Due to the nature of the course and lab tasks, it was most natural to design the study to occur in collaborative student work groups. This design limits the ability to make claims about the progress, learning, or strategies of individual students rather than overall work groups unless the student were part of the focus structured interviews.

A final limitation present in the study occurred through the selection of individual students to take part in the one-on-one interviews. Students were chosen through convenience sampling after considering differences in mindset. This sampling method was necessary in order to complete all interviews as soon as possible following lab tasks while thoughts and experiences were still fresh in participant minds. It is possible that this lead to student selection that is not congruent with what would have been found through a truly random sample.

5.5 Implications for Practice

As a teacher, the goal of each day is to adequately prepare students for life after high school. In a rapidly changing and evolving world, it is likely that I am working to prepare my students for careers that do not yet exist. This presents a challenge to teachers that focus solely on content and academic prowess of students. My own preference is to develop long-lasting thought processes and habits of mind in students that will benefit them regardless of future hopes and plans. The results of this research support two implications to practice in my own classroom to benefit my students.

The first impact on my practice is increased confidence in the use of difficult, rigorous challenges in the classroom. Through my years of teaching, I have seen that students are less inclined to enjoy or look forward to tasks that they know will be a struggle as opposed to those that have a clear and simple answer. This research has shown me that not only are these challenges meaningful in teaching students new content, they also present the opportunity for deeper changes to occur in the noncognitive thoughts of students. The data analyzed in the research indicated that through supportive productive struggle experiences, students develop both a more positive outlook during challenges and more of a growth mindset. This data shows me, as a teacher, that the benefit of purposeful support during classroom productive struggle is worth the time and effort because it introduces my students not only to new skills and concepts, but also to new and more positive ways of thinking about themselves as a problem solver and learner. Based on prior research on student mindset and the impact it has on other life areas, it is reasonable to assume that improving student mindset could also improve grade point averages in college coursework (Wilson & Linville, 1982), course grades (Hulleman & Harackiewicz, 2009) and lower dropout rates (Wilson & Linville, 1985).

In my professional relationships and experience, I have encountered a majority of technology and engineering educators who are heavily focused upon content and manipulative skills rather than the process and progression that occurs in learning. While this approach is justifiable in that the standards related to the field have traditionally been very content and skill-focused, this research presents an impactful way to teach noncognitive skills and technical content simultaneously. The second implication of this study is that it presents a major teacher shift that must occur in teaching and preparation. The research findings support a need for teachers to plan and prepare questioning and support strategies. My own experiences as teacher-researcher showed that very conscious effort needed to be put toward the planning of distinct questions and probing guidance techniques that would balance adequate support while maintaining student-aligned thinking and solution approaches.

Based on the data collected and analyzed in this study, a connection does exist between supportive productive struggle experiences and growth in positive student noncognitive factors. Due to this finding, the productive struggle lab tasks used in the mechanical advantage unit of the Honors Engineering Principles course will be continued in future iterations of the curriculum. Beyond that, it is likely that the use of collaborative productive struggle lab tasks will be expanded into other units and possibly other courses as well.

My own understanding and views as a teacher have also been impacted by conducting and reflecting on this research. The findings of the study will have an impact on how I use questioning and discussion techniques in my classroom. Rather than aiding students toward the single correct solution as viewed from my perspective, the focus will be turned moreso toward exploring student thinking and confidence in their own solutions to foster the ability to self-correct, route, and direct solution strategies on their own. The focus of teaching and learning in my classroom will shift from teacher-aligned thought and instruction to collaborative, complex problem solving scenarios that engage students in productive struggle paired with careful and conscientious teacher support. Not only will this shift in focus impact the task-related and self-evaluative thoughts of students, it will also expose me, as the teacher, to a much broader spectrum of student thought processes and approaches.

5.6 Implications for Future Research

With positive results to multiple inquiry questions, it is promising what future research in this vein could hold. First, it would be interesting and important to determine if similar scenarios in other subject areas show evidence for the same relationships. The natural trial and error of the engineering design process is not as present in other subject areas such as the humanities and social sciences. Could similar results be garnered in other learning fields?

Another key characteristic of this study that could be altered in future research would be the groups in which students worked together on lab tasks. One option would be to group students by similar rather than contrasting ITIS mindset scores. This would further define if changes in mindset were the result of support through struggle or due to working with individuals of differing mindsets. Another option in revisiting student grouping through future research would be to increase the opportunities for gathering data at the individual level on the impact of the productive struggle lab tasks. These increased data collection opportunities may include increased individual student interviews or a transfer task performed by each student after conclusion of the lab task.

Another alteration to the study in future research could be the lengthening of its timeframe through the use of additional productive struggle tasks or time-delayed transfer tasks. Being that groups responded with more positive emotional cues during different tasks in the study, it would be important to determine what might happen during additional tasks. I would hypothesize that additional shifts toward positive emotional response to struggle could be possible in these tasks. I also believe, based on previously discussed prior research, additional time working in supportive productive struggle environments could begin to show shifts toward internal error attribution in students. The time-delayed transfer tasks could also be used to determine if the acquisition of knowledge through the supportive productive struggle lab tasks is long-lasting or only present in the short-term. Each of these possibilities would lengthen student engagement in the study and strengthen the understanding of the impact of teacher support through productive struggle.

A third possible vein of research to branch from this initial study would take a closer look at the actual attempts and student work completed during the productive struggle experiences. Albeit outside of the scope of this particular study, while reviewing student through-task journals, it was interesting to see the different approaches that students took in solving the problems. This was especially true of the initial attempts by each student upon receiving the problem prompt. Some students seemed to draw more diagrams and sketches while others jumped directly to equations and variables. It would be interesting, in future research, to consider if these differing strategies during productive struggle either lead to different outcomes or are varied depending on student demographics. In particular, it would be interesting to investigate the difference in problem solving attempts between males and females during productive struggle experiences. Considering the wide gender gap in STEM disciplines, it is important to know the different factors in play in the difference between how students think and work in STEM courses. In this same line of research, it would also be interesting and important to explore if one strategy of solving a complicated problem leads to higher academic success or more of a shift in noncognitive factors such as student mindset.

Appendix A Implicit Theories of Intelligence Scale

Implicit Theories of Intelligence Scale for Children – Self Form

(For children age 10 and older)

Read each sentence below and then circle the one number that shows how much you agree with it. There are no right or wrong answers.

1. You have a certain amount of intelligence, and you really can't do much to change it.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

2. Your intelligence is something about you that you can't change very much.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

3. You can learn new things, but you can't really change your basic intelligence.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

4. No matter who you are, you can change your intelligence a lot.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

5. You can always greatly change how intelligent you are.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

6. No matter how much intelligence you have, you can always change it quite a bit.

1	2	3	4	5	6
Strongly Agree	Agree	Mostly Agree	Mostly Disagree	Disagree	Strongly Disagree

Appendix B Post-Task Student Interview Protocol

Thank you for participating in my research project for my doctorate program. Through this research, I am using what I have been learning in my classes to try to see the effect that all of our lab work has on the way that you think about yourself as a learner. For the next 20 minutes or so, I am going to ask you questions to try to better understand how you felt and what you thought during the lab work. To help you remember what you went through and worked on, I am giving back your work journal and problem prompt from class.

While we are talking, I am going to jot down quick notes just to make it easier for me when I go back and try to remember what you have shared with me. If it is okay with you, I am also going to record the conversation so that I can go back and listed to ensure that I don't miss anything important that you shared. Do you have any questions before we get started?

Experience

1. Describe your initial reaction when starting to solve this problem.
2. When you were finished solving the problem with your group, how confident were you of your solution?

Struggle

3. What made arriving at the correct solution difficult?
4. Why did your group encounter these struggles/what caused your group to encounter difficulties in this lab task?
5. Explain to me your thought processing when encountering one specific problem.
6. What was the most challenging/difficult aspect of this lab task?

Techniques

7. What was the most effective strategy that you or one of your group members used in the lab task?

8. What made that strategy so effective?

Teacher Supports

9. Based on my notes from class, I assisted your group by (context from teacher journal), what were your thoughts and feelings after that?

10. What role did I play in your group arriving at your final solution?

11. Were there specific actions that I took that helped your group most?

Live Application Problem

12. Could you please walk me through your thought process and techniques to solve this technical problem?

Again, thank you for participating in my project. If you have any questions, feel free to ask me in class or email me for clarification.

Appendix C Productive Struggle Lab Task Briefs

Lab Task 1: Mechanical Advantage in Wedge Systems

Oh No! The Frigo String Cheese Company has called your engineering firm in a hurry due to their big problem! The cutting machine for all of their string cheese is down! In the meantime, they would like to supply employees with some sort of cutting device in order to cut the large rope of cheese down into marketable string cheese portions. In order to make the best cutting device, and to prepare to repair the cutting machine, your team is tasked with coming up with a mathematical system for calculating the mechanical advantage of the cutting device.

Lab Task 2: Mechanical Advantage in Lever Systems

NASA is having a major issue in designing safe ways for astronauts to make in-orbit repairs to the inside of shuttles. Astronauts can only lift 50 pounds without risking damage to their space suit system. NASA must figure out a way to guide astronauts through the use of a lever system to decrease the overall force needed to maneuver heavy machinery during repairs. Your team of engineers is responsible for designing a mathematical system that can be employed in all lever repairs to calculate the size and type of lever needed to reduce needed force to one that is safe for astronauts and their suits.

Lab Task 3: Mechanical Advantage in Inclined Plane Systems

UPS is having trouble meeting the Holiday demand due to worker safety restrictions. Workers are not able to lift anything heavier than 40 pounds without having assistance from another worker. This not only slows down the time needed for loading each truck but also can be challenging during some shifts when there aren't many workers present. In order to alleviate this issue, UPS is hiring your team of engineers to develop a solution using inclined planes. They would like for you to create an easy equation that workers use to determine how they can create an inclined plane system that brings the total force needed to move a package down to a 40 pound equivalent.

Appendix D Thinking-Through Lesson Plan: Lab Task 1: Wedges

<table>
<tr>
<td><u>Learning Goals (Residue)</u>

Students will establish:
• Behaviors and procedures effective for thinking like an engineer in the ability to use knowledge and observations to develop and test theories.
• An effective formula for use in estimating mechanical advantage and designing wedge systems for separation of material.</td>
<td><u>Evidence</u>

Students will produce:
• A final formula for submission, sharing, and use in designing wedge cutting systems that meet provided criteria.
• Through-task journals highlighting progression through engineering habits of mind in working through struggle through equation development.</td>
</tr>
<tr>
<td><u>Task</u>

Students will use modeling of wedge-based cutting systems utilizing a variety of materials and equipment to create wedge systems. Students will measure applied force using a spring scale to determine mechanical advantage present in the system. Using these measurements, students will begin to theorize the relationship being observed between size and configuration of wedge and the resulting mechanical advantage.</td>
<td><u>Instructional Support—Tools, Resources, Materials</u>

Materials to be provided include spring scale and string cheese. These materials should be used in modeling the problem to take and record measurements. Students will also be provided with calculators. The lab and its materials will also be at student disposal including machines, scrap wood, design materials, etc.</td>
</tr>
<tr>
<td><u>Task Launch</u>

Prior to task launch, students will review their Rube Goldberg machines completed early in the semester to explore the use of and interaction between simple machines in completing tasks. Students will discuss the various ways that the lab tools and equipment accomplish cutting material away from a product. All of these devices use wedge-based cutting systems. Upon conclusion of the discussion, students will be prompted to engage with the lab task in exploration of a quantifiable value for mechanical advantage rather than a comparative analysis of items becoming easier or less difficult to cut based on the cutting device used.</td>
<td><u>Prior Knowledge</u>

Prior to the lab task, students will have explored a variety of engineering concepts that will come into play in the lab task including simple machines, engineering calculations, friction, and forces. Students will have experienced guided lab experiments with more guidance and prompting. Students will also have completed an individualized engineering project of their own from proposal to material acquisition to presentation of results.
All prior work has utilized the engineering design process which could be used to guide progression through this lab task. All of student prior work has led to this lab task of student theorizing and development of equations based solely on observation and findings.</td>
</tr>
<tr>
<td><u>Anticipated Solutions</u>

I anticipate that students will begin to form wedge systems in order to take measurements of force required to cut through the pieces of string cheese. I also anticipate that students will take some measurements of the wedge including length, thickness, angle, weight, etc.</td>
<td><u>Instructional Support—Teacher</u>

Questions to be asked of student groups:
• How could you begin to collect measurements of how much force is needed to cut the string cheese with the wedge?</td>
</tr>
</table>

During completion of the lab task, one of the biggest distractors from successful formulation of an equation for mechanical advantage being the presence of friction or perceived resistance while cutting the string cheese. The force read from the scale will be affected by this resistance against the cutting mechanism Also, groups that take the route of exploring angles my take longer in arriving at a solution, the ultimate equation usually considers the length and thickness of the wedge in calculation of mechanical advantage.	• While what you have explained may be true for this system, would that be true of other group's wedges? • Tell me about what you have tried. • What are you finding in your measurements? • What are you wondering about what you have observed? • What might be working against your ability to cut through the string cheese? • As the wedge gets thinner, what happens to your measurements (and vice versa)? • Go back through your journal and review what you have tried and measured. What do you notice?

Based on Smith et al., 2008

Appendix E Thinking-Through Lesson Plan: Lab Task 2: Levers

<table>
<tr>
<td> <u>Learning Goals (Residue)</u>
Students will establish:

Behaviors and procedures effective for thinking like an engineer in the ability to use knowledge and observations to develop and test theories.
An effective formula for use in estimating mechanical advantage and designing lever systems for safe work performance.
</td>
<td> <u>Evidence</u>
Students will produce:

A final formula for submission, sharing, and use in designing lever systems that meet provided criteria.
Through-task journals highlighting progression through engineering habits of mind in working through struggle through equation development.
</td>
</tr>
<tr>
<td> <u>Task</u>
Students will use modeling of lever systems utilizing a variety of materials and equipment to create lever systems. Students will measure applied force using a spring scale, or other means, in order to determine mechanical advantage present in the system. Using these measurements, students will begin to theorize the relationship being observed between configuration of levers and the resulting mechanical advantage. </td>
<td> <u>Instructional Support—Tools, Resources, Materials</u>
Students will have a variety of lab tools, materials and equipment at their disposal. A variety of scrap wood, weights, materials, etc. will be placed where easily accessible in the lab environment.
Students will also be provided with calculators and spring scales specifically for the task at hand. </td>
</tr>
<tr>
<td> <u>Task Launch</u>
Prior to task launch, students will reunite with their work group from the prior productive struggle lab task dealing with wedges. Students will be asked to take a brief 30-60 seconds of reflection on that lab task before moving forward with a similar challenge.
Students will be asked to reflect on the applications of levers in real life through the use of group discussion. Upon conclusion of the discussion, students will be prompted to engage with the lab task in exploration of a quantifiable value for mechanical advantage rather than a comparative analysis of work becoming easier or less difficult. </td>
<td> <u>Prior Knowledge</u>
Prior to the lab task, students will have explored a variety of engineering concepts that will come into play in the lab task including simple machines, engineering calculations, friction, and forces. Students will have experienced guided lab experiments with more guidance and prompting. Students will also have completed an individualized engineering project of their own from proposal to material acquisition to presentation of results.
In addition, students will have had one prior productive struggle support experience in the wedge-based lab task during the first round of data collection for this study. </td>
</tr>
<tr>
<td> <u>Anticipated Solutions</u>
I anticipate that students will begin to form small-scale levers and take measurements of force required to move the load weight similar to the previous lab task. I also anticipate that students will take some measurements of the levers including length, weight, height, flexibility, etc. </td>
<td> <u>Instructional Support—Teacher</u>
Questions to be asked of student groups:

How could you begin to collect measurements of how much force is needed to lift a weight using a lever?
</td>
</tr>
</table>

During completion of the lab task, one of the biggest distractors from successful formulation of an equation for mechanical advantage is the necessity for students to distinguish between a load arm and an effort arm in the lever system. With three different distinct classifications of levers, there are many different possible set-ups even when trying to manipulate simple load weights. For this reason, I anticipate students struggling to combine findings across more than one classification of lever.	• While what you have explained may be true for this lever, would that same equation work for a different type of lever? • Tell me about what you have tried. • What are you finding in your measurements? • What are you wondering about what you have observed? • Why did you… (ex: Why did you change materials of the lever? Why did you change the configuration of the fulcrum?) • What might be working against your ability to lift the load in this specific system? • As the lever gets longer, what happens to your measurements (and vice versa)? • Go back through your journal and review what you have tried and measured. What do you notice?

Based on Smith et al., 2008

Appendix F Thinking-Through Lesson Plan: Lab Task 3: Inclined Planes

Learning Goals (Residue) Students will establish: • Behaviors and procedures effective for thinking like an engineer in the ability to use knowledge and observations to develop and test theories. • An effective formula for use in estimating mechanical advantage and designing inclined plane systems for safe work performance.	**Evidence** Students will produce: • A final formula for submission, sharing, and use in designing inclined plane systems that meet provided criteria. • Through-task journals highlighting progression through engineering habits of mind in working through struggle through equation development.
Task Students will use modeling of inclined plane systems utilizing a variety of materials and equipment to create inclined plane systems. Students will measure applied force using a spring scale to determine mechanical advantage present in the system. Using these measurements, students will begin to theorize the relationship being observed between size and configuration of inclined plane system and resulting mechanical advantage.	**Instructional Support—Tools, Resources, Materials** Students will have a variety of lab tools, materials and equipment at their disposal. By the time of this lab task, students will be familiar with lab materials from completion of prior lab activities and units. Materials and equipment include but are not limited to lumber, plywood, weights, ladders, risers, woodworking equipment, etc. Students will also be provided with calculators and spring scales specifically for the lab task at hand.
Task Launch Prior to task launch, students will reflect on mechanical advantage through the use of class discussion on inclined planes in their surroundings including wheelchair ramps, loading ramps, etc. Upon conclusion of the discussion, students will be prompted to reunite with their lab groups and engage with the lab task in exploration of a quantifiable value for mechanical advantage rather than a comparative analysis of work becoming easier or less difficult.	**Prior Knowledge** Prior to the lab task, students will have explored a variety of engineering concepts that will come into play in the lab task including simple machines, engineering calculations, friction, and forces. Students will have experienced guided lab experiments with more guidance and prompting. Students will also have completed an individualized engineering project of their own from proposal to material acquisition to presentation of results. In addition, students will have had two prior productive struggle support experiences in the wedge and lever lab tasks during the first and second round of data collection for this study.
Anticipated Solutions I anticipate that students will begin to form inclined planes and take measurements of force required to advance objects up the ramp. I also anticipate that students will take some measurements of the ramp including height, length, angle, etc.	**Instructional Support—Teacher** Questions to be asked of student groups: • While what you have explained may be true for this inclined plane system, would that be true of other inclined plane systems? • Tell me about what you have tried. • What are you finding in your measurements?

During completion of the lab task, one of the biggest distractors from successful formulation of an equation for mechanical advantage being the presence of friction in the measurements. The force read from the scale will be affected by friction generated in moving the object against the ramp. Students may try to alter the friction of the ramp rather than simply considering that some effort is lost in competing against friction. While groups that take the route of exploring angles my take longer in arriving at a solution the ultimate equation should consider the length of the slope and height of the slope in calculation of mechanical advantage.	• What are you wondering about what you have observed? • Why did you… (ex: Why did you change materials of ramp? Why did you change the height of the ramp?) • How confident are you in your solution? Why? • What are you currently working to solve? • Go back through your journal and review what you have tried and measured. What do you notice?

Based on Smith et al., 2008

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