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Learning to Jump Like Corbin Bleu: The Physics Behind Jump Rope

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LEARNING TO JUMP LIKE CORBIN BLEU:

THE PHYSICS BEHIND JUMP ROPE

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By

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ABSTRACT

This project seeks to determine how engineering can be applied to the sport of jump rope so that athletes may better understand the science behind the sport and apply it to improve their performance in “speed jumping.” This style of jump rope consists of a jumper alternating their feet, with the rope passing under them with each step. Several types of ropes, handles, rope lengths, and widths between a jumper’s handles were tested to determine correlations between each variable and different STEM concept. These findings were then transitioned into a lesson plan so that both the jumpers and coaches could better understand the connections between STEM and their sport in a way that would be useful to them. Additionally, this lesson draws from teaching standards to supply an incentive for teachers to incorporate into their classrooms. This project is especially valuable since the majority of jumpers are female and women are still underrepresented in many STEM disciplines. Similarly, several initiatives from national organizations, such as the Department of Defense and National Science Foundation, have been created to involve women in STEM which further emphasizes the need for women in STEM. Overall, this project will give jumpers the opportunity to consider the field through the context of one of their existing passions and encourage their participation in STEM.

I dedicate this thesis to everyone in the jump rope community that helped with this project and all those who have and will devote their time to improving the sport.

ACKNOWLEDGEMENTS

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Additionally, there were many people from the jump rope community that helped me throughout the project. Brian Hsu from the American Jump Rope Federation provided me with statistics from the last AMJRF national championship so I could determine the gender composition of the sport. Becky Zelewski with USA Jump Rope helped me find past jumper's research on the sport. Matt Hopkins and Blake from Buyjumpropes.net helped me determine what ropes would be useful for me to use for testing as well as answered many of my preliminary questions about the ropes themselves. Tori Boggs, creator of Tally Jump, let me borrow a Tally Jump device free of charge. Dee McNeily from the Jumpin' Jaguars and Cindy Weatherford from the Hotshots TN both offered practice time for me to test with and teach the jumpers on their team. Lastly, Kaylee Woodard shared her own research on the sport and offered her advice for my project.

Lastly, I would like to thank my friends and teammates who helped throughout the process especially, Murray Huber, who was my go-to jumper when I needed to think through an idea, was always willing to help me during the testing process, and was able to provide insight into the CE/T process, Zoe McNeily, who assisted me with filming, Grace Wells, who assisted me with creating figures, and my sister Abigail Camfield, who assisted me with testing when I was at home, provided me with an outside opinion as I was composing this paper, and listened to me talk about jump rope much more than she would have preferred.

DEFINITIONS

Jumpers- A person who jumps rope as a part of a competitive jump rope team.

STEM- Science, technology, engineering, and math

Speed step- A form of jumping where jumpers alternate their feet while jumping, with the rope passing under them each time. In competition, according to the IJRU judging manual, "judges count the first completed right foot jump and each additional alternating right foot jump" [1].

Double unders- A jump rope trick where the jumper pushes off of the ground with two feet and the rope passes under them twice before they land.

Triple unders- A jump rope trick similar to a double under but the rope passes under the jumper three times instead of two.

Single rope- A form of jumping where the jumper uses a 7-10 foot rope which they both turn and jump themselves.

Double dutch- A form of jumping where two jumpers (called "turners") turn two 12-40 foot ropes in an alternating fashion, so that one rope is in the air when the other is on the ground. As the turners turn the ropes, there is at least one jumper inside jumping.

Clicker- A device used by judges in competition to count the number of right-foot jumps a jumper complete during a speed event.

AMJRF- American Jump Rope Federation, The national governing body for the United States.

IJRU- International Jump Rope Union, A merger of WJRF and FISAC-IRSF in 2018 and the current international organization for the sport.

FISAC-IRSF- Federation Internatioale de saut a la Corde-International Rope Skipping Federation, An organization created with the help of Richard Cendali in 1995 which was one of the international organizations for the sport until 2018.

USAJRF- United States Amateur Jump Rope Federation, An organization created with the help of Richard Cendali in 1995 which is currently one of the national jump rope organizations in the U.S.

WJRF- World Jump Rope Federation, An organization that split from USAJRF in 2011 which was one of the international organizations for the sport until 2018.

VITA

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Caroline Camfield, Clay Priddy, & David Cambron (2020, October). *Development of a Research and Educational Platform for Collaborative Robotics*. Poster presented at the ACIEE conference. Kingston, RI.

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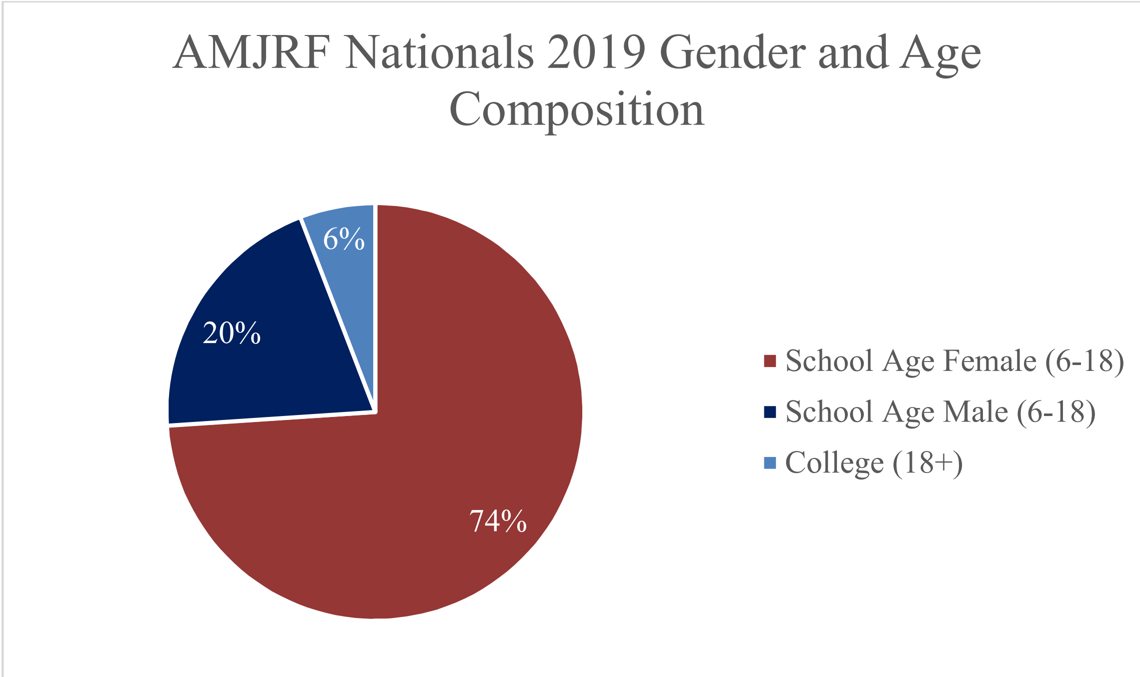
SECTION ONE- INTRODUCTION

The sport of competitive jump rope unites jumpers from a wide range of cultures through local, state, national, and international competitions. Athletes in the sport have created a collaborative community where jumpers actively work together to better the sport as a whole, through teaching younger generations of jumpers new skills and techniques. This is all in the hopes that the younger generation will be the one to progress the sport to the Olympics. This project hopes to take this same spirit of teaching to teach jumpers the relationships between their sport and STEM so that they might develop a greater understanding of both topics. Since jumpers already teach other jumpers new skills and techniques and, considering 93.5% of jumpers attending the AMJRF national tournament in 2019 were 18 years of age or younger, as shown in Figure 1, the majority of jumpers are currently in school learning STEM [2]. Thus, this project utilizes jump rope as a teaching medium for STEM to provide jumpers with a way to apply what they have already learned in school to their own lives.

Furthermore, at the 2019 AMJRF national competition, 80.6% of the athletes were female, also shown in Figure 1, suggesting that the majority of jumpers in the sport are girls [2].

Figure 1: Gender and age composition of AMJRF Nationals in 2019



Thus, using jump rope to teach STEM is especially beneficial since there are still gender inequalities in certain STEM disciplines, like engineering, this project has the potential to encourage those who otherwise may not have entered the STEM field to do so. According to one survey done by the United States Bureau of Labor Statistics on people's occupation and gender, one quarter or less of those in the computer, math, architecture, and engineering fields are women [3]. Similarly, the National Science Foundation and the Department of Defense have begun initiatives to encourage more women to enter the STEM field through the creation of programs offering research opportunities and scholarships that favor minority applicants, including women [4] [5]. This aligns with the demographic in the sport since most jumpers are female and can potentially encourage those previously uninterested in pursuing a STEM career to consider it.

Nonetheless, for jumpers of either gender, there is an increasing need, and benefit, from being employed in a STEM discipline. According to data from the BLS, it is predicted that the number of available jobs in the STEM field will increase by 8.8% between 2018 and 2028 [6]. Additionally, the BLS describes that the median annual salary for a job in the STEM field in 2019 is just below $87,000 [6]. Comparing these values with those for non-STEM jobs, the BLS predicts a 5% increase between 2018 and 2028 and a median annual salary of about $38,000 [6]. This data indicates that jobs in the STEM field are both higher paying and will be more numerous in the coming years and students must be prepared to embrace STEM and fill these positions.

The inspiration from this project was due to my personal experience in the sport. I have been involved in the sport of jump rope for the past nine years and have competed the last eight.

Figure 2: Image of me teaching younger jumpers at a local team's practice

Figure 3: Image of a more experienced jumper teaching me at the WJRF camp

Throughout this time, I have had the chance to work with and teach jumpers from around the world (Figures 2 and 3 show me teaching younger jumpers at their practice and learning from more experienced jumpers at a WJRF camp) and from these experiences, I noticed that most jumpers fail to consider the impact physics and engineering have on their performance. Especially at a young age, a jumper’s desire to learn new, harder skills overpowers their desire to learn the science of why the rope behaves like it does, even if it would benefit their jumping ability.

The relationships between STEM and sport have been drawn between many popular sports, however since jump rope is less common, only a minimal amount of scientific work has been done on the sport and no prior work has been done in the realm of sports engineering education. Therefore, this project first sought to establish some of the basic relationships between STEM and jump rope before creating a way to relay these relationships to jumpers so they can apply and benefit from them.

SECTION TWO- BACKGROUND

HISTORY OF JUMP ROPE

Despite gaining some recognition from Corbin Bleu in the Disney movie *Jump In!*, competitive jump rope can still be considered a niche sport, especially when it is compared to sports such as soccer and baseball that are much more popular in the United States [7]. The sport, however, is not new and the history of how it came to reach its current state is complex. Nick Woodard, an internationally recognized competitive jumper, looked at the history of the sport while completing his Master's thesis in sports management, titled "Jump Rope! Connecting the Past, Present, and Future!" As with much of the research on jump rope, the history of the sport in the United States has been sparsely documented and several of Nick's sources were gathered by interviewing key contributors to the sport [8].

The earliest record of the sport is in 17th century China where it was used as an activity for children [9]. The sport did not appear in the United States until children from the Netherlands brought it with them during colonization [9]. Jump rope, especially double dutch, remained popular as a children's game, until the 1950s when technologies like television began to supplant the sport [Rope skipping history]. In the 1960s, however, a football player in Colorado, Richard Cendali, was introduced to jumping rope, specifically single rope, as a workout and in 1973, double dutch was used by New York

City police officers to keep kids active and out of trouble [10]. From these two instances, various national double dutch organizations in the United States and national and international jump rope organizations around the world have been created [10] [11] [12]. The current international organization, IJRU, a merger between FISAC and WJRF, has obtained observer status with the Global Association of International Sports Federation (GAISF), one of the steps to becoming an Olympic sport [8]. Additionally, while there are several national jump rope organizations in the United States, AMJRF is recognized as the national governing body by IJRU which is why statistics from their latest national competition and rules are referenced in this paper.

COMPETITIVE JUMP ROPE

Jump rope competitions usually consist of two major sections: speed and freestyle. The goal of speed jumping is for jumpers to go as fast as they can in a set duration of time; events range from 30 seconds to 3 minutes and jumpers compete by themselves or in a group, using either a single rope or set of double dutch ropes. While many of these events consist of jumpers doing speed step, competitions also include a single rope and double dutch event where jumpers compete as many double unders as they can in a set duration of time and a single rope event where jumpers compete as many triple unders as they can under no time constraint. In competitions, speed events are based purely on the number of jumps a jumper takes during the duration of the event, therefore a jumper’s goal is to go as fast as possible. To count the number of jumps, trained judges use either a manual or digital clicker to keep track of every time the jumper's right foot lands. While a jumper missing a jump does not deduct from any jumps they have already done, a false start will impose a penalty of 10 jumps [1].

The other facet of a jump rope competition is freestyle jumping, where jumpers receive a score based on the difficulty, presentation, number of misses, and number of required elements for a timed routine [1]. Like speed events, freestyle events are done individually or in groups, using either single ropes or double dutch ropes. Since freestyle jumping is subjective in how it is scored, and heavily dependent on the creativity, personal preferences, and a jumper's skillset, my project analyzed individual single rope speed jumping. However, once a jumper understands the science behind the rope's motion, they should be able to apply it to both speed and freestyle jumping.

SECTION THREE- LITERATURE REVIEW

INTEREST BASED LEARNING

The foundation of this project is derived from the assumption that teaching a jumper a potentially unappealing topic–STEM–through a topic they are already interested in–jump rope–will promote an increased ability to learn the new topic. Backing for this assumption can be found in Judith Harackiewicz and Chris Hulleman's article, "The Importance of Interest: The Role of Achievement Goal and Task Values in Promoting the Development of Interest" [13]. According to their research, "both situational and individual interest promote attention, recall, task persistence, and effort" [13]. Thus, if a student is being taught through the lens of something they are interested in, such as jump rope, their ability to learn and remember the topic will be greater than it would have been otherwise; however, this would first require the jumper to indeed be interested in the sport. Thus, for jumpers who are already interested in jump rope, teaching STEM through the sport is theoretically an effective teaching strategy.

STEM AND SPORT PROGRAMS AND THEIR EFFECTIVENESS

While there have not been any programs that have taught STEM through jump rope with this strategy in mind, there have been several programs designed to carry out this approach with other sports [14] [15] [16]. In one program, Elizabeth Barton combined STEM and sport at her son's rowing club with the goal of getting students in middle and early high school interested in STEM as well as physically fit [14]. Barton also tailored the concepts taught to align with that of the local school district so students had the chance to apply what they were already learning in school to the sport [14]. This idea that students must be taught STEM through sport in language they would understand is key and, in her article, Barton describes one example of how STEM relates to rowing for the reader, demonstrating the active teaching style she uses.

An active teaching approach is beneficial when it comes to teaching STEM since it effectively engages students in the learning process, instead of passively listening to a lecture about STEM. Sports are a good medium for this teaching approach since students are already physically active when doing them, making the incorporation of an active teaching approach much more accessible. This is one reason why an active learning approach was chosen for the lesson plan in my own project; while lecturing to jumpers about their sport and STEM may have been a simpler method, from experience, I knew jumpers were used to being active while at practice and a lesson that incorporated that into their learning would be much more engaging.

Another program that relates STEM and sport is the one focused on in the article "Sports as a Creative Way to Teach Science," where Jonan Donaldson and Penny Hammrich note a current discrepancy present when sports are used to teach science [15]. Hammrich and Donaldson claim that teachers only focus on the STEM side and not teaching students how to better their ability to do a sport through science; "[students] learn about the trajectory of a golf ball without connecting this principle with the actual practice of hitting a golf ball" [15]. As with Barton's program, Hammrich and Donaldson's program employed an active learning approach; in their example about the golf ball, the authors are describing the benefits to an active approach compared to the traditional passive one. For this example, while it might be difficult for a teacher to convince the school's administration that a field trip to the local golf course to teach projectile motion is justified, in my project, jumpers will already be in a place where applying the concepts through jumping is both accessible and encouraged, allowing them the opportunity to actively apply what they are learning.

Looking to a sport similar to jump rope, another project I reviewed, consisted of students from the University of California San Diego who taught high schoolers concepts relating to physics and life science through gymnastics [16]. The concepts they used to instruct the students were based in a prior study that analyzed the physics of gymnastics; once the classes were complete the students were surveyed to determine if their opinions of STEM had changed [16]. The teaching methodology used by these students was beneficial to my project and the structure of the lesson plan I prepared for jumpers resembled the lesson used in this project.

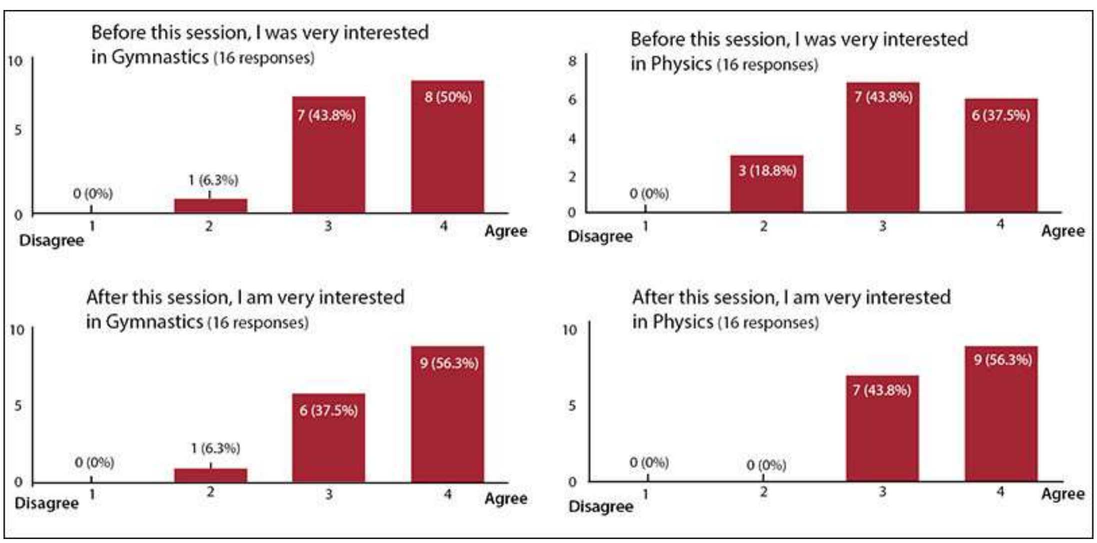
One method that the gymnastics camp employed was "embodied learning" a technique where students learn from the physical movement of their bodies [16]. While doing the different gymnastics elements, students can feel how exactly the science is working as they are moving their body in different ways; similarly, jumpers can feel the science as they manipulate their rope in different ways. Additionally, this program connected each element of gymnastics to the Next Generation Science Standards (NGSS) discipline core ideas to ensure that the STEM topics they covered were ones students were already learning in school [16]. One difference between my project and the gymnastics one, however, is that no prior study relating jump rope to STEM has been completed. Therefore, before developing a lesson, I must first determine the physics of jump rope.

Similar to my project, several of these programs also targeted unrepresented students in the STEM field so that they might gain a wider range of positive experiences with STEM. For example, Donaldson and Hammrich's program was done for middle school girls, who go to "urban middle schools," and had the intent of "increas[ing] students' positive attitudes, achievement, and exposure to science" through their participation in sports [15]. The authors described their research as a "bridge" between "the academic and the everyday experiences of students" where "sports [are] a mechanism to [learn] science and mathematics" [15]. Here, the authors acknowledge that students are currently experiencing a disconnect between their lives in and outside of school and they express that their goal is to draw connections between the two.

What lacked in many of the programs I found was the assessment of how well participants were learning the ideas being taught [14]. While it is probable students are learning about STEM and sport, Barton failed to address the effectiveness of her program, most likely because it was outside of the realm of academia [14]. Hammrich and Donaldson, on the other hand, did attempt to determine the success of their program; by comparing the results of the pre- and post-assessments they gave participants, students' scores increased between "27 to 60 percentage points" [15]. However, the authors noted that the results from this program cannot be compared to anything, since they did not also teach a program where students learned science without the help of sports [15]. The authors concluded that "it seems that sports provide a creative way to facilitate students' cognitive understanding of science concepts" and that participants responded positively to it [15]. The researchers at UC Davis that did the gymnastics program also attempted to determine the effectiveness of their program by surveying participants at the end of the lesson [16]. In the survey, the results from which can be found in Figure 4, participants indicated that they wanted to learn more about various physics-concepts and they also said they were more interested in physics than they were prior to it [16].

Comparing the results from before and after the program, there was a slight increase in participants' interest in gymnastics. Additionally, while before the program three participants expressed they somewhat disagreed with the statement that they were interested in physics, afterwards no participants said they disagreed with the statement and the majority of participants said they strongly agreed with the statement [16].

Figure 4: Survey results from UC Davis gymnastics program [16]



In general, considering the effectiveness of these programs, the authors indicate there is probably a positive correlation between teaching sports and STEM, however more research needs to be done to prove this [14] [15] [16]. Additionally, it should be noted that there were no sources that argued for the ineffectiveness of teaching STEM through sport. As indicated by the previously described programs, many researchers, professors, parents, and other community members have assumed that these programs will work, despite this lack of evidence.

PRIOR RESEARCH ON JUMP ROPE- NON-JUMPERS

Proceeding with my assumption that this teaching method, while not definitively proven, is viable, I looked at the research done on the sport of jump rope in specific. In reviewing previous projects related to my own, there has been a minimal amount of analytical experiments involving jump rope, especially as how it is connected to STEM. Many experiments involving jump rope were designed for younger students and subsequently lacked quantitative results or complex connections between STEM and the sport. One program that fits this category is an experiment for beginning jumpers to determine the length of jump rope that is best suited for them [17]. The conclusion of this experiment only generally described how a “medium” sized rope would be best for a beginning jumper, since a long rope was too hard to control and a short rope would catch the jumper’s head or feet and require them to have a greater level of familiarity with the motion of the rope before using it [17]. Because my goal is to help experienced jumpers, who possess a greater level of familiarity with the motion of the rope, improve, this study provided minimal assistance.

Furthermore, in the STEM research on the sport, two researchers, Aristoff and Stone, investigated the aerodynamics of a jump rope and were able to derive a combination of non-linear differential equations that depended on the length of the rope and the distance a jumper holds the handles apart from one another [18]. This study considered the effect of drag on the rope, which shifts the structure of a rope from a catenary cable, which can be described in two dimensions, to a more complex shape that must be considered in all three dimensions [18]. The study also took into account the non-negligible thickness of the rope which was also found to affect the shape of the rope as it was revolving [18]. Two of the models these researchers created of the shape of the rope from the consideration of these variables can be found in Figures 5 and 6; in these figures, they modeled the shape of the rope in terms of the ratio between the length of the rope and distance between handles and the ratio between the drag and centrifugal force.

Figure 5: Model of the shape of a jump rope at different drag ratios [18]

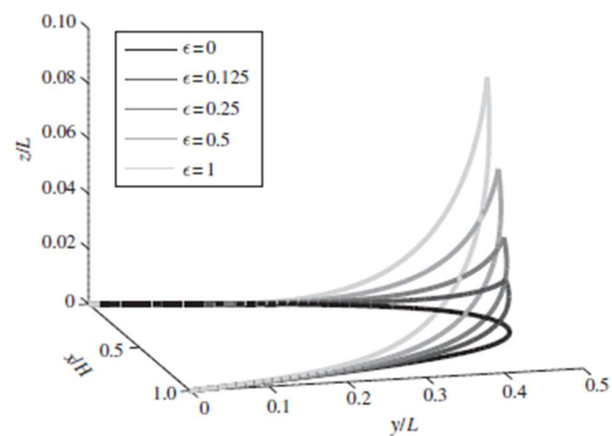
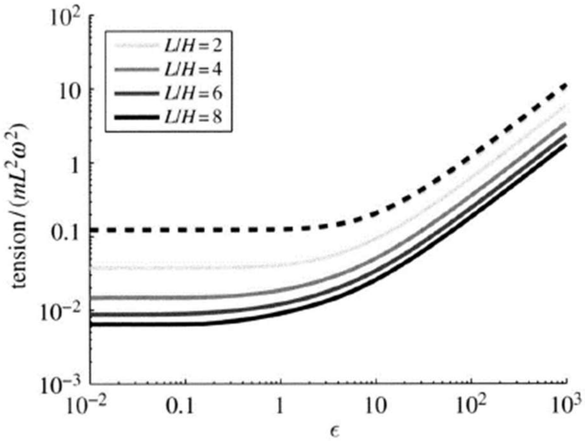


Figure 6: Model of the shape of a jump rope at different length and width ratios [18]



Overall from their research, Aristoff and Stone found that "a fast rope is one that is light and has a small diameter, a short length and a low drag coefficient" [18]. While necessary to accurately model the rope, the drag and thickness of the rope, were not tested in my project because aerodynamics is not a concept my intended audience, high-school aged jumpers, would have covered in school. The length of the rope and width between the handles, however, were variables I used while testing since they are more accessible for jumpers to understand independent of the aerodynamics of the rope.

One study done in Korea investigated the optimal width between a jumper's feet and their preferred posture through the use of infrared cameras [19]. The results of this study indicated that inexperienced jumpers were laterally imbalanced and the width of a jumper's feet did not vary significantly between experienced and inexperienced jumpers [19]. While this study did quantify some of the kinematics involved in jump rope, its conclusions were not relevant since they mainly concerned the effect of a jumper's skill level on their posture and in my project the skill level of a jumper was a variable that was held constant.

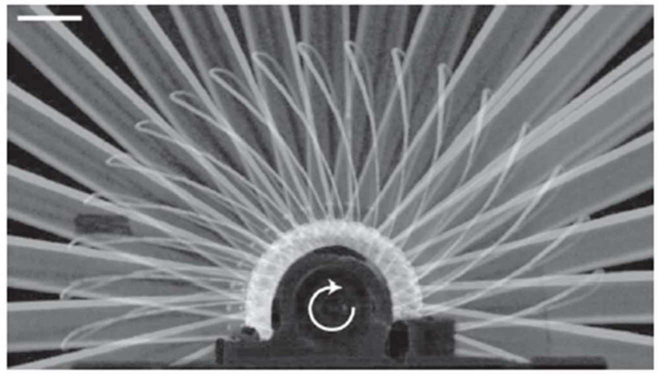
RESEARCH ON METHODS

Concerning the application of high-speed photography to jump rope, Harold "Doc" Edgerton, known for stroboscopic photography, involving a strobe light flashing at the same frame rate as the high-speed camera, photographed a woman as she was jumping rope, as shown in Figure 7 [20].

Figure 7: Edgerton image of a women jumping rope [21]

This application inspired the use of high-speed videography to analyze the rope; its original purpose, however, was only to develop the technology and not to analyze what was being photographed. Outside of this, the researchers that attempted to quantify the aerodynamics of a jump rope also used the stroboscopic technique in their work, shown in Figure 8.

Figure 8: Stroboscopic image of a jump rope [18]



Outside of these two examples, I did not find any other record of high-speed photography being used to analyze the sport.

PRIOR RESEARCH ON JUMP ROPE- JUMPERS

In addition to Nick Woodard's research on the history of the sport, several other jumpers have researched jump rope, however none that I found connected STEM to the sport, except for those relating to injury prevention.

The first of these is a thesis by former jumper Jen Gibbons (Evans), who wrote an "Analysis of Jump Landing Technique and Lower Extremity Injury in the Sport of Competitive Jump Rope" [22]. While injury awareness and prevention are critical in improving a jumper's performance, especially long term, the report focused on the anatomical side of jumping while my project was focused on the mechanical side of the sport.

The second thesis is one done by Murray Huber, a teammate of mine, who completed her honors capstone experience on "Exploring the Community Integration and Involvement of Immigrant Children in the US through Jump Rope Camps" [23]. While this project related to both jump rope and teaching, it focused less on competitive jumpers and STEM and more on beginning jumpers and the positive impact a sports camp can have on children who are not originally from the United States [23].

Noah Mancuso, who studied chemistry and global health at UNC Chapel Hill and created Carolina Jump Rope, created an after-school program called Jump Ahead as part of his capstone project. The goal of this program is to help fight childhood obesity through teaching students the importance of physical exercise and healthy eating. Of the research jumpers have done on the sport, this project is the most similar to the STEM and sports programs mentioned previously. However, the program's main goal is not to teach students about STEM, but instead how to be healthy; nonetheless, several health science concepts are taught through the program.

Kaylee Woodard (Couvillion) is a jumper and exercise science professor at Western Kentucky University who completed her PhD in motor behavior and sport psychology. One of her areas of research has centered on how expert jumpers direct their focus as they learn new skills and how their input can be applied to help instruct intermediate level jumpers [24]. In a conversation with Kaylee, she described that theory suggests that athletes follow external focus cues better, however in jump rope coaches tend to use internal cues; therefore, Kaylee wanted to determine whether coaches should adapt their methods to facilitate jumpers' learning. Additionally, Kaylee has researched how expert jumpers learn tricks and how their approach could be used to help teach advanced, but not expert, jumpers.

Lastly, Nick Woodard's work on the history of jump rope and its present state, which is referenced in section two to supply background to the status of the sport, was beneficial to understanding the origin of the sport as well as confirming my personal knowledge of the sport’s organizations [8].

SECTION FOUR- APPROACH

QUANTITATIVE JUMP ROPE TESTING

The first step in my project involved using high-speed videography to record the rope and jumper as different rope variables were changed; these variables included the jump rope length, the width the jumper holds their handles apart from one another, the type of handle, and the type of rope. Using this technology allowed me the opportunity to see changes in the rope or its speed while I was jumping and thus determine the effect of each variable. To perform this part of my experiment, I purchased 6 different types of handles and 5 different types of ropes; the other variables, the width between the jumper's hands and length of the rope, did not require the purchase of additional ropes. The different types of ropes and handles were ordered from Buyjumpropes.net, a company which many competitive jumpers in the United States purchase their ropes from and one with experience in the realm of competitive jumping that designs ropes to optimize jumpers' capabilities. Furthermore, the ropes and handles I chose were all chosen because they are ones that competitive jumpers commonly use for speed jumping. The ropes and handles that were purchased for the project are listed in Figure 9. Additionally, the specific rope types and handles, as well as the variances of the length of the rope and width between handles can be found in Table 1.

Figure 9: Ropes and handles purchased for testing

Table 1. Testing Variables

Handles	Ropes	Length	Width
Elite surge	*Coated Cable*	*-5%*	*Narrow*
Ultra-Light	*Uncoated Cable*	*Baseline*	*Baseline*
Bullet Comp	*Ultra-Thin (1.1 mm)*	*+5%*	*Wide*
Bullet FIT	*Ultra-Thin (1.3 mm)*		
RPM	*Freestyle cable (only fits in elite surge and bullet fit)*		
Korean			

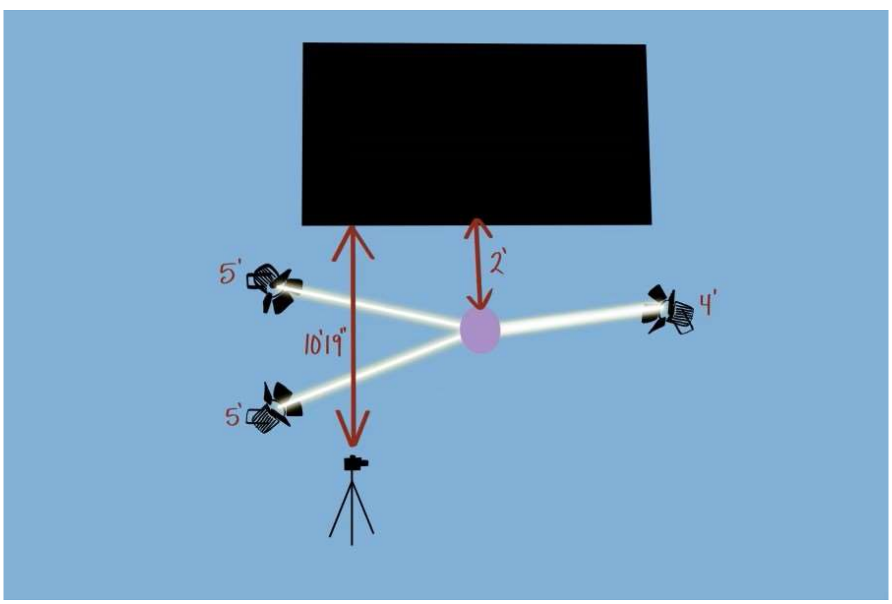
The different lengths of rope were based off of my height and the variation in the length of the rope was ±5% of the baseline length. As I was testing this variable, my baseline length was 84 inches, which is the current length of my personal speed rope; subsequently the short rope I used was 80 inches and the long rope I used was 88 inches. The ropes were all cut to the longest length and the handles were moved closer together when trials for the baseline and short lengths were performed. To test the width between my handles, I held my arms at a narrow, wide, or normal width throughout the entire length of the trial. This variable was left to the jumper's discretion since measuring and ensuring a consistent distance between a jumper's handles was outside of the scope of the technology used in this project.

If I were to have tried each combination of handle, rope, rope length, and width between my handles, it would have required 270 rounds of jumping. To validate each test, however, each combination would need to be tested 3 times, yielding 810 trials. Jumping for 10 seconds per round, and jumping each trial in succession, I would have needed to jump for 2.25 hours to complete all of the combinations. Factoring in breaks between each trial and the time needed to switch out ropes, the total time would be at least triple of this amount and would be too time intensive and exhausting for any jumper to complete while maintaining the integrity of the results.

To reduce the number of trials, as well as to prevent the data from being influenced by fatigue, I reduced the number of combinations to three per variable. These combinations were chosen to maximize the potential for variance between them. For example, the RPM, Ultra-light, and Korean rope handles were all tested with a normal length coated rope and tested at the normal width between the jumper's handles. The weight, bearing types, and size all vary for these handles, therefore optimizing the chance for variance between them.

Before testing these variables, I first tested a variety of combinations myself and with the help of my teammates to ensure that the camera and equipment set-up would be able to clearly record each of the ropes. These trials were only used to determine the experimental set-up and no data was taken from them. The first attempt to film the jump ropes used the outfacing video camera on an iPhone 8 and a Sony CX580 camera. Having the jumper face the cameras front on against both a white wall and blue wall allowed the rope to be somewhat visible, however the rope moved drastically from one frame to the next when analyzing the videos from both devices. Having the jumper's side face the camera, using the same white and blue walls, made the rope almost impossible to see throughout the duration of the videos from both devices. The next round of testing used a high-speed, Casio EX-F1 camera, with a frame rate of 600 frames per second, with three non-LED shop lights, one in front of the jumper, one behind the jumper, and one on the side of the jumper. A diagram of this set-up can be found in Figure 10.

Figure 10: Experimental testing set-up for high-speed camera and three lights



Non-LED shop lights were used, because LED lights are not suitable for high speed videography since their light will flicker, which, while undetectable to the human eye, becomes clear in footage taken with such a high frame rate. Additionally, to maintain consistency between the trials, I marked the position on the floor where my feet should land for each trial.

Professor Joel Lenoir is the mechanical engineering professor who oversees many of the engineering projects involving high-speed photography and videography; thus, he provided me with the equipment and expertise needed to see the rope as it is revolving around a jumper. A black backdrop was used, and the “worst-case” scenario was tested, where the jumper’s side was facing the camera. In the previous set-up, when three lights were used, the rope was visible as it moved frame to frame but could have been illuminated more clearly. Thus, in the final round of testing, I used four shop lights to achieve this. An image of this experimental set-up is found in Figure 11 as well as appendix B.

Figure 11: Experimental testing set-up for high-speed camera and four lights

Once the set-up was established, I moved on to testing each variable and rope combination. As I tested each combination, I jumped at a pace of 120 right-foot jumps per minute to ensure that the speed of the rope between the trials was held constant. For simplicity, when I had a miss while testing a rope combination, I started the trial over and tallied the number of misses I had for each combination. Furthermore, when I started too early, I would stop and try again instead of subtracting 10 jumps from my final score, like would occur in competition.

For these tests, a Tally Jump sensor was used to track my speed for each trial. This device is placed under the jumper's shoelaces and an app is used to track the speed of the jumper. The time of the trial's duration (10 seconds) and targeted number of jumps (20 jumps) were input into the app and, at the end of the trial, a graph of the jumper's speed over time was generated along with their total number of jumps. An example of the data collected by the sensor as well as a picture of the Tally jump sensor used are shown in Figures 12 and 13, respectively.

Figure 13: Data collected from Tally Jump

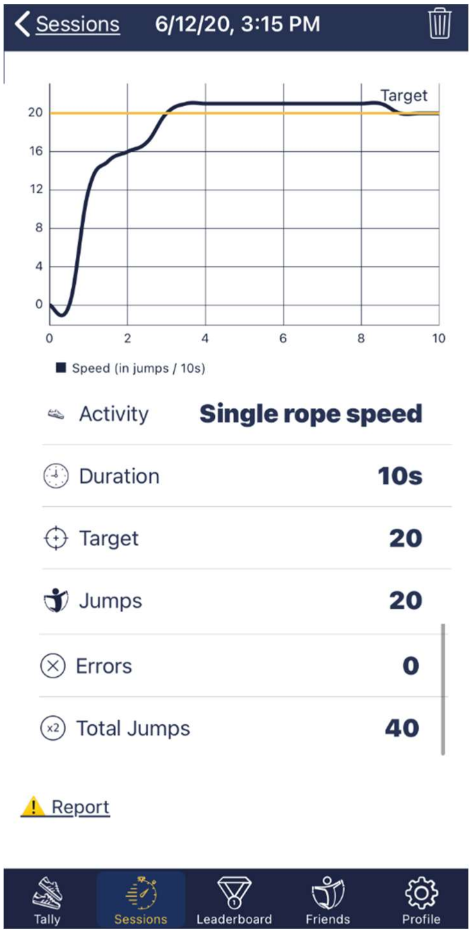


Figure 12: Tally Jump Sensor

As I analyzed the footage, I looked for differences in the arc of the rope and the rope's interaction with the ground and drew conclusions based off of my observations and experience in engineering. Once this was completed, my initial goal was to have jumpers from the Jumpin' Jaguars and Hotshots, TN jump rope teams test different combinations to determine the validity of my initial conclusions, however due to COVID-19 limitations this portion of the project was eliminated.

QUALITATIVE JUMP ROPE DISCUSSIONS

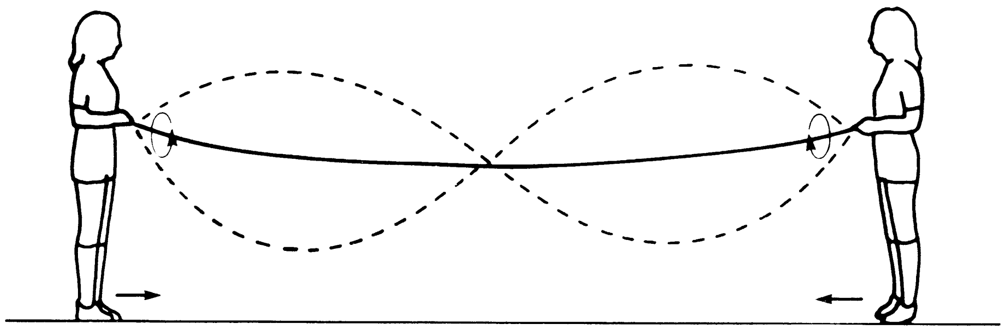
To supplement the analysis of the high-speed videos, I talked with a variety of jumpers to determine how they thought the sport was influenced by STEM. This indicated that qualifiable relationships between jump rope and STEM exist, even if they have not been fully quantified.

Relating my own experience in the sport to concepts related to my major, mechanical engineering, I have noticed connections to basic physics concepts such as energy, momentum, and waves. In freestyle jumping, the jumper should work “with” the motion of the rope, following the direction of its energy and rotational inertia, instead of trying to work against it. This is one concept that I use when teaching beginning jumpers; oftentimes, I tell them that the rope “knows” what it should be doing for different tricks, you just have to listen to and follow it.

Additionally, the weight of a rope will influence its rotational inertia and energy; for example, a lighter rope will bounce off the ground more than a heavier rope while a heavier rope will hold its shape more, and tangle less, than a lighter rope. Furthermore, a lighter rope requires less energy to rotate than a heavier rope; this can be a major factor in choosing a rope for multiple-under skills, where the rope goes under the jumper several times in the span of one jump, or speed. Many coaches already use these concepts, without explicitly relating them to STEM by requiring beginning jumpers to use heavier beaded ropes as they are learning speed to solidify their form before they are able to use lighter freestyle or wire ropes. Similarly, for double dutch, some coaches will have beginning jumpers use cloth ropes, which are much lighter than the traditional beaded ones, so that they can learn to control the rope before they are given beaded ropes to use.

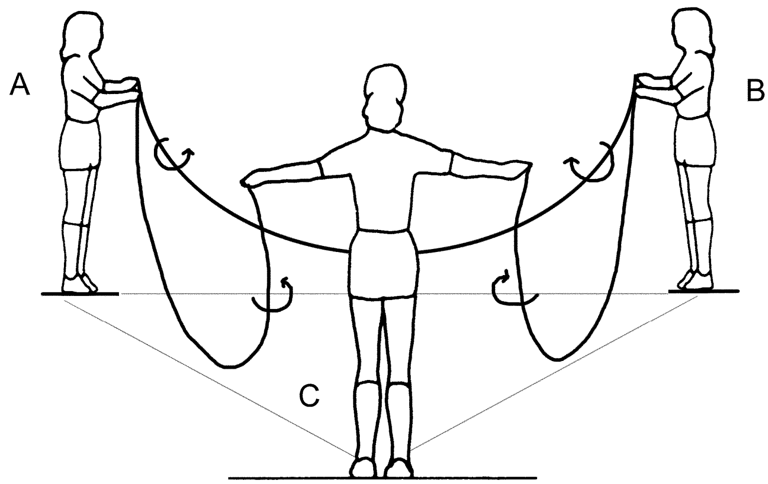
Lastly, some long rope tricks, such as an eggbeater, shown in Figure 14, create a node in the middle of the rope, making a full wave between turners instead of just half of a wave like a normal set of double dutch ropes.

Figure 14: Eggbeater, where rope forms a complete wave between turners [25]



My teammate Murray Huber, mentioned earlier in reference to her thesis on a jump rope camp for international and refugee children, explained how jump rope related to one of her fields of study: mathematics. First, she described how various geometry concepts, like angles and midpoints, help determine the success of different long rope skills, such as triangle, shown in Figure 15, and square, similar to triangle but with four turners and ropes instead of three, because jumpers must position themselves with these concepts in mind.

Figure 15: Turners positioned for triangle [25]



Murray also mentioned that jumpers need to apply angles to the sport as they learn different turning skills so they can rotate themselves accordingly to do a 90-, 180-, and 360-degree turn. Murray continued that as jumpers are rotating, they also must be aware of the axis about which the rope is rotating so that it does not hit them during or after the rotation skill. Furthermore, basic math skills, such as counting, are used by the jumper in multiple-under skills to ensure the rope is rotating around them enough times.

One final relationship Murray drew between her field and the sport is the connection between two different push-up based skills and STEM. The first is a single rope skill where a jumper starts in a push-up position, jumps off the ground while turning the rope under them, and then lands in a push-up position. In this trick, the jumper must bring their legs into their chest to decrease their size, and make it easier for the rope to rotate around them in between the two push-up positions. Similarly, Murray mentioned a double dutch skill, turntables, where a jumper begins in a push-up position and as the rope passes under them, brings their legs into their chest and rotates 90-degrees before going back into another push-up. As jumpers are learning this trick, it is emphasized that they need to ball up as much as they can to make it easier for them to rotate the full 90 degrees; this is because by doing so, a jumper is decreasing their moment of inertia by decreasing their "radius".

Consulting another former teammate, Hannah Chaney, who studied biology, she described how if the rope is continually hitting her in the same spot, she will start to think about the mechanics of the rope and her body in relation to where it is hitting her and how she could apply physics to resolve the issue.

Lastly, talking with Kaylee Woodard, referenced earlier for her research on the sport of jump rope, she noted the relationships she saw between various physics, exercise science, and biomechanics topics and the sport. To start, Kaylee mentioned the influence the length of a handle has on the leverage a jumper has while completing tricks in freestyle jumping. Comparing long and short handles, the two main types that jumpers use, longer handles offer the jumper more leverage while shorter ones offer less. By using a longer handle, the jumper needs to exert less force to rotate the rope since, in this case, work is equal to the length of the handle multiplied by the force applied by the jumper.

Relating to the field of biomechanics, Kaylee also described the biomechanical differences between ankle and knee jumpers since ankle jumpers have less ground contact and can jump faster, but lower, while knee jumpers have more ground time and can jump higher, but slower. Both of these jumping styles also have different injury profiles, since ankle jumpers rely on their calf muscles more while knee jumpers use their quadricep muscles more.

In our conversation, Kaylee also described how she drew many basic relationships between jump rope and various school subjects in a program she helped develop called

Jump Start. While the concepts focused on in Jump Start are meant for elementary school students, the premise of the program implies that the relationships between jump rope and STEM can be used to help students better understand what they are learning in school. Additionally, several of the elementary concepts that are introduced in the Jump Start curriculum, such as speed and acceleration, can be reviewed in terms of jump rope for high school students in the process of introducing more advanced concepts, such as energy and Newton's second law. Other topics described in this program are anatomy and physiology, through the angles of different body parts and the function of ligaments and tendons, and physics, through the friction present when a rope wears down and breaks in certain locations. Additionally, Kaylee mentioned that an activity for older students would ask them to apply the engineering and physics concepts they had already learned in school to design the optimal rope to use.

As Kaylee was describing Jump Start, she described that the basis of this program came from the idea that motor learning memory consolidation is enhanced when aerobic exercise is done in tandem with learning. Therefore, jump rope would be an ideal medium for teaching students since it would provide the element of aerobic exercise. She also explained that when you can feel the concept you are learning about, such as the speed or acceleration of the rope, your understanding of it increases more than if you were just passively learning and listening to a teacher describe it.

Through talking with former and current jumpers, as well as incorporating my own experience in the sport of jump rope, I have found that jumpers, through both experience and research, have noted relationships between STEM and jump rope. Specifically, the fields of physics, mathematics, and biomechanics were the most common ones referenced in relation to the sport; however, it should be noted that while these fields also correlate with the fields of study of the jumpers I spoke with, relationships between jump rope and other STEM disciplines are also likely present. Nonetheless, despite this small sample size, it is apparent that STEM has a notable influence on the sport of jump rope.

LESSON PLAN DEVELOPMENT

Using the qualitative and quantitative jumping data, a lesson was developed for high school-aged competitive jumpers. Due to the restrictions currently in place from COVID-19, this lesson has not been taught to jumpers, but is ready to be taught when it is safe to do so. The goal of this lesson is to inform jumpers how STEM relates to their sport, giving them the opportunity to improve their jumping ability as well as showing them that STEM has viable applications outside of the classroom and sparking their interest in the field. The lesson uses the Biological Sciences Curriculum Study (BSCS) 5E instructional model of inquiry-based learning to keep jumpers actively engaged as they were learning about STEM [26]. The BSCS 5E model adheres to the constructivist teaching approach, where students gradually derive knowledge from their experiences over time [26]. In this model, students are actively involved in the learning process and are oftentimes performing hands-on, minds-on activities as opposed to passively listening to a lecture [26].

The 5 phases that make up the BSCS 5E model are engage, explore, explain, elaborate, and evaluate [26]. In the engage phase, the instructor uses a teachable moment to spark students’ interest in the topic and evoke questions which will be answered in the subsequent phases [26]. The explore phase is where students are first given the chance to investigate the concepts mentioned in the engage phase through an activity [26]. During this phase, the teacher serves to prompt and guide students' focus instead of directly explaining what students are experiencing. This portion of the lesson allows students to gain a unified set of experiences for the instructor to use in the following phases to more formally introduce the concepts to the students [26]. Next, in the explain phase, students are asked to describe the observations they made from their exploration; this is then followed by the instructor combining their observations and explaining them more formally [26]. This is the phase where necessary technical terms are defined for students to use to understand their own experiences [26]. Next, the elaboration phase allows students to build off of the concepts introduced in the explanation portion of the lesson and further develop their understanding of the topic at hand [26]. This is oftentimes done through applications similar, but not identical, to the one initially used in the exploration phase [26]. Lastly, the evaluate phase is where the students' understanding of the topic is assessed, even though informal assessments will be embedded throughout the lesson [26]. A summary of each phase is shown as Figure 16.

Figure 16: Purposes of the phases in the BSCS 5E Instructional Model [26]

ENGAGE
- Create interest and stimulate curiosity.
- Provide a meaningful context for learning.
- Raise questions for inquiry and science practices.
- Reveal students' current ideas and beliefs.

EXPLORE
- Provide experience of the phenomenon.
- Examine students' questions to test their ideas.
- Investigate questions and problems.

EXPLAIN
- Introduce concepts and practices that can be used to interpret data and construct explanations.
- Construct multimodal explanations and justify claims in terms based on evidence.
- Compare different explanations generated by students.
- Review current scientific explanations.

ELABORATE
- Use and apply concepts and explanations in new contexts.
- Reconstruct and extend explanations using different modes, such as written language, diagrammatic and graphic modes, and mathematics.

EVALUATE
- Provide an opportunity for students to review and reflect on their understanding and skills.
- Provide evidence for changes to students' understanding, beliefs, and skills.

Source: Adapted from AAS 2008.

The BSCS 5E instructional model was derived from successful teaching models by Johann Herbart, John Dewey, and Robert Karplus, who are all major contributors to the current understanding of teaching and learning [26]. Furthermore, field testing done on the model indicates both the effectiveness of active learning and the BSCS 5E model, especially when compared to other teaching approaches [26]. Additionally, this method of delivery was chosen since jumpers are used to being active at practice and the BSCS 5E approach requires students' active participation throughout the entire lesson. While it might have been more time efficient to develop and teach a lesson that involved a more passive method of learning, such as lecturing, jumpers would likely not have learned as effectively.

Applying this model to my own project, each phase of the BSCS 5E model was described in the lesson plan I created, which can be found in appendix I. The lesson was designed to be taught to a group of 5-20 jumpers during one of their scheduled practices, at the place where they usually practice. It will start with a video of a well-known jumper who is currently working in the STEM field, doing something relating to their current field of work. This will introduce jumpers to the ideas that STEM relates to everything, however, sometimes we just do not realize it. Additionally, this will give the jumpers an example of a female jumper with a successful career in STEM. After this video, while jumpers are doing their regular warm-up, I will ask them questions about ways they think STEM might relate to their sport as well as observe their current jumping and rope preferences. During the warm-up, I also will describe the goal of my project so they can understand how their participation is helping to contribute to the body of knowledge about the sport as well as how a project on the sport might be structured. This will serve as the engage phase of the lesson where jumpers will begin to question how exactly their sport relates to STEM and what STEM disciplines are the most relevant to the sport.

After the warm-up, I will ask the jumpers to experimentally investigate the influence that the width they hold their handles has while they are jumping. Jumpers will be assigned in groups of two, where older and younger jumpers are paired so jumpers with a broader knowledge of STEM are with those that have had less experience with it. Each group will be asked to create an experiment to test how the three different widths a jumper holds their handles impacts their jumping and the science of the sport. The jumpers will alternate who is jumping and make observations both as they watch their partner jump as while they jump. They will be asked to apply the concepts they have already learned in school as they are making these observations and record them on a handout similar to the one included at the bottom of the lesson plan, found in appendix J. During this phase, I will ask jumpers about the types of science they think affect the rope as they are jumping, how the rope's motion and interaction with the ground changes as the jumper manipulates the width between their handles, and how the width between a jumper's handles might impact the rest of the rope.

After jumpers have recorded their observations, we will move to the explain portion of the lesson and reconvene as a group to discuss what they noticed and what their explanation for the effect that holding their handles at a variety of widths had on their jumping. To help jumpers articulate their observations I will ask them about what STEM concepts they found the most relevant to their observations, if they noticed any variation in how they rope felt while jumping with the different widths between their handles, and how their perception of their control of the rope varied between the trials. I will then introduce the idea of momentum and impulse in relation to this variable to build on the jumpers' observations.

Moving on, jumpers will be asked to return to their groups and transfer these concepts to the investigation of a new variable: the length of the jump rope, the type of handle, or the type of rope. This will allow me to introduce other relevant terms, depending on the variable they are asked to investigate. For the length of the rope, I will introduce terms such as moment of inertia, kinetic energy, speed, energy conservation, and Newton's second law. For the type of handle, I will introduce friction, speed, and force. And for the type of rope, I will introduce friction, rotational energy, and the coefficient of restitution. Throughout this phase of the lesson, I will also ask jumpers how they could apply these concepts to their freestyle jumping and why they think they prefer to use the specific rope they use for speed. This will constitute the elaborate section of the lesson since many of the ideas pertaining to the width a jumper holds their handles also correlate to the other variables.

After the elaborate phase of the lesson is complete, I will review the relationships we discussed between jump rope and STEM during the cool down and stretching portion of practice. Here jumpers will be asked to provide any feedback they had on the lesson and my delivery of it, as well as to answer a survey to determine how the lesson influenced their perception of and interest in STEM. Lastly in the evaluate portion, I will ask the coaches to record jumpers speed scores two weeks prior and two weeks after the jumpers receive the instruction so that an improvement in their performance can be determined.

SECTION FIVE- DATA ANALYSIS

During the initial jumping trials, I focused on the equipment set-up to ensure that meaningful observations could be made from the videos. Therefore, these videos were only used for this purpose and were not analyzed to determine any relation between STEM and jump rope. Once the proper set-up was established, I analyzed the subsequent videos by comparing ones from two different rope combinations and making observations on the visual differences I noticed between them. To reduce the number of videos I would need to analyze, I compared three different sets of videos for each independent variable. Ideally, the rope would have been clearly visible as it was moving in each of these videos, however this was not the case for several of the trials. The selected combinations for each of these variables can be found below in Table 2 where the combinations that could not be analyzed due to the footage quality are marked with a strikethrough.

Table 2: Different Testing Combinations

Width	Length	Handle type	Rope type
Bullet FIT, freestyle cable, short	*Ultra-light, coated, normal*	*Ultra-light, coated*	~~*RPM, coated and ultra-thin*~~
~~*Elite surge, ultra-thin*~~	*Korean, coated, wide*	*RPM, coated*	~~*Bullet comp, coated and uncoated*~~
Bullet comp, uncoated, normal	*Bullet comp, coated, narrow*	*Korean, coated*	~~*Elite surge, freestyle cable and ultra-thin*~~

Starting with comparing different widths a jumper holds their handles, I found that the greater the width the handles are apart from one another, the lesser the rope interacts with the ground. To test this variable, I used the Bullet Fit handles with the freestyle cable at the short length and the Bullet Comp handles with the uncoated wire at the normal length. Additionally, I had planned to assess the Elite Surge handles with the ultra-thin wire, however, the rope was not sufficiently visible in the video recordings for me to make any significant observations. For every width, the tip of the rope deflected as it touched the ground, inciting a wave to move through the rest of the rope as it rotated around the jumper. The subsequent oscillations were greatest when the handles were held at a narrow distance while least when the handles were held at a wide distance. This interaction between the rope and the ground, relative to the width of the jumper's handles, relates to the momentum of the rope. As described in the impulse-momentum theorem, the more contact the rope has with the ground, the longer its collision with it, yielding a greater transfer of momentum. This interrupts the normal rotation of the rope, at a magnitude proportional to that of the momentum, and causes the jumper to restore the lost momentum by turning their handle. Connecting this to one of the NGSS, it relates to HS-PS2-2 where students are supposed to "use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system" **[27]**.

Moving on to comparing the different lengths of the rope, I observed that despite the difference in length, the ropes were moving at similar speeds. For this test, I compared the long and normal lengths of a coated wire with the Ultra-Light handles held at a normal width, the short and normal lengths of a coated wire with the Korean handles held at a wide width, and the short and long lengths of a coated wire with the Bullet Comp handles held at a narrow width. To determine the speed of the rope, I counted the number of frames it took for the rope to make one full revolution. The average number of frames for one rope revolution as well at their standard deviation can be found in Table 3.

Table 3: Average and standard deviation of the number of frames in one revolution of the rope

Rope	Average Number of Frames in One Revolution	Standard Deviation of Frames in One Revolution
Ultra-Light handles, coated wire, normal width	153.5	2.5
Korean handles, coated wire, wide width	135.5	1.5
Bullet Comp handles, coated wire, narrow width	144	1

From counting the number of frames between each of the different ropes, I found that the number of frames was consistent despite the difference in length. This makes sense since the length of each trial and number of jumps per trial were held constant; therefore, I can assume that the overall speed of the rope does not vary depending on its length. Through also assuming the rope moves with a constant angular acceleration between trials, it can be deduced that the rotational momentum must be changing. For a hoop rotating about its diameter, a rough approximation for the motion of a rope, the moment of inertia is equal to one half of the mass of the rope multiplied by the square of the radius of the rope. For a longer rope, assuming that the rope type is held constant, both the mass and radius of the rope increase, yielding a larger value of moment of inertia, confirming our expectations. The energy of the different rope lengths can also be compared using the rope's moment of inertia. Once again assuming that the speed of the rope is held constant between two different rope lengths, the kinetic energy would increase proportionally to the increase in the moment of inertia. This idea relates to the NGSS HS-PS3-2 where students are to understand the conservation of energy **[27]**. Similarly, continuing with the assumption that the angular acceleration is constant between each rope length, applying Newton's second law reveals that the torque also increases proportionally to the increase in moment of inertia. This connects to one of the NGSS, HS PS2-1, where students learn about Newton's second law **[27]**.

Next, when I analyzed the videos where the handle type was changed between the rope combinations, I compared videos of the RPM and Ultra-light handles held at a normal width and with a normal length coated wire filmed from the front and videos of the Korean and RPM handles held at a normal width and with a normal length coated wire filmed from the side. Comparing each set of videos, I could not discern any noticeable difference between the different handles. Despite this, there is likely a difference in the force required to rotate each of the handles since each has a different weight, length, and diameter. Similarly, the energy lost due to friction also likely varies between the handles; this is because the Ultra-Light and Korean handles rotate about a plastic dowel while the Elite Surge, Bullet Fit, and Bullet Comp handles use ball bearings, which likely incite much less friction. Additionally, both the Bullet Comp and RPM handles, which use an oilite bushing, advertise that they have a "near frictionless spin" **[28] [29]**. Therefore, a different analysis technique, such as one to better quantify the friction differences between the handles, should be used in the future.

Lastly, while my initial plan included rope type as a variable for analysis, limitations from COVID-19 prevented me from obtaining all of the footage needed to successfully make significant observations about this variable. If I continue this project in the future, this variable will be investigated further.

From these variables, I concluded that several STEM concepts, such as the impulse-momentum theorem, Newton's Second Law, and the conservation of energy and momentum, relate to the length of a jump rope and width a jumper holds their handles. While additional testing needs to be performed in order to draw conclusions about the influence of STEM on the different handle and rope types, the conclusions made about the other two variables indicate that a discernible relationship between jump rope and STEM does indeed exist.

SECTION SIX- CONCLUSION

Throughout this project I have established the relationship between STEM and jump rope both quantitatively, through the analysis of different variables during speed jumping, and qualitatively, through the experiences from STEM-minded jumpers. The conclusions drawn from these two aspects of the project suggest that STEM has a meaningful impact on the sport. Furthermore, the connection between the two can be leveraged to make STEM more accessible to jumpers by demonstrating STEM concepts to them through jump rope. This was accomplished by transforming the relationships between jump rope and STEM into a lesson plan, which was created following the BSCS 5E instructional model and will later be used to teach high school aged jumpers the connections between their sport and STEM.

Since the testing capacity for this project was reduced due to COVID-19, the conclusions drawn from the analysis of myself jumping should be validated with others jumping as well. Additionally, more advanced technology, such as a motion analyzing software to better quantify the visual variances in the rope, as well other ways to quantify the energy loss and movement of the rope, could be used to more precisely define the link between STEM and jump rope. A jumper's non-quantifiable observations while they are testing different rope combinations, for example if a certain combination requires more control to turn the handle without missing versus another, would be an additional element to consider as different variables are analyzed in future research. Additionally, as mentioned in section three, the effectiveness of using a sport such as jump rope to teach STEM has not previously been quantified; this could be accomplished, through control and experimental test groups, when the lesson plan is eventually taught to jumpers. Combining the foundation of my CE/T with the kinesiology field, additional research could be done to determine how physics can be used to tailor a rope to a specific jumper. Furthermore, in my conversation with Kaylee, she mentioned that there should be more research on the sport overall to quantify different physical attributes of a jumper as they are jumping, such as their caloric use, aerobic capacity, and blood-lactic levels. These are all measurements that have been studied extensively for more popular sports, such as running and cycling, and would allow for researchers to better understand the physiology of the sport. Additionally, Kaylee described how the impact forces present for advanced power skills are not currently known which, if quantified, could help jumpers prevent injury. In terms of engineering, this work could be used to develop new jump ropes as well as to inform jumpers of which type of rope scientifically best suits their needs. Lastly, while this research only examined speed jumping, the relationships between STEM and freestyle jumping, as well as double dutch jumping, will likely be similar to the ones I found.

This CE/T has been presented at WKU's Student Research Conference in 2020 and will be presented at the next National Collegiate Jump Rope Association's University Jump Rope Summit. Additionally, once the lesson plan is further refined, it will be shared with those in the jump rope community.

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APPENDIX

APPENDIX A- PURCHASED ROPES AND HANDLES

Handles						
Item	Cost	Weight (oz)	Diameter (in)	Length (in)	Action	Other features
Elite surge 3.0 Rope	$ 29.99	1	0.6	5	Ball bearings	
Ultra-light 3.0	$ 6.50	0.6	0.87	5.35	Plastic dowel	
Bullet fit rope	$ 49.99	2.5	0.6	6.6	Ball bearings	
Bullet COMP Rope	$ 44.99	1	0.5-0.7	5.5	Ball bearings	"near frictionless spin"
RPM Session 3.0	$ 55.00	4.2 (w 12 ft coated)	0.5	5.5	Oilite bushing	"near frictionless spin"
Korean rope	$ 25.00	?	1.1-0.7	5.2	Ball bearing	

Ropes		
Item	Diameter	Coating
Replacement speed cable	3/32 in	Nylon
Non-coated Bare wire cable - 1/16"	1/16 in	No
Ultra-thin Speed Cable - 1.3mm	1.3 mm	PTFE
Ultra-thin Speed Cable - 1.1mm	1.1 mm	PTFE
Freestyle cable	1/8 in	PVC

APPENDIX B- TESTING SET-UP

Third round using high speed camera and 3 lights:

Fifth round using high speed camera and 4 lights:

APPENDIX C- PRELIMINARY TESTING ORDER

First round testing (iPhone and Sony CX580 camera, no tripod)			
Tested:	Front View:	Side View:	Notes:
Bullet comp rope with blue coated cable	Yes	No	
Bullet comp rope with 1.1 mm thin cable	No	No	Cable didn't stay very well in handles
Elite surge with 1.3 mm thin cable	Yes	No	
Bullet Fit with red coated cable	Yes	No	
Ultra-light with orange coated cable	Yes	Yes	
RPM with clear coated cable	Yes	No	

Second round testing (high speed camera, 3 lights, at Y)			
Tested:	Front View:	Side View:	Notes:
Korean rope with clear coated cable	No	Side	Too dark to see

Third round testing (high speed camera, 3 lights, at Natcher)			
Tested:	Front View:	Side View:	Notes:
Bullet comp rope with blue coated cable, long	Yes	No	Hard to see cable against black
Elite surge with 1.3 mm thin cable, (too) long	No	No	Cable didn't stay very well in handles

Fourth round testing (high speed camera, 2-3 lights, at Y)		
Tested:	Front View:	Side View:
Korean with clear coated cable, normal	No	Yes
Elite surge with 1.3 mm thin cable, short	No	Yes
RPM with clear coated cable, normal	Yes	Yes
Bullet comp with blue coated cable, short	Yes	No
Bullet fit with freestyle cable, normal	Yes	No
Ultra-light with orange coated cable, normal	No	Yes

Fifth round testing (high speed camera, 4 lights, at HCIC)		
Tested:	Front View:	Side View:
Korean with clear coated cable, short	No	Yes
Elite surge with 1.3 mm thin cable, normal	No	Yes
Ultra-light with orange coated cable, long	No	Yes
Bullet comp with uncoated cable, short	No	Yes
RPM with 1.1 mm thin cable, normal	No	Yes
Bullet fit with freestyle cable, short	No	Yes
Bullet comp with uncoated cable, normal	No	Yes
RPM with 1.1 mm thin cable, short	No	Yes

APPENDIX D- PRELIMINARY TESTING DATA

Trial	Rope	Handles	Length (in)	Width	Score 1	Score 2	Score 3	Avg. Score	Errors	View
1	C (blue)	BC	88	No	19	20	19	19.3	0	Side
2	C (blue)	BC	88	W	21	19	20	20.0	0	Side
3	C (blue)	BC	88	Na	19	20	20	19.7	2	Side
4	UT (1.3 mm)	ES	92	No	21	19	19	19.7	0	Side
5	UT (1.3 mm)	ES	92	W	18	19	19	18.7	0	Side
6	UT (1.3 mm)	ES	92	Na	20	20	20	20.0	~10	Side
7	C (clear)	K	84	No	20	18	20	19.3	0	Side
8	C (clear)	K	84	W	20	21	21	20.7	1	Side
9	C (clear)	K	84	Na	21	20	20	20.3	1	Side
10	UT (1.3 mm)	ES	80	No	21	21	20	20.7	2	Side
11	UT (1.3 mm)	ES	80	Na	19	18	18	18.3	3	Side
12	UT (1.3 mm)	ES	80	W	21	20	20	20.3	1	Side
13	C (clear)	R	84	No	20	20	20	20.0	0	Side
14	C (clear)	R	84	W	21	21	20	20.7	0	Side
15	C (clear)	R	84	Na	19	19	19	19.0	0	Side
16	C (clear)	R	84	No	20	20	19	19.7	0	Front
17	C (clear)	R	84	W	19	21	20	20.0	0	Front
18	C (clear)	R	84	Na	19	19	20	19.3	1	Front
19	FC	BF	84	No	19	19	18	18.7	0	Front
20	FC	BF	84	Na	19	18	18	18.3	0	Front
21	FC	BF	84	W	19	19	19	19.0	0	Front
22	C (blue)	BC	80	No	20	20	19	19.7	0	Front
23	C (blue)	BC	80	W	21	19	21	20.3	5	Front
24	C (blue)	BC	80	Na	19	20	19	19.3	1	Front
25	C (orange)	UL	84	No	19	19	19	19.0	0	Side
26	C (orange)	UL	84	Na	19	18	18	18.3	0	Side
27	C (orange)	UL	84	W	20	20	20	20.0	1	Side
28	C (clear)	K	80	No	19	19	19	19.0	3	Side
29	C (clear)	K	80	W	20	21	20	20.3	2	Side
30	C (clear)	K	80	Na	20	19	19	19.3	4	Side
31	UT (1.3 mm)	ES	84	No	19	19	19	19.0	0	Side
32	UT (1.3 mm)	ES	84	Na	19	19	19	19.0	?	Side

Trial	Rope	Handles	Length (in)	Width	Score 1	Score 2	Score 3	Avg. Score	Errors	View
33	UT (1.3 mm)	ES	84	W	20	21	20	20.3	2	Side
34	C (orange)	UL	88	No	19	19	19	19.0	0	Side
35	C (orange)	UL	88	Na	18	18	18	18.0	2	Side
36	C (orange)	UL	88	W	19	19	20	19.3	1	Side
37	UC	BC	80	No	20	20	20	20.0	0	Side
38	UC	BC	80	Na	19	19	18	18.7	3	Side
39	UC	BC	80	W	21	21	21	21.0	0	Side
40	UT (1.1 mm)	R	84	No	20	20	20	20.0	0	Side
41	UT (1.1 mm)	R	84	Na	19	18	18	18.3	8	Side
42	UT (1.1 mm)	R	84	W	20	21	20	20.3	6	Side
43	FC	BF	80	No	19	19	19	19.0	2	Side
44	FC	BF	80	W	20	20	19	19.7	2	Side
45	FC	BF	80	Na	19	18	19	18.7	3	Side
46	UC	BC	84	No	19	20	19	19.3	0	Side
47	UC	BC	84	W	20	20	20	20.0	0	Side
48	UC	BC	84	Na	18	18	22	19.3	0	Side
49	UT (1.1 mm)	R	80	N	19	19	19	19.0	1	Side
50	UT (1.1 mm)	R	80	Na	19	19	19	19.0	0	Side
51	UT (1.1 mm)	R	80	W	21	21	20	20.7	3	Side

Key:
Widths: Narrow- Na Wide- W Normal- No
Handles: RPM- R Korean- K Bullet COMP- BC Bullet FIT- BF Ultra-light- UL Elite Surge- ES
Ropes: Ultra-thin- UT Uncoated- UC Coated- C (color) Freestyle Cable- FC

APPENDIX E- ANALYSIS OF PRELIMINARY TESTING DATA

Variable	Test	Analysis		
Width	Bullet fit handles, freestyle cable, all widths, short length	Normal- tip of rope deflecting on ground some (doesn't touch the ground a lot) and continues to deflect as it rotates	Narrow- tip of rope deflects as it hits ground then rotates	Wide- lower clearance over my head, rope still deflects from touching ground (but possibly less so)
	Elite surge handles, ultra-thin, all widths, short and normal length	Normal- Unable to see rope	Narrow- unable to see rope	Wide- unable to see rope
	Bullet comp handles, uncoated wire, all widths, normal length	Normal- tip of rope moves a lot but the evens out as the rope rotates	Narrow- Unable to see rope	Wide- doesn't touch the ground as much (doesn't deflect as much)
Length	Ultra-light handles, coated wire, 2 lengths, normal width	Normal- rope vibrating some, not symmetrical horizontally, 156 frames for 1 rope rotation	Long- Rope vibrates a lot, seems more irregular, evens out at 12:00, 151 frames for 1 rope rotation	Different views (one side one front) Average: 153.5 frames SD: 2.5 frames
	Korean handles, coated wire, 2 lengths, wide width	Normal- Looks pretty similar to short, 134 frames for 1 rope rotation	Short- Rope doesn't touch the ground a lot, waves move up entire rope (but low amplitude), 137 frames for 1 rope rotation	Average: 135.5 frames SD: 1.5 frames
	Bullet comp handles, coated wire, 2 lengths, narrow width	Short- Rope doesn't noticeably deflect a lot (but catches on my ponytail a lot), maybe one "wave" passes through rope before it returns to steady position, 145 frames for 1 rope rotation	Long- Waves that move from tip to end are present but with a lower amplitude and constantly disturb the rope, 143 frames for 1 rope rotation	Average: 144 frames SD: 1 frame

Handle Type	Comp of all at normal length/width and coated wire	Ultra-light and RPM (front view)- no noticeable difference from videos	Korean and RPM (side view)- no noticeable difference from videos	
	RPM handles, coated and ultra-thin wires at normal width/length	Coated- Did not analyze since couldn't see ultra-thin	Ultra-thin- Unable to see rope	
Rope Type	Bullet comp handles, coated and uncoated wires at normal width/short length	Coated- Unable to see rope	Uncoated- deflection after rope hits ground (unsure how much more/less)	Different views (one side one front)
	Elite surge handles, freestyle cable and ultra-thin wire at normal width/length	Freestyle- Did not get the chance to test this combination	Ultra-thin- Unable to see rope	

APPENDIX F- SCREEN GRABS FROM PRELIMINARY TESTING

First round (iPhone, Natcher, blue background):

Second round (Sony CX580 camera, Natcher, blue background):

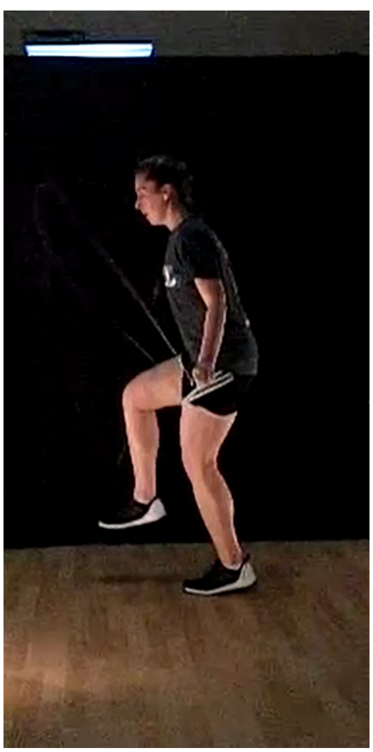
Third round (High speed camera, YMCA, black background):

(regular filming)

(high speed filming, same set-up)

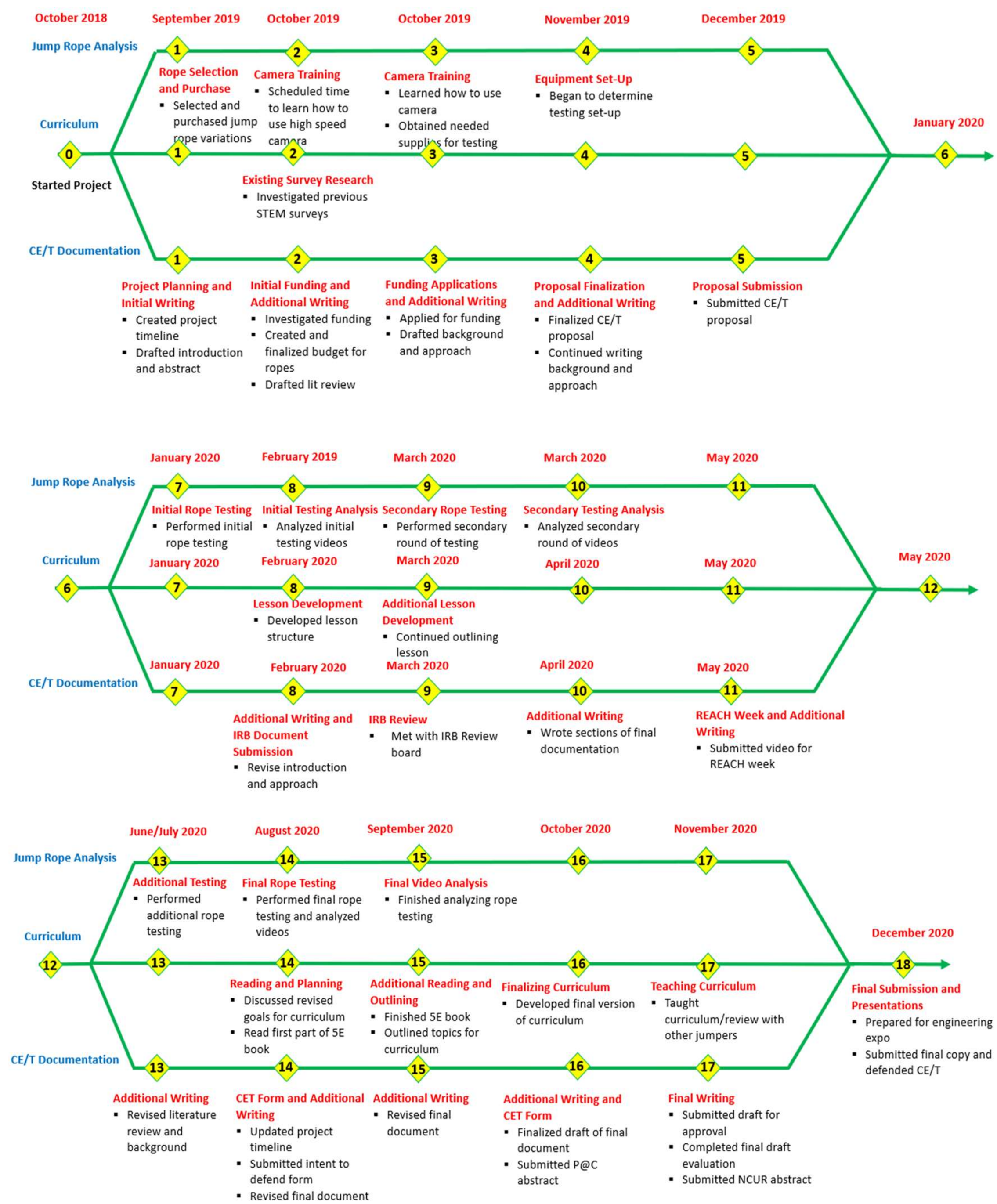
Fourth round (High speed, Natcher, black background):

Fifth round (High speed, YMCA, black background):



Sixth Round (High speed, HCIC, black background):

APPENDIX G- MACRO PLAN



APPENDIX H- BILL OF MATERIALS

Bill of Materials					
Components					
Item	**Description**	**Order Site**	**Quantity**	**Unit Cost**	**Cost**
Replacement speed cable - 3/32"	Wire, coated	https://buyjumpropes.net/3-32-nylon-coated-replacement-speed-cable/	1	$3.00 Each	$0.00*
Non-coated Bare wire cable - 1/16"	Wire, un-coated	https://buyjumpropes.net/bare-wire-replacement-jump-rope-cable/	1	$3.50 Each	$0.00*
Ultra-thin Speed Cable - 1.3mm	Wire, thin	https://buyjumpropes.net/ultra-thin-cable/	1	$11.50 Each	$0.00*
Ultra-thin Speed Cable - 1.1mm	Wire, thinnest available	https://buyjumpropes.net/ultra-thin-speed-cable-1-1mm/	1	$8.10 Each	$0.00*
Freestyle cable- 1/8"	PVC coated wire	https://buyjumpropes.net/1-8-freestyle-replacement-cable/	1	$3.00 Each	$0.00*
Outdoor Heavy Speed Cable	Heaviest, most durable, nylon coated	https://buyjumpropes.net/3mm-outdoor-heavy-cable/	1	$4.00 Each	$0.00*
Thin to thick cable	Changes thickness (smaller diameter underfoot)	https://buyjumpropes.net/thick-2-thin-cable/	1	$4.00 Each	$0.00*
Korean Rope	?????	Not online but from buyjumpropes.net	1	$0.00 Each	$0.00*
Elite surge 3.0 Rope	Speed- ball bearings	https://buyjumpropes.net/elite-surge-3-0-jump-rope/	1	$29.99 Each	$29.99
Speed rope handle - Ultra light 3.0	Speed- plastic dowel (no bearings)	https://buyjumpropes.net/ultra-light-speed-cable-jump-rope/	1	$8.99 Each	$8.99

Bill of Materials					
Components					
Item	**Description**	**Order Site**	**Quantity**	**Unit Cost**	**Cost**
Bullet FIT	Speed- ball bearings	https://buyjumpropes.net/bullet-fit-rope/	1	$49.99 Each	$49.99
Bullet COMP Rope (1 oz handles)	Speed- ball bearings	https://buyjumpropes.net/bullet-comp/	1	$44.99 Each	$44.99
RPM Session 3.0	Speed- oilite bushing	https://buyjumpropes.net/rpm-session-3-0/	1	$55.00 Each	$55.00
Tally Jump	Device to track speed/number of jumps	https://www.tally-jump.com	1	$7.00 Each	$7.00
Wire cutters	Used to cut the ropes to correct size	In store at Walmart	1	$6.00 Each	$6.00
Shop lights	Lights to use for high speed filming	In store at Walmart	2	$10.47 Each	$20.95
Total					**$222.91**

* Item was provided free of charge from Buyjumpropes.net

APPENDIX I-LESSON PLAN

Teacher: Caroline Camfield

Date: TBD

Subject / grade level: STEM/9th-12th grade

Materials:

- Jump ropes belonging to participants
- Additional specialty jump ropes as needed for elaboration

Relevant Next Generation Science Standards (NGSS):

- **HS-ETS1-2** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **HS-PS2-1** Analyze data to support the claim that Newton's second law of motion describes the mathematics relationship among the net force on a macroscopic object, its mass, and its acceleration.
- **HS-PS2-2** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
- **HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

Lesson goal(s): The learner will investigate the connections between STEM concepts and the physical processes involved in competitive jump rope. The outcome of this exploration will be improved jumper performance based on their deeper conceptual understanding of the sport.

Differentiation strategies to meet diverse learner needs:

- Jumping skill should not impact learning (and will also likely correlate with grade/STEM knowledge)
- Students will be paired so that younger students, with less STEM background, are with older students, with more experience in STEM, so that experience in STEM is distributed among the groups

ENGAGEMENT

- The lesson will begin with a video of a well-known jumper applying STEM-related concepts in their current field of work. This will introduce jumpers to the idea that STEM relates to many real-world experiences, we sometimes just don't realize it.
- Afterwards, as jumpers are warming up, I will ask jumpers questions to continue to spark this interest, such as why does a jumper prefer to use a beaded versus licorice rope or a short handle versus long handle rope?
- Questions the students ask themselves after the engagement:
    - How are STEM and jump rope related?
    - What STEM disciplines are modeled in the sport?

EXPLORATION

- Students will be put into pairs and asked to investigate how they think STEM influences their jumping when they vary the width they hold their handles. To investigate this variable, students will be asked to "design an experiment" to test the 3 different widths between the jumper's handles.
- In this section, they will be asked to apply the concepts they've already learned in school to make observations both as they are jumping and as they are watching their partner jump. They will be given a handout, similar to the one below, to record their observations on.
- "Big idea" conceptual questions the teacher will use to encourage and/or focus students' exploration:
  - What science concepts do you think have an effect on the rope as you're jumping?
  - When you change the width between your handles how does it affect the rope's motion? Does the rope's interaction with the ground change? What about the rope's interaction with the air as its spinning?
  - When you change the width between your handles, how does it influence the rest of the rope?

EXPLANATION

- As a group, we will discuss the observations jumpers made and the STEM concepts that they noted had an effect on the variable they tested.
- Questions or techniques the teacher will use to help students connect their exploration to the concept under examination:
  - What concepts did you find most relevant to the observations you were making?
  - Did you feel a difference when you were jumping with the different handle widths?
  - How did your control of the rope change when you changed the width between your handles?
- Higher order thinking questions which the teacher will use to solicit *student* explanations and help them to justify their explanation:
  - Can you think of an example of how your coaches use STEM to make you better jumpers? (ex. coaches have jumpers start off with using heavier ropes in speed to solidify jumpers form before they are allowed to use the lighter ropes)
  - When you experimented with different widths, did you observe any differences in the force you needed to exert to turn the handles?

ELABORATION

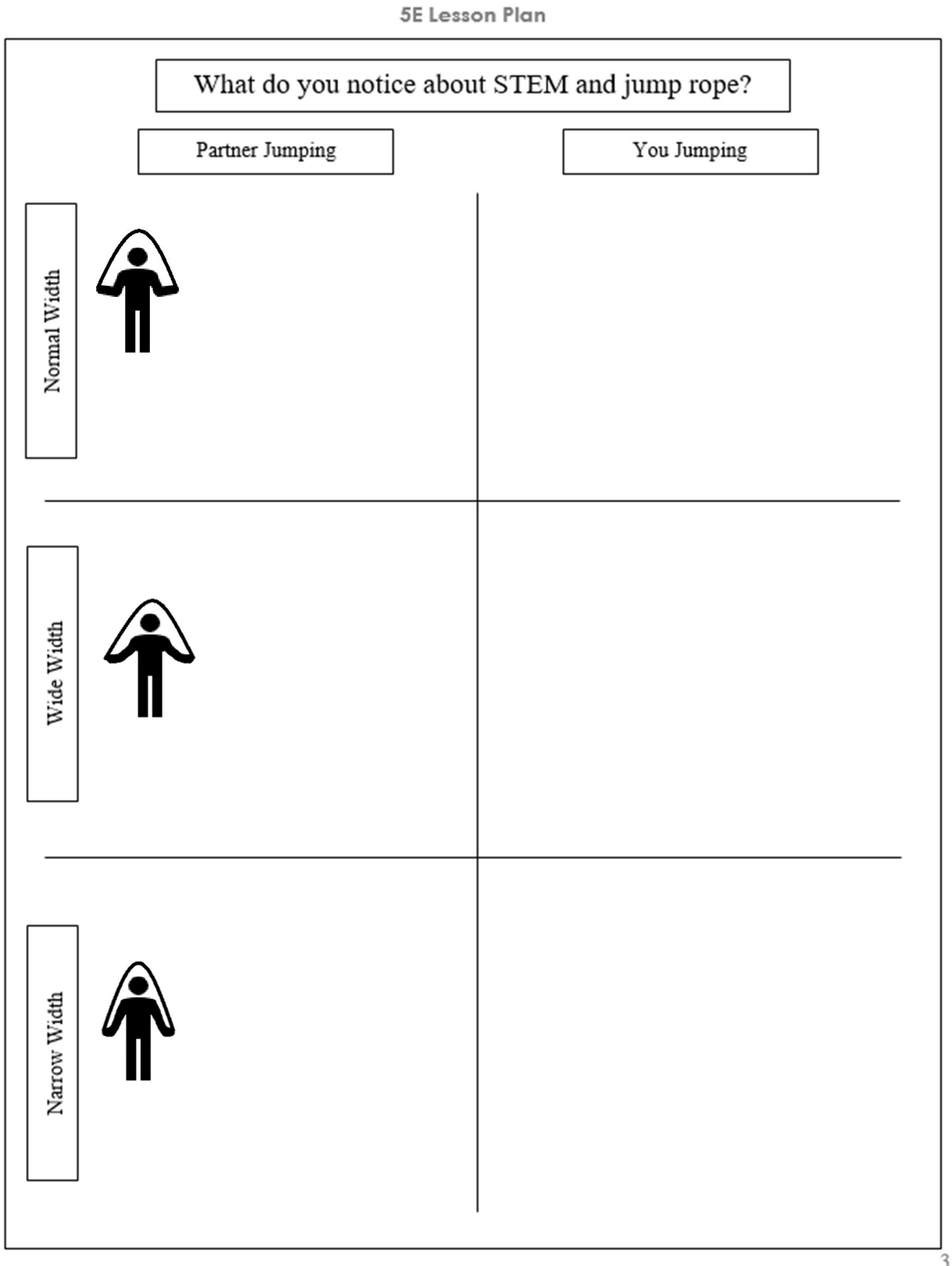
Students will further explore and experiment with the other three variables (rope length, rope type, and handle type). Using these results, they will increase their understanding of the STEM concepts already discussed (as well as additional relevant concepts) so that they can improve their performance.

- Vocabulary that will be introduced for each variable:
  - Width between handles: impulse-momentum theorem
  - Length of rope: moment of inertia, kinetic energy/speed/energy conservation
  - Type of handles: friction, speed, force
  - Type of rope: coefficient of restitution, friction, rotational inertia/energy
- Vocabulary that will be introduced:
  - Conservation of energy and momentum
  - Newton's second law
- How this knowledge is applied in our daily lives:
  - How do they think these concepts could apply to other jumping skills (ex. rotational inertia/newton's 2nd law with freestyle jumping (the jumper should work "with" the motion of the rope and follow it's direction of energy and rotational inertia)?
  - Why do you think you prefer to use the combination of rope that you do? What do you notice feels different about using a different rope?

EVALUATION

- Jumpers speed scores from before and after the lesson will be collected to show how their jumping has improved since they were taught the lesson.
- Jumpers will also be surveyed after the lesson to determine if their interest/understanding of STEM has changed.

APPENDIX J- LESSON PLAN SUPPLEMENTAL MATERIALS


5E Lesson Plan

What do you notice about STEM and jump rope?

	Partner Jumping	You Jumping
Normal Width		
Wide Width		
Narrow Width		

3

APPENDIX K- GENDER AND AGE STATISTICS FROM THE AMJRF NATIONAL COMPETITION IN 2019

	Total Athletes	Female	Male
Total	186	150 (80.6%)	36 (19.4%)
School Age (8-18)	174	145 (83.3%)	29 (16.7%)
High School Age (14-18)	78	63 (80.8%)	15 (19.2%)