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Utilizing Physical Education to Support Principals of Biomechanics

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ABSTRACT

Purpose: We aimed to engage middle school students in science standards (NGSS) and physical education standards (SHAPE America). We employed targeted physical activities that concurrently emphasized both standards in an effort to improve middle school level students' understanding of biomechanical principles.
Methods: Eleven 8th grade children (age 12-14 years; 7 female, 4 male) participated in the NBD activities. As a group, students first participated in physical activities designed to emphasize principles related to forces. Students were then divided into two smaller groups in order to rotate through two additional sessions designed to quantify/analyze movement.
Results: We hypothesized that physical education activities that explicitly emphasized elements of physical and life sciences would help provide 8th grade students with a more meaningful understanding of the content. By using physical education activities as a pedagogical tool; we hypothesized that students would enjoy learning and would make meaningful, real-world connections between biomechanics and everyday interests.
Conclusion: By using movement to understand the science of movement, children were able to improve their knowledge of interrelated STEM areas. Targeted physical activities emphasizing biomechanical principles appear to be viable pedagogical tool for enhancing the understanding of physical and life sciences in middle school curricula.

Keywords: National Biomechanics Day, Physical Education, Physical Literacy

1. INTRODUCTION

Interdisciplinary learning helps advance critical thinking and cognitive development by decompartmentalizing the learning process and allowing students to learn different concepts and skills across multiple classes (Weinberg & Sample, 2017). Isolated disciplines have been criticized for being static and for not offering the reality of experience (Braunger & Hart-Landsberg, 1994; Hurd, 1991; Nielsen, 1989; Tanner, 1989). In contrast, interdisciplinary instruction allows teachers to showcase real-world examples using multiple disciplines as context for the topic which may spark more engagement from their students (Weinberg & Sample, 2017). There are several benefits to using interdisciplinary learning such as higher order thinking and expanding the capacity of knowledge by providing additional richness of viewing the topics through multiple lenses (Hursh, Haas, & Moore, 1983; Liu, Lee, Hofstetter, & Linn, 2008). These concepts bring the learning to life making it more realistic and easier to understand for the student (Hursh, Haas, & Moore, 1983; Liu, Lee, Hofstetter, & Linn, 2008).

Teaching practices with an interdisciplinary approach can help students make sense of science in regard to abstract scientific concepts and the role and function of science in modern-day society (Fogarty, 1991). A real world, interdisciplinary approach is the best way to learn and perceive the complex topics in science (You, 2017). Physical Education (PE) is an opportune venue to showcase the integration of Science, Technology, Engineering, and Math (STEM) concepts. Physical Education as a subject involves not only physical performance but also practical and theoretical knowledge related to STEM topics; specifically, motor learning and biomechanics, as well as applied anatomy and physiology, movement and data analysis, socio-cultural influence of sport, health, and fitness (Forey, G & Cheung, 2019).

The Next Generation Science Standards (NGSS) are designed to engage students in multidisciplinary practices that enhance their understanding of core ideas in science (Standards, N. G. S. (2013). Some of the core ideas emphasized at the middle school level for the physical sciences are related to *mechanics* (PS2.A: forces & motion; PS2.B: types of force interactions) and for the life sciences *(biology*) are related to structure and function of nerves (LS1.A: Structure and function and LS1.D: Information processing). The Society of Health and Physical Educators (SHAPE) America standards (2013) are designed to deliver high quality physical education and develop knowledge and skills that will lead to a physically active lifestyle. The NGSS overlap with two of SHAPE America's physical education standards. Specifically, Standard 1: Demonstrating competency in movement and Standard 2: Applying movement concepts to learning and the development of motor skills) (SHAPE America, 2013).

Between NGSS standards (i.e., standards) and physical education standards teachers can create multiple interdisciplinary activities that demonstrate and combine student's knowledge in an engaging and fun way that will help students understand and apply STEM content through physical education.

National Biomechanics Day (NBD) was established in 2016 with the main goal of introducing biomechanics to K-12 students (DeVita, 2018; Shultz et al., 2019). NBD events are encouraged to include hands-on experiences and activities through STEM as it relates to biomechanics (DeVita, 2018; Merica, Chun, Bailey, & Egan, 2021). It is a perfect platform to showcase how both STEM and Physical Education can work in tandem to educate students on future careers in STEM. NBD is held annually in early April around the world. It targets school age students by exposing them to biomechanics prior to entering university through interactive activities and demonstrations. From 2016 to 2018, it reached over 20,000 students and 800 teachers worldwide (Teeter, Husseini, & Cole, 2020; DeVita, 2018).

To join in the celebration of NBD, two Physical Education Teacher Education (PETE) faculty and one biomechanics faculty combined ideas, activities, and concepts to create an engaging experience for middle school students to begin to understand and be engaged with biomechanical principles. Using physical activity and academic achievement, we aimed to simultaneously engage middle school students in science standards (NGSS) and physical education standards (SHAPE America) with targeted physical activities and biomechanics principles to improve the middle school level students' understanding of biomechanical principles. By using physical education activities as a pedagogical tool; we hypothesized that students would enjoy learning and would make meaningful, real-world connections between biomechanics and everyday interests and activities.

2. METHODS

Eleven 8th grade children (age 12-14 years; 7 female, 4 male) from a middle school in the Northeast in the United States participated in NBD themed physical activities specifically designed for a middle school physical education class. The students were bussed in from a local junior high school and the interdisciplinary lessons and activities, based on the SHAPE America National Standards and the Next Generation Science Standards, were presented in a physical education class. As a group, students first participated in physical activities designed to emphasize principles related to forces and life science principles related to neuromuscular control of movement. Students were then divided into 2 smaller groups in order to rotate through 2 additional sessions designed to quantify/analyze movement. In the first session, students learned to analyze movement using simple methodology and breaking the skills down such as 1) recording the progression of balance using agility balls and 2) using vertical jump measuring equipment. In the second session, students visited the Motion Analysis Laboratory for an interactive demonstration of sophisticated methodology used to quantify and analyze movement such as 1) motion capture cameras, 2) force plates, and 3) electromyograms (EMG). Description of activities are provided in Table 6. Prior to participating in the activities, students completed an 8-question quiz (pre-test) designed to assess prior knowledge related to vectors, forces, net force, biomechanics equipment and the neuromuscular control of muscle contractions. Students completed the same quiz again (post-test), once all activities had been completed. The post-test included one additional question asking students what aspect of the day they enjoyed the most.

2.1 Statistical Analysis

A one-way MANOVA with 2 levels of time and an a´priori alpha level of 0.05 was performed to assess change in quiz scores as a result of participating in the NBD activities. All statistical tests were performed using SPSS 16.0 for Windows (Chicago, Illinois). The protocol for the study was approved by an institutional review board and the parents or legal guardians authorized the informed consent for all children included in the study. The children also assented to the research.

3. RESULTS

Pre-test results indicated that most children had knowledge of forces and vectors (Q1-Q3b) prior to participating in the NBD activities. However, for questions related to neuromuscular control and application to real world activities (Q4-Q6), most students were unable to answer on the pre-test (Appendix A). Conversely on the post-test, the multivariate analysis revealed that most students were able to provide significantly more accurate responses to several of the questions ($F(7, 14) = 23.025$, $p < 0.001$; Hotelling's Trace = 11.512). The responses on the post-test were also more in-depth and detailed. See Tables 1-5 for pre- and post-test results and the results from the 8 one-way ANOVAs for the 7 questions and total quiz scores.

Table 1

Participant Responses (Pre- and Post-Test) for Question 4: How Can You Use Force to Jump Higher?

Participant	Pre-test answer (n=11)	Post-test answer (n=11)
3	*You crouch down lower so your legs push farther.*	*You can crouch before you jump, the more force you have the higher you jump.*
5	*If you crouch lower your legs will push farther or #starwars*	*The more force you create the higher you jump.*
8	*Bend your knees.*	*Apply more force before you jump.*
9	*Bend your knees.*	*Apply more force before you jump by bending your knees and the floor will push force back.*
12	*You can use force to kick off and propel yourself off of the ground and into the air.*	*You can use force to push off the ground to jump higher (to propel yourself higher in the air).*
13	*You can build momentum and build force to extend upward.*	*You can jump higher because more force means you will jump higher.*
15	*By bending your knees because you will have more gravity force.*	*You can use your knees to use force.*
16	*You can push off harder with your feet by bending your knees.*	*You can push off harder with your feet so you can jump higher.*
17	*You can squat to push off the ground.*	*You can use more force to jump higher.*
21	*Bend your legs while jumping,*	*Bend your legs and contract your muscle.*
22	*Pushing yourself up.*	*More force makes a higher jump.*

Table 2

Participant Responses (Pre- and Post-Test) for Question 5: What Type of Equipment Can You Use to Measure Force Under Your Feet? What Type of Equipment Can You Use to Measure Muscle-Force?

Participant	Pre-test answer (n=11)	Post-test answer (n=11)
3	*You can use a scale. I don't know.*	*You can use force plates to measure the force under your feet. You can use the Electro Myograph to measure muscle-force.*
5	*Using a scale as you jump. I don't know.*	*A force plate. An EMG.*
8	*Treadmill = force under feet. Bike = muscle force.*	*The force plate. The EMG.*
9	*Treadmill = force under feet. Bike = muscle force.*	*The force plates under the treadmill. EMG for muscle force.*
12	*You can use a trampoline to see how far you kick off of the ground. You can use a rubber band and push against it to measure muscle force.*	*You can use a force plate to measure force under your feet. You can measure muscle force by using the sticky pads and metal dip things (forgot name) to Electromagnetic Pyograph.*
13	*Stair steppers. Bench press.*	*Force plates, balance balls. EMG, vertical jump.*
15	*You can use an elliptical. Spin bike.*	*A force plate (treadmill). You can use a gel pad thing with cords.*
16	*Elliptical. Spin Bike.*	*Treadmill force plates. EMG.*
17	*Elliptical. Spin Bike.*	*You can use a force gauge. And an EMG.*
21	*I don't know.*	*Force plate. Vertec.*
22	*I don't know.*	*Force plate.*

Table 3
Participant Responses (Pre- and Post-Test) for Question 6: What Causes a Muscle to Contract? Words to Use: Brain, Muscle, Electrical-Signal or Electrical-Message, Nerve, Muscle-FORCE, Muscle Contraction.

Participant	Pre-test answer (n=11)	Post-test answer (n=11)
3	*I don't know.*	*The electrical-signal or electrical message from the brain causes muscles to contract.*
5	*I don't know.*	*The brains sends a message in the form of an electrical signal telling a muscle to contract.*
8	*The muscle in your arms make force.*	*The brain sends the signal to the neurons and that causes the muscles to move and contract.*
9	*When a muscle is being forced to move.*	*The brain sends the signals to the neurons and that causes the muscle to move and contract.*
12	*A muscle will contract after the brain sends an electrical-signal to your nerves to use muscle force, then forming muscle contraction (I have no idea).*	*The brain sends an electrical-message through the nerves to the muscle to contract.*
13	*Nerves.*	*The brain and nerves because they send messages.*
15	*The nerve, muscle force, and muscle contraction allows the muscle to contract.*	*The nerve or muscle sends an electrical signal and message send to the brain which cause a muscle contraction and muscle force.*
16	*When your brain sends an electrical signal to your muscle through your nerves and it contracts.*	*Your brain sends an electrical-signal to the muscle so it contracts.*
17	*The brain will send an electrical signal to the muscle telling it when to move.*	*Brain sends an electrical signal to the muscle.*
21	*I don't know.*	*The brain sends a signal or message through the nerves to the muscle for the muscle to contract.*
22	*I don't know.*	*The brain is sending an electrical-signal to the muscle and the muscle contracts.*

Quiz scores on questions 4, 5a, 5b, and 6 improved significantly at the .05 level after completing the activities. Questions 4, 5a, and 5b mainly focused on the concept of force, whereas question 6 focused on the neuromuscular control of movement. The overall results or total scores on the quizzes were also significant at the .05 level. Overall, students improved their total score by 34.7% (from 50.5% to 85.2%). Finally, when asked which aspect or activity of the National Biomechanics Day was their favorite, 81.8% (n=9) of students reported one of the physical education activities. The other two students reported enjoying "everything."

Table 4
Mean Scores (± Standard Deviations) for Questions 1-6, Pre- and Post-Test.

Question (Points)	Pre-test Score (n=11)	Post-test Score (n=11)	*p* value
Q1 (1)	*1.0 ± 0.0*	*1.0 ± 0.0*	*NA*
Q2 (1)	*0.5 ± 0.5*	*0.9 ± 0.3*	*0.06*
Q3a (1)	*1.0 ± 0.0*	*0.8± 0.4*	*0.08*
Q3b (1)	*0.8 ± 0.4*	*0.7 ± 0.5*	*0.63*
Q4 (1)	*0.3 ± 0.5*	*0.9± 0.3*	*0.00**
Q5a (1)	*0.1 ± 0.2*	*1.0 ± 0.0*	*0.00**
Q5b (1)	*0.0 ± 0.1*	*0.8± 0.4*	*0.00**
Q6 (1)	*0.2 ± 0.3*	*0.7 ± 0.2*	*0.00**
Total (8)	*4.0 ± 1.4*	*6.8 ± 0.8*	*0.00**

*Significant at $p < 0.05$

Table 5
Participant Responses (Post-Test) for Question 7: What was your favorite part of the National Biomechanics Day: Muscle in Motion?

Participant	Post-test answer (n=11)
3	*Balance on Yoga Balls*
5	*Balance on Yoga Balls*
8	*Balance on Yoga Balls*
9	*All Gym Activities*
12	*All Gym Activities*
13	*Human Bowling*
15	*Balance on Yoga Balls*
16	*Everything*
17	*Everything*
21	*Sumo*
22	*Human Bowling*

Table 6

Descriptions of physical activities and methodologies used to breakdown, quantify, and analyze human movements (simple and sophisticated).

Physical Education Activities	
Human Bowling	Students sat on traditional physical education scooters (similar to a skateboard, but wider) and rolled into light weight bowling pins. This activity was used to help students learn about forces, velocity, momentum, and Newton's second Law of motion (i.e. unbalanced forces result in motion and the magnitude of the motion is related to the magnitude of the unbalanced force).
Balanced Poses	Students created and maintained poses with 2, 3, or more students. This activity was used to help students learn about Newton's first Law (i.e. balanced forces lead to maintaining a static equilibrium).
Sumo Game	In pairs, students attempted to throw each other off balance from a static standing position with a small base of support (when thrown off balance, they would be required to take a step). This activity was used to help students learn about Newton's second Law (unbalanced forces result in motion).
You're Getting on my Nerves	Students worked *together as a team* to carry a message from point A to point B. This activity was used to help students learn about the neurons and the neuromuscular control of movement (i.e. how the cells of the nervous system transmit electrical signals from the brain to the muscles telling them to contract and generate muscle force necessary for movement).
Methodologies used to breakdown, quantify, and analyze human movement	
Simple Methodologies	
Balance on Yoga Balls	While sitting on agility balls, students progressed through various poses designed to challenge their

	sense of balance. This activity was used to help students learn about postural control.
Vertical Jump	Using a simple-to-use and portable piece of equipment, students performed vertical jumps requiring them to displace the highest possible vane (plastic blades spaced 0.5 inches apart and that rotate when struck with the tip of the hand) on the Vertec® trainer.
Sophisticated Methodologies	
Demonstration of Motion Capture Cameras	Using a large monitor and volunteers, children observed motion capture cameras capturing reflective markers that are used to track body segments in space (kinematic analysis of human movement).
Demonstration of Force Plates	Using the large monitor and volunteers, children observed the force plates collecting ground reaction forces during standing and jumping (kinetic analysis of human movement).
Demonstration of Electromyographs	Using the backyardbrains SpikerBox (www.backyardbrains.com), a teaching-grade EMG system (connected to a laptop), children observed the muscle electrical activity present during a muscle contraction.

4. DISCUSSION

We hypothesized that using physical education activities that explicitly emphasized elements of physical and life sciences would help provide 8th grade students with a more meaningful understanding of the biomechanics and the science of human movement concepts. Furthermore, we hypothesized that students would enjoy learning and would make real-world connections between biomechanics and their everyday interests and activities. The results of this research support the hypothesis and point to the myriad of benefits of interdisciplinary learning (Hursh, Haas, & Moore, 1983; Liu, Lee, Hofstetter, & Linn, 2008) in these disciplines. Also, this research underscores the feasibility of tying the two content areas of biomechanics and physical education together in a relatively seamless and enjoyable approach. Students also demonstrated a new understanding of knowledge related to neuromuscular control and application to real world activities which they did not have prior to participating in the research. This result is supported by previous research linking physical education and biomechanics concepts (Forey & Cheung, 2019).

In addition, the participants reported enjoying the physical education activities the most. This supports teaching biomechanics through physical education lessons and activities as the physical education activities lead to increased student engagement and enjoyment. Having a deeper understanding of biomechanics could also potentially contribute to the research participants overall health and physical literacy. As with all research, there are several limitations of this research: a limited sample size (11 participants). Another limitation was that the research was only collected during one day. Data collection over several days with a larger sample size could possibly contribute to results that might lead to generalizations that could be applied to the general population. Finally, this research took place in the Northeast part of the United States; data collection in several other geographic areas would also increase the ability to make additional generalizations that are applicable to the general population.
The researchers recommend replicating the research with a larger sample size, over several days of data collection with use of a control group in several geographic areas.

5. CONCLUSIONS

By using movement to understand the science of movement, children were able to improve their knowledge of interrelated STEM areas. Targeted physical activities emphasizing biomechanical principles appear to be viable pedagogical tool for enhancing the understanding of physical and life sciences in middle school curricula.

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6.2 Conflict of Interest (de-identify in blinded manuscript)

The authors declare no conflicts of interest.

6.3 Contribution of Authors (exclude in blinded manuscript)

EDC: study design, data collection, manuscript preparation, manuscript editing. KO: study design, data collection, manuscript preparation, manuscript editing. KF: study design, data collection, data analysis

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8. APPENDIX

Appendix A
Pre- and Post-Test Questions

National Biomechanics Day: Science in Motion

Name: ______________________________

1. *What symbol (○, □, +, or →) can be drawn to represent a FORCE? Please draw your answer:*

2. *In the picture to the right, who is pushing with more FORCE? Please circle your answer:*
   A. *The person on the left*
   B. *The person on the right*
   C. *Both people are pushing with the same amount of force.*

3. *(a) Leila is pushing the ball with 20N of FORCE and Cameron is pushing the ball with 18N FORCE. Can you DRAW the FORCES on the picture below?*

Cameron Leila

3. *(b) If both Leila and Cameron push at the same time, which direction will the ball roll in? Please circle your answer:*
   A. *To the LEFT*
   B. *To the RIGHT*
   C. *The ball will stay in the same place*

4. *How can you use FORCE to jump higher?*

5. *What type of equipment can you use to measure FORCE under your feet? What type of equipment can you use to measure Muscle-Force?*

6. *What causes a muscle to contract? Words to use: Brain, Muscle, Electrical-Signal or Electrical- Message, Nerve, Muscle-FORCE, Muscle Contraction.*