A Case Study for Integrated STEM Outreach in an Urban Setting Using a Do-It-Yourself Vertical Jump Measurement Platform

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Abstract— **The purpose of this study was to develop and deploy a low cost vertical jump platform using readily available materials for Science, Technology, Engineering, and Mathematics (STEM) education and outreach in the inner city. The platform was used to measure the jumping ability of participants to introduce students to the collection and analysis of scientific data in an engaging, accessible manner. This system was designed and fabricated by a student team of engineers as part of a socially informed engineering and design class. The vertical jump platform has been utilized in 10 classroom lectures in physics and biology. The system was also used in an after school program in which high school volunteers prepared a basketball based STEM outreach program, and at a community outreach events with over 100 participants. At present, the same group of high school students are now building their own set of vertical jump platform under the mentorship of engineering undergraduates. The construction and usage of the vertical jump platform provides an accessible introduction to the STEM fields within the urban community.**

I. Introduction

Present STEM outreach methods in the United States centered on the use of robotics and other STEM intensive topics have resulted in many beneficial outcomes for participants. Students who participated in the popular FIRST robotics program were found to have higher standardized test scores, a higher grade point average, and to have taken more math and science classes relative to the national average. 99% of students graduated high school and 89% of students attended college.[1] While these are laudable outcomes, it is unclear whether these types of programs experience a self-selection of high achieving students for participation.

This "STEM-centric" method of outreach centered on robotics can be viewed as a value proposition for those involved. The scientific material within traditional STEM outreach is viewed by those providing the material as inherently valuable. Students who similarly find the presented STEM material valuable are easily engaged. This mutually agreed valuation of the worth of STEM can be seen as a source of fungible capital that allows students to succeed academically. This may explain the high achievement of the students within the FIRST robotics program; the only students with the proper "capital" to engage with the program are the ones who are already on the path to academic and career success. Participation in robotics clubs is a time-intensive activity and many students forgo out-of-school academic activities in favor of sports, social, or art activities. [2] As the importance of a STEM degree increases due to technological advances, it becomes critical to provide students of all academic levels with an accessible introduction to the STEM fields.

As many STEM outreach activities rely on students who already possess this STEM capital, many minority communities are chronically underrepresented in the STEM fields. A persistent issue in engaging African-American students in academic enrichment activities is the fear of seen as "acting white"[3]. To address this, the use of culturally relevant learning materials for STEM instruction has been shown to increase student learning and retention relative to traditional approaches [4], [5]. This may be because activities tied to local culture are seen to be an extension of a community's cultural heritage rather than a strictly STEM activity. In effect, the types of capital that are fungible within the STEM pipeline are being expanded into the cultural practices of underrepresented groups.

This use of cultural capital has been expanded into the domain of athletics.[6] Students are recruited for STEM programs based on a pre-existing interest in basketball or community service, not STEM. As sports are one of the most popular and engaging out of school activities [2], this opens a whole new population of students to STEM activities. Students used commercially available force plates, light sensors and electromyography to investigate their own questions regarding athletic performance using the scientific method. They summarized their results and presented their work to younger students at accessible community events. [7] They also developed STEM-based basketball experiments that are used during basketball clinics for player instruction. The students are empowered to create their own STEM outreach materials based on their own interests. Coaches and other community members collaborated in the development of these programs which ensured that the program remained authentically tied to basketball. [8] This program had great success in terms of engagement and participation because it transitioned the students and community members from being consumers of STEM outreach into the producers of STEM outreach.

This approach can be expanded into the engineering design process through the creation of a Do-It-Yourself (DIY) biomechanics equipment. The purpose of this case study was to develop a DIY vertical jump measurement platform for use in an urban school district. The platform was created to tie the engineering design process and scientific inquiry to the intrinsic motivation of basketball players and fans to improve their understanding of the game. Just as some robotics

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outreach programs are trying to make the internal workings of robots more understandable to students through the use of augmented reality devices [9], we are attempting to make biomechanics equipment that we use in our outreach more understandable by including the design and fabrication process of our equipment in classroom lessons and afterschool programs. Furthermore, the construction plans of this system is freely available online so that teachers or students can make their own plate. (community.csdt.rpi.edu/cms/application-contexts/diy-sports-science-lab)

II. Methods

A. System Design

The design of the vertical jump measurement platform took place during a socially informed engineering and design class. Commercially available force plates and vertical jump platforms range in price from 600 to 750 dollars. This would be difficult for individual teachers to afford for their classrooms. Additionally, students would not understand the engineering design process that is central to modern STEM careers because they are left as the consumers of a commercially made product. The designers of the plate were given the prompt to design a low cost alternative to these products that the educators and students could build themselves. This turns the fabrication of one of these systems itself into a teachable process. This recursive process of fabrication, deployment, and redesign was used as a teachable moment when presenting the system to students. This enabled us to highlight the need for a "growth mindset" when working with the students: Just as we were unable to make the perfect system on our first try, students shouldn't expect to understand STEM topics on first exposure.

B. System Fabrication

The basic concept of the system was to measure the hang time of someone jumping on the platform. The system consists of separate inferior and superior wooden boards separated by a sections wood beams with compliant material such as rubber on the top. This 7.62 cm internal volume houses the measurement circuitry. A diagram of the physical construction of the plate can be found in (Fig. (1)).

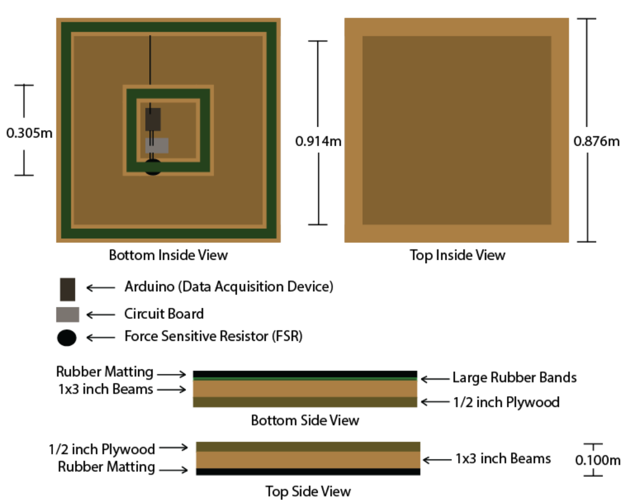

Figure 1. The platform is composed of readily availible materials that can be assembled using basic handtools.

The cost and supplies for the construction of the platform is found in Table I.

TABLE I. Materials For The Construction of the Plate

Material Name	**Numbers and Cost**		
	Number	***Price***	***Cost***
15/32" 4'x8' Plywood Sheet	1	$18.57	$18.57
1"x3" beams	4	$1.74	$6.96
2" Wood Screws	1	$5.58	$5.58
3/4" Nails	1	$2.98	$2.98
Handles	1	$2.50	$10.00
1 ¼' rubber bands	1	$2.78	$2.78
Rubber mat	2	$2.52	$5.04
Arduino Uno	1	$24.85	$24.85
bread board	2	$4.95	$9.90
FSR	1	$5.95	$5.95
Jumper Wire Kit	1	$6.95	$6.95
Total Cost:			$99.56

By placing a Force Sensitive Resistor (FSR) between the boards, the system can detect when someone is standing on the system. When the subject jumps, the FSR is unloaded and then loaded when the subject lands. The FSR is connected to a signal conditioning circuit connected to an Arduino microcontroller. The microcontroller was connected to an external laptop for data processing and visualization. The pinouts and signal conditioning circuit can be found below (Fig. (2)).

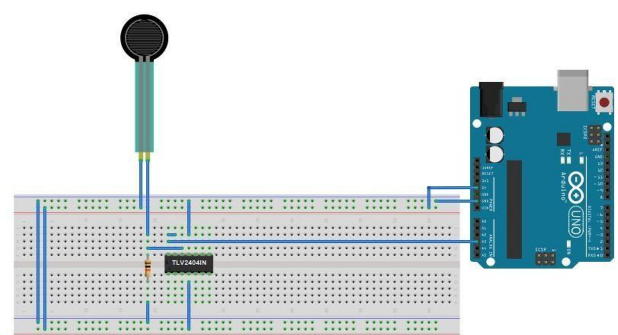

Figure 2. The force sensitive resistor is connected to signal conditioning circuitry that is read using an open source microcontroller.

The voltage from the FSR was read using one of the analog pins of the Arduino. The data could be viewed using the serial port monitor in the Arduino program. Excel can then be used to graph the data. To facilitate the real time analysis of data at a high speed, we wrote a program that connects to the Arduino using a graphical user interface. The computer program allowed the users to select the point where the subject left and landed on the plate. The program automatically calculated the jump height using the flight time method.

C. System Design

The signal of the circuit is at a maximum when loaded and a minimum when unloaded. As a result, the hang time of a subject jumping (Δt) is the time during which the signal is at a minimum as shown in Fig. (3).

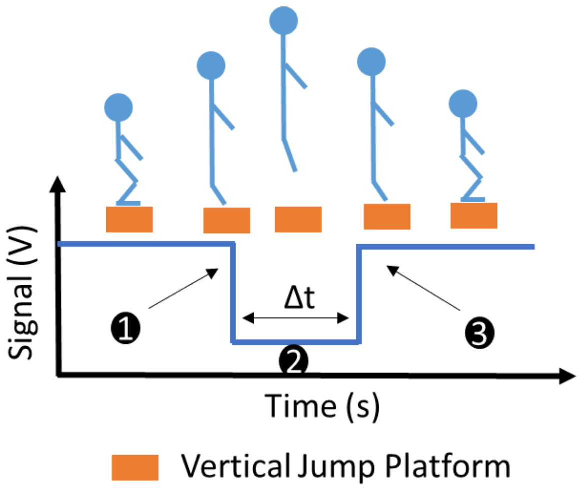

Figure 3. The signal output from the force sensitive resistor reflects the participants jumping on the platform.

The vertical jump height of the subject can be calculated using the flight time method. [10] The first step is to use an equation that can be derived by calculating the total energy of the subject at the point of take-off (point 1 on Fig. (3).) and at the maximal height of the jump (point 2 on Fig.(3)).

$$\frac{1}{2} m_{jumper} {v_i}^2 + m_{jumper} g h_i = \frac{1}{2} m_{jumper} {v_f}^2 + m_{jumper} g h_f \quad (1)$$

The starting height (h_i) can be set to zero and the final velocity at the top of the jump (v_f) is equal to zero. The relationship between maximal jump height (h_f) and starting velocity (v_i) can be solved to be the following.

$$h_f = \frac{{v_i}^2}{2g} \quad (2)$$

This relationship can be used in conjunction with the one dimensional kinematic equation for the subject's takeoff (point 1 on Fig. (3)) and landing on the platform (point 3 on Fig. (3)) in order to relate velocity to hang time.

$$v_f - v_i = -g(\Delta t) \quad (3)$$

Assuming that the subject's center of mass is at the same location for takeoff and landing, the velocity at each point should be the same magnitude with opposite signs. (v_f=-v_i) This allows us to solve Eq. (3) in terms of takeoff velocity.

$$v_i = -\frac{g(\Delta t)}{2} \quad (4)$$

Combining Eq. (2) and Eq. (4) allows us to solve for jump height in terms of hang time.

$$h_f = \frac{g \Delta t^2}{8} \quad (5)$$

This process for calculating the jump height of a test subject is based on one dimensional projectile motion, kinetic and potential energy concepts and algebraic manipulation within the physics and mathematics high school curriculum.

III. Results and Discussion

The vertical jump platform was developed over a four month period by a team of undergraduate and graduate students. The system was deployed in an urban public high school. Once this system was fabricated and preliminary validation took place, it was used as part of classroom lectures in an advanced physics or a remedial biology classroom. The system was used in the physics classroom twice and the biology classroom eight times.

In the physics classes students were invited to derive the relationship that was outlined in Eqs. (1-5). Students then used their own work to calculate the height of their own jump. As this equipment will be used in basketball and other sports programs in the future, students were able to see how the STEM topics from their class are used in the real world.

In the biology classes, the students used the program that automatically calculated the jump height of the subject. This allowed the class to use the scientific method to analyze data that was related to their own jumping ability. The use of their own data got the students very engaged with asking and answering their own questions using the scientific method. Common topics included the comparing the performance of heavier people with lighter people, taller people with shorter people, jumping off one or two legs and boy vs. girls. While these questions are not strictly related to biology, an understanding of the scientific method is crucial for any scientific question. Also, these experiments served as an excellent starting point for discussions of how the musculoskeletal system functions and how diet and exercise affects body composition.

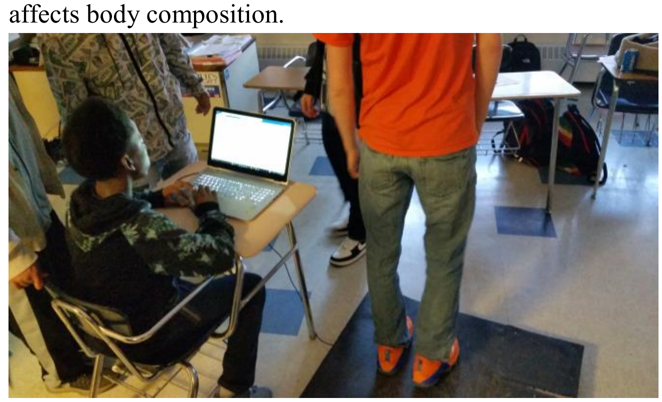

Figure 4. Students learned how to use the platform as part of in-class activities. These students also joined the after school program.

The vertical jump platform was also used as part of a high school afterschool program in which students designed their own sports science experiments. These students learned how to use the DIY vertical jump platform and have brought it into practices for the basketball and track programs at the high school. The basketball players were able to compare the jumping ability of different positions between the varsity and junior varsity teams. After the data was collected it was plotted by an instructor and the athletes were given a chance to view the data as shown in Fig. (5). As basketball players are extremely interested in improving their own performance, a long discussion centered on interpreting the data, including the meaning of standard deviation as error bars took place.

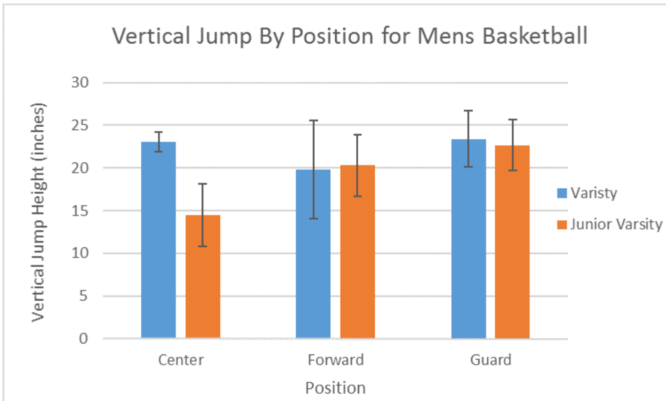

Figure 5. The collection of the athletes vertical jump data provided participants with the oppourtunity to engage in STEM activities based on their own interest in improving and understanding athletic performance.

Students from the afterschool program also used the system for a "Science of the Slam" community event in front of a group of 100 younger students. We found that the use of the DIY equipment allowed for a discussion of how technical equipment is designed and fabricated. This enabled us to discuss the engineering design process within the context of the equipment that the students were using. This is in contrast to the program which used commercial equipment. While the engineering design process was discussed, it was difficult to convince participants that a series of redesigns took place before the commercial equipment was released.

An interesting interaction happened between the in school and after school programs. Several students who participated in the in school activities joined the afterschool program in order to continue their work. This occurred with both biology and physics students. The physics students usually were motivated to learn more about how to build scientific equipment while the biology students were usually interested in using the existing equipment to answer additional scientific questions related to sports. The interaction between the groups provoked more technical questions on the part of the biology students and more basketball-related experiments on the part of the physics students.

The use of the DIY contact platform allowed students with a different set of interests interact with the scientific method and the engineering design process in a meaningful way. The use of sports as a venue for STEM engagement resulted in a diverse group of student participants in the after school program. The students who participate in the after school program typically report that they are drawn to the program due to its focus on sports. The student participants have presented the DIY platform to 100 younger students and they have reported that they feel a sense of ownership over the material covered in the program. The high school students are now in the process of making their own version of the vertical jump platform while being mentored by engineering students.

IV. Conclusion

We have developed a low-cost DIY vertical jump measurement platform for use in an urban high school. The plate cost less than 100 dollars in materials and provides students with an introduction with to the engineering design process. The system was used in both accelerated and remedial science classes and was met with enthusiasm from participants. It was also used in an after school program in which students created their own sports based outreach programs for use in basketball clinics and at community events. The use of this DIY platform has enabled students with different interests outside of STEM to become engaged in the STEM pipeline.

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