Work in Progress: Brainstorming with Yo-Yos in High School Outreach: Inspiring Students' Interest in Learning Physics

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Abstract

This work-in-progress paper submitted for the poster session of the K-12/Pre-college Division describes a new and unique set of hands-on activities called "brainstorming with yo-yos" that was designed as a recruiting tool in a high school outreach event to inspire high school students' interest in learning physics and pursuing post-secondary education in science, technology, engineering, and mathematics (STEM). A total of 122 high school students, including 91 males and 31 females, from different school districts across the author's state participated in the present study. During an one-and-a-half-hour "Phun" with Physics session period, student teams identified, via brainstorming, more than 50 physics concepts that are related to yo-yos. All participating students enjoyed "brainstorming with yo-yos" activities. In their written comments, many students used the words and phrases such as "fun," "play," "hands on," and "real life" to describe their experiences with these activities. The future work will focus on collaborating with K-12 physics teachers to incorporate these activities in the formal K-12 course curriculum.

Introduction

As science, technology, engineering, and mathematics (STEM) play an increasingly critical role in the nation's economy, competitiveness, and security, K-12 STEM education has received growing attention nationwide in recent years. Significant efforts have been made not only to improve STEM education in K-12 schools [1, 2], but also to attract and recruit K-12 students for a post-secondary study in STEM disciples [3, 4]. For example, the National Research Council identified three important goals that a successful program in K-12 STEM education has: learning STEM content and practices, developing positive dispositions toward STEM, and preparing students to be lifelong learners [1]. Both the National Research Council [1, 3] and the National Science Board [4] of the National Science Foundation emphasize the pressing need to significantly increase the number of K-12 students who choose STEM disciplines as their post-secondary study and ultimately pursue advanced degrees and careers in STEM fields.

Institutions of higher learning have developed a wide variety of strategies to attract and recruit K-12 students for post-secondary STEM education. Some representative examples include outreaching to high school students to introduce STEM career options and benefits, developing academic articulation/bridge plans with high schools, holding recruitment seminars, working with K-12 teachers to offer hands-on learning activities in the classroom, and providing financial support for targeted students [5-7].

The College of Engineering at Utah State University (i.e., the author's institution) organizes an annual three-day "Engineering State" event held each summer. During this event, high school students across the state are invited to the campus to visit each engineering department and laboratories to learn about engineering and engineering sciences. Serving as a recruiting tool, the goals of this "Engineering State" event are twofold: 1) to positively impact high school students and create an interest in STEM, and 2) to offer students hands-on experiences and an in-depth view of engineering using the strategies and tools of contemporary engineers.

To date, the three-day "Engineering State" event has attracted participants from 43 school districts and four charter schools across the state. Each year approximately 200 high school juniors and seniors attend this event. Approximately 25% are female students. The event consists of nine hands-on challenge sessions, including Baja Buggies, Water Engineering, "Phun" with Physics, Biofuels and Bioplastics, Magnetic Cannon, Metabolic Engineering, Spider Silk, Steel Bridge, and Ping Pong Shuffle. Each session is scheduled for one and a half hours. Faculty members from all six departments in the College of Engineering at the author's institution donate their time to design and conduct these challenge sessions.

This work-in-progress paper submitted for the poster session of the K-12/Pre-college Division describes one of challenge sessions – "Phun" with Physics – which was recently designed and conducted by the author of this paper. This session consisted of a new and unique set of hands-on activities called "brainstorming with yo-yos." During an one-and-a-half-hour session period, each student was provided with a yo-yo to use. Students were divided into teams with four students on each team. Each team was asked to identify, via brainstorming, as many yo-yo-related physics concepts as possible. The team that identified the largest number of physics concepts was chosen as the winner of the final contest. At the end of the session, students were asked to respond to an anonymous survey concerning their experiences with these activities.

The high school students who attended the "Phun" with Physics session had a wide variety of experience and background because they came from different school districts across the state and were at different grades (Grade 11 or Grade 12). Some students had taken a physics course, while others had not. Because the session was scheduled for less than two hours and primarily served as an informal learning opportunity outside the K-12 classroom, the session *was designed as a recruiting tool to inspire students' interest in learning physics and then pursue post-secondary STEM education*, rather than as a robust pedagogical tool to assess and significantly improve students' understanding of physics concepts and problem-solving skills within a short period of time. Developing a robust pedagogical tool for use in formal K-12 course curriculum, and reliable and validated assessment instruments, are out of the scope of this work-in-progress paper.

After a brief review of literature on learning science and engineering with toys in STEM education, this paper provides several examples to show how yo-yos were used to demonstrate specific physics concepts, and what physics concepts students had identified via brainstorming with yo-yos. Representative student comments are provided. The limitation of the present study and the future work are also discussed. The conclusions are made at the end of the paper.

Learning Science and Engineering with Toys in STEM Education

Learning science and engineering with toys, particularly with inexpensive and readily available toys, has received growing applications in K-12 education in a variety of formal and informal educational settings both inside and outside the classroom. Extensive research evidence [8-10] has revealed that students can develop and reinforce their understanding of fundamental science concepts through hands-on active learning with toys. Educational toys and associated games also add excitements to the process of learning, especially for K-12 children, and inspire and promote their interest in learning science and engineering. Representative examples of the toys and games that have been used as a learning tool for various educational purposes include Legos, yo-yos, wooden construction cars, toy electronic cars, leapfrogs, card games, and video games, to name a few [11-14].

For example, Emerson [13] employed civil engineering toys, e.g., the foam beam, beams of wood lath, circular foam beams, and photo-elastic beams, to teach students key engineering concepts such as bending, torsion, shear center, shear flow, shear developed from transverse loading, normal stress, compression and tension, and others. Emerson [13] found that among all those toys he employed, the foam beam was the most successful because it covered the largest number of concepts. The foam beam was employed as a visual aid at the onset of the course, "immediately showing students there are physical and visual representations of the course's concepts." [13]

In another example, Saviz and Shakerin [14] employed a variety of fluids-related toys to demonstrate various phenomena related to fluid mechanics. Their toys included density differential fluids toys, colors in motion toys, density-driven fluids toys, flowing color spectrum toys, and colored sand motion toys, and so on. Saviz and Shakerin [14] concluded that "when used in conjunction with examples, problems, and applications, these hands-on toys can help address learning styles of those students who may not respond as positively to the verbal and inductive teaching styles traditionally used in engineering classrooms."

Yo-Yos have also been employed to demonstrate science concepts, particularly physics concepts. For example, Murfin [15] employed yo-yos to help students explore physics concepts related to energy and motion. Magill [16] developed a classroom learning module in which a rolling yo-yo was used for students to understand the equation of motion and how to apply Newton's Second Law to determine the acceleration of the rolling yo-yo. In an effort to improve student problem-solving skills, Elger et al. [17] demonstrated yo-yos to students and asked students to calculate the rotation rate of a yo-yo that was dropped and allowed to spin freely.

The author of this paper has conducted an extensive literature review using a variety of popular databases, such as the Education Resources Information Center, Science Citation Index, Social Science Citation Index, Engineering Citation Index, Academic Search Premier, the ASEE annual conference proceedings (1995-2012), and the ASEE/IEEE Frontier in Education conference proceedings (1995-2012). The results of this literature review show that nearly all published literature on learning science and engineering with toys (especially with yo-yos) focuses on using toys in a semester-long course, on a limited number of science concepts. There exists no prior literature reporting the unique use of yo-yos – brainstorming with yo-yos – for students to identify as many yo-yo-related physics concepts as possible.

As will be shown in the subsequent section of this paper, the students who participated in the "Phun" with Physics session in the present study identified as many as 31 physics concepts associated with yo-yos. These "brainstorming with yo-yos" activities allowed students to see the connection of physics with the real world. The effectiveness of using yo-yos in this unique way to greatly promote student interest in learning physics is evident from highly positive comments received from all student participants, including those who had taken a physics course and those who had not. Therefore, the present study, although still in its work-in-progress stage, makes a new and unique contribution to the current state of knowledge within the K-12/Pre-college STEM education community.

Brainstorming with Yo-Yos

A total of 122 visiting high school students, including 91 males and 31 females, from different school districts across the author's state attended the "Phun" with Physics session. The students were divided into six cohorts with approximately 20 students in each cohort. Each cohort took turns to attend the one-and-a-half-hour "Phun" with Physics session. Each cohort (20 students) was further divided into five teams with four students on each team.

At the beginning of the session, the instructor (i.e., the author of this paper) demonstrated what physics concepts could be found from yo-yos. For example, when a yo-yo drops, it has a "velocity." "Velocity" is a physics concept. The yo-yo itself always has a "mass." "Mass" is a physics concept too. Given mass and velocity, one can determine the "kinetic energy." "Kinetic energy" is also a physics concept.

By playing with yo-yos, each team was required to identify (via brainstorming) as many physics concepts as possible. All teams entered the final contest and were required to explain how the physics concepts they had identified were associated with yo-yos. Figure 1 shows a student team in the final contest. The instructor served as a judge for the contest. If a student team identified a physics concept incorrectly, or a concept was a mathematics concept rather than a physics concept, that concept was not counted. The team that identified the largest number of physics concepts won the contest.

Figure 1. A student team showing how the physics concepts that they had identified were associated with yo-yos

Physics Concepts Identified by Students via Brainstorming with Yo-Yos

The student participants had a variety of academic backgrounds. Some students had previously taken a physics course in their schools, while other students had never taken any physics course.

Team members worked together and helped each other via collaborative learning [18]. The instructor provided just-in-time instruction [19] whenever students had questions.

Tables 1-3 show three representative examples of the physics concepts identified by three student teams via brainstorming with yo-yos. Team #1 identified a total of 31 physics concepts; Team #2: 27 concepts; Team #3: 21 concepts. The concepts listed in Tables 1 to 3 are re-arranged alphabetically by the first letter of each concept. The total number of different physics concepts identified by all student teams was more than 50.

Table 1. Physics concepts identified by Team #1 via brainstorming with yo-yos

Acceleration	Mass
Angular momentum	Mechanical energy
Center of mass	Momentum
Centrifugal force	Newton's 1st law
Density	Newton's 2nd law
Distance	Newton's 3rd law
Energy	Particle
Friction	Position
Force	Potential energy
Gravitational potential energy	Rotation
Gravity	Rotational kinetic energy
Impulse	Speed
Inertia	Time
Kinetic energy	Torque
Linear momentum	Velocity
	Work

Table 2. Physics concepts identified by Team #2 via brainstorming with yo-yos

Acceleration	Mass
Centrifugal force	Motion
Centripetal force	Newton's 1st law
Density	Newton's 2nd law
Distance	Newton's 3rd law
Drag force	Position
Energy	Potential energy
Friction	Power
Force	Speed
Gravity	Tension
Heat	Time
Inertia	Velocity
Kinetic energy	Weight
	Work

Table 3. Physics concepts identified by Team #3 via brainstorming with yo-yos

Acceleration	Inertia
Air resistance	Inertia of rotation
Angular momentum	Kinetic energy
Centripetal force	Linear momentum
Energy	Newton's first law
Equilibrium of forces	Oscillation
Friction	Potential energy
Gravitational potential energy	Power
Gravity	Rotational kinetic energy
Heat	Tension force
	Velocity

Using Team #1 as an example, the students on this team explained: When a yo-yo drops, it has an "acceleration" measured in m/s^2 or ft/s^2. "Acceleration" is a physics concept. The yo-yo also has an "angular momentum" because it has a "linear momentum" and a radius. Both "angular momentum" and "linear momentum" are physics concepts. When a yo-yo rotates, it generates a "centrifugal force" that draws the yo-yo-away from its center. "Centrifugal force" is a physics concept. And so on.

Experiences and Lessons Learned

At the end of the session, the students were provided an open-ended questionnaire survey asking for their comments on the strengths and weaknesses of the session. Student comments were highly positive. Many students expressed that the "Phun" with Physics session was one of favorite sessions they had attended in the "Engineering State" event. All students enjoyed hands-on learning, and the final contest added excitement to the learning process. In students' written comments, the words and phrases most frequently used by students included "fun," "play," "hands on," and "real life."

The following paragraphs list representative student comments:

- "It was my first exposure to physics and it made me really understand."
- "I liked the yo-yo's. They are more hands on, so I was able to test and see concepts I learned from school."
- "It made me think about physics for the first time since summer begins."
- "[I was impressed with] the challenge to come up with as many physics concepts in playing yo-yo. It broadened our understanding of what things are considered concepts."
- "I liked how much interaction there was with the yo-yo's."
- "This session gets me very excited about taking physics next year."
- "I have learned more about physics here than I have ever done in school."

An important lesson was learned from the “Phun” with Physics session. Because the session was conducted in a very limited one-and-a-half-hour time period, the instructor, and students as well, could not provide *in-depth* explanations for many physics concepts. This caused learning difficulties for those students who had never taken a physics course. As stated, the “Phun” with Physics session was part of the “Engineering State” event, which primarily served as a recruiting tool to attract high school students for a post-secondary study in STEM. To ensure deep learning by students, these “brainstorming with yo-yos” activities must be incorporated in formal course curriculum in the K-12 classroom throughout the entire semester.

Limitation of the Present Study and the Future Work

The present work-in-progress study has a primary limitation. Although the uniquely-designed “brainstorming with yo-yos” activities did inspire students’ interest in learning physics, as evidenced by student comments, these activities could not be immediately employed as a robust pedagogical tool to ensure *deep* learning by students within a short period of time. Conducted only one time within less than two hours for a diverse population of students across the state, the “Phun” with Physics session covered more than 50 physics concepts. It was impossible to ensure every student developed a deep understanding of each physics concept by the time students left the room. In addition, because the questionnaire survey was anonymous, the present study made no efforts to examine if there was any distinction in survey responses based on gender.

Therefore, the future work will be collaborating with K-12 physics teachers to incorporate these “brainstorming with yo-yos” activities in the formal K-12 course curriculum. A series of learning activities will be designed for students to identify relevant physics concepts via brainstorming with yo-yos throughout the semester, so students can develop a deep and better understanding of each physics concept. Educational research will also be conducted to investigate the role of brainstorming in student learning, and particularly how brainstorming relates to engineering activities such as engineering design [20].

Conclusions

Extensive literature reviews have shown that nearly all published literature on learning science and engineering with toys, especially with yo-yos, focuses on using toys in a semester-long course on a limited number of science concepts. This work-in-progress paper has described a new and unique set of hands-on activities called “brainstorming with yo-yos” that was designed as a recruiting tool in a high school outreach event to inspire high school students’ interest in learning physics and pursuing post-secondary education in STEM. In these activities, students formed teams to identify, via brainstorming with yo-yos, as many physics concepts as possible. In the present study, the total number of physics concepts that all student teams identified were more than 50. Student comments were highly positive. Many students used the words and phrases, such as “fun,” “play,” “hands on,” and “real life,” to describe their hands-on learning experiences with yo-yos. The future work will be focusing on collaborating with K-12 physics teachers to incorporate these activities in the formal K-12 course curriculum, so “brainstorming with yo-yos” can be fully developed not only as a recruiting tool, but also as a robust pedagogical tool to help students develop a deep and better understanding of physics concepts.

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