Increasing High School Students' Interest in STEM Education Through Collaborative Brainstorming with Yo-Yos

Ning Fang
Utah State University

Abstract

Brainstorming is a creativity technique in which a group of people (or an individual person) spontaneously generates a set of ideas to find the solution to a particular problem. This paper describes an innovative approach called "brainstorming with yo-yos," which was implemented in an outreach to high school event to increase high school students' interest in learning physics and consequently, pursuing postsecondary STEM education. In this approach, student teams identify, via collaborative brainstorming, as many yo-yo-related physics concepts as possible, and thus students can connect what they learn in the K-12 classroom to real-world applications. A total of 122 high school students, including 91 males and 31 females, from different school districts across the author's state participated in "brainstorming with yo-yos" activities in a recent summer. Student teams identified more than 50 physics concepts. Student comments were also highly positive. Many students used words and phrases such as "fun," "play," "hands on," and "real life," to describe their experiences with the brainstorming activities. Based on a close examination of students' submissions of physics concepts, it is suggested that instructors incorporate the mind-mapping technique into brainstorming activities to make brainstorming more effective and to simultaneously enhance student learning.

Background

The Pressing Need to Attract K-12 Students for Postsecondary STEM Education

In recent years, STEM education has received growing attention nationwide as STEM plays an increasingly critical role in the nation's economy, competitiveness and security. The National Governors Association (NGA) recently released an update on state actions on the STEM education agenda in which two goals were set for strengthening STEM education across the country: 1) increase the proficiency of all students in STEM, and 2) grow the number of students who pursue STEM careers and advanced studies (Thomasian, 2011). The NGA update also cited recent results from the Program for International Student Assessment that provide cross-country comparisons of 15-year-olds' performance in reading literacy, mathematics literacy and science literacy. It is shown that among 34 OECD (Organization for Economic Co-operation and Development) countries, the U.S. students rank behind 25 countries in math scores and behind 17 countries in science scores (OECD, 2011).

The National Research Council (2011a, 2011b, 2007) and the National Science Board (2007) of the National Science Foundation also emphasize the pressing need to significantly increase the number of K-12 students who choose STEM disciplines as their postsecondary field of study and ultimately pursue advanced degrees and careers in STEM fields. The National Research Council (2011a) identified three important goals that a successful program in K-12 STEM education has for students: learning STEM content and practices, developing positive dispositions toward STEM and preparing to be lifelong learners.

The Importance of Motivation and Interest in STEM Education

The NGA report (Thomasian, 2011) highlighted several reasons that the United States lags behind its international competitors in producing STEM graduates. These reasons include lack of rigorous K-12 math and science standards, lack of preparation for postsecondary STEM study, failure to motivate student interest in math and science, etc. For example, in many K-12 systems, math and science subjects are "disconnected from other subject matters and the real world, and students often fail to see the connections between what they are studying and STEM career options" (Thomasian, 2011). To increase student interest in STEM education, it is suggested that teachers should use informal learning, e.g., museums, STEM centers, after-school programs, seminars and workshops, and college outreach programs, to expand STEM beyond K-12 classrooms (Hunley, Whitman, Baek, Tan, & Kim, 2010; Morgan, Porter, & Zhan, 2011; Porche, Mckamey, & Wong, 2009).

The above suggestion is supported by the significant number of findings from motivational research (for example, Alderman, 2008; Bransford, Brown, & Cocking, 1999; McCombs, 1991; Pintrich & Schunk, 1996). In their well-known book entitled *How People Learn*, Bransford et al. (1999) pointed out that motivation affects the amount of time that people are willing to devote to learning. McCombs (1991) and Pintrich and Schunk (1996) found that learners are more motivated when they can see the usefulness of what they are learning. A statistically significant co-relationship has also been found between learners' motivation and their learning performances (Alderman, 2008; Harlena & Cricka, 2003).

Brainstorming as a Creativity Technique for Idea Generation

Brainstorming is a creativity technique in which a group of people (or an individual person) spontaneously generates a set of ideas to find the solution to a particular problem (Larey & Paulus, 2012; Litchfield, Fan, & Brown, 2011). The term was popularized by Osborn (1953), an advertising executive who was devoted to developing methods for creative problem solving. Since its inception as an effective idea-generation, thinking and problem-solving technique, brainstorming has been applied in a wide variety of industrial and educational settings, such as business, nursing, sciences and engineering (Bolin & Neuman, 2006; Shirey, 2011; Wang, Rosé, & Chang, 2011; Felder & Silverman, 1988).

Osborn (1953) emphasized that for effective problem solving, four general rules should be employed in brainstorming: focus on quantity, withhold criticism, welcome unusual ideas, and combine and improve ideas. In many cases, group collaborative brainstorming is found to be more effective than individuals working alone in generating ideas (Larey & Paulus, 2012; Osborn, 1953; Paulus & Paulus, 1997).

Innovation of the Present Study

In the present study, an innovative approach called "brainstorming with yo-yos" was developed and implemented at Engineering State, an event to increase high school students' interest in learning physics, and consequently to increase their interest in pursuing postsecondary STEM education. Organized by the College of Engineering at the author's institution, Engineering State is an annual three-day event held each summer. During this event, high school students across the state are invited to the campus to visit each engineering department and its laboratories to learn about engineering and engineering sciences. Serving as a recruiting tool, the goals of Engineering State 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. Each year approximately 200 high school juniors and seniors attend this event. Approximately 25 percent are female students.

The Engineering State event consists of nine hands-on challenge sessions that are conducted by faculty members, including "Phun" with Physics, Baja Buggies, Water Engineering, 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. Primarily serving as an informal learning opportunity outside the K-12 classroom, all of these sessions are designed as recruiting tools to inspire students' interest in STEM and then pursuing postsecondary STEM education, rather than as a robust pedagogical tool to significantly improve students' understanding of STEM concepts and problem-solving skills within a short period of session time. The development of a robust pedagogical tool for use in the formal K-12 course curriculum, along with reliable and validated assessment instruments, is out of the scope of the present study.

"Brainstorming with yo-yos" is the primary activity that students conduct in the "Phun" with Physics session. Yo-yos are chosen not only because many students are familiar with yo-yos, but also because numerous physics concepts can find their applications in yo-yos (Harding, 1984; Krupa & Tanska-Krupa, 1997). Each student is provided with a yo-yo to use. Students are divided into teams with four students on each team. Each team is asked to identify, via collaborative brainstorming, as many yo-yo-related physics concepts as possible. The team that identifies the largest number of physics concepts is chosen as the winner of the final contest. Therefore, "brainstorming with yo-yos" helps students connect what they learn in the K-12 classroom to a real-world application and hence, develop an interest in learning STEM.

The author of this paper has conducted an extensive literature review using a variety of popular databases and search engines, 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), the ASEE/IEEE Frontier in Education conference proceedings (1995-2012), Google Scholar, and Scoups. The results show that there is no literature reporting the unique use of yo-yos as a brainstorming tool for students to use by identifying as many yo-yo-related physics concepts as possible. Brainstorming has been primarily used as a technique for generating ideas, rather than as a catalyst to motivate learners' interest in learning science and consequently pursuing postsecondary STEM education (Larey & Paulus, 2012; Litchfield, Fan, & Brown, 2011; Wang, Rosé, & Chang, 2011).

This paper describes in detail how "brainstorming with yo-yos" activities were performed. The effectiveness of these activities was assessed by 1) the number of physics concepts identified by student teams, and 2) student comments. The lessons learned and the limitations of the present study are discussed. Conclusions are made at the end of this paper.

Collaborative Brainstorming Activities

Participants

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 one-and-a-half-hour "Phun" with Physics session at the Engineering State event held in a recent summer. The students had a variety of academic backgrounds and were in different grades (Grade 11 or Grade 12). Some students had previously taken a physics course in their schools, while other students had never taken any physics course.

The students were divided into six cohorts with approximately 20 students in each cohort. Each cohort took a turn to attend the "Phun" with Physics session. For this session, each cohort (20 students) was further divided into five teams with four students on each team. Therefore, a total of 30 student teams were formed.

Brainstorming with Yo-Yos

First, the instructor (i.e., the author of this paper) demonstrated examples of what physics concepts could be found in 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.

A yo-yo was provided to each student. By playing with yo-yos, each team was asked to identify, via collaborative brainstorming, as many physics concepts as possible. All teams entered the final contest and were required to explain and demonstrate how the physics concepts they had identified were associated with yo-yos. The left-hand-side image in Figure 1 shows students who were playing with yo-yos. The right-hand-side image in Figure1 shows a student team explaining and demonstrating physics concepts in the final context. The instructor served as the judge for the final contest. If a student

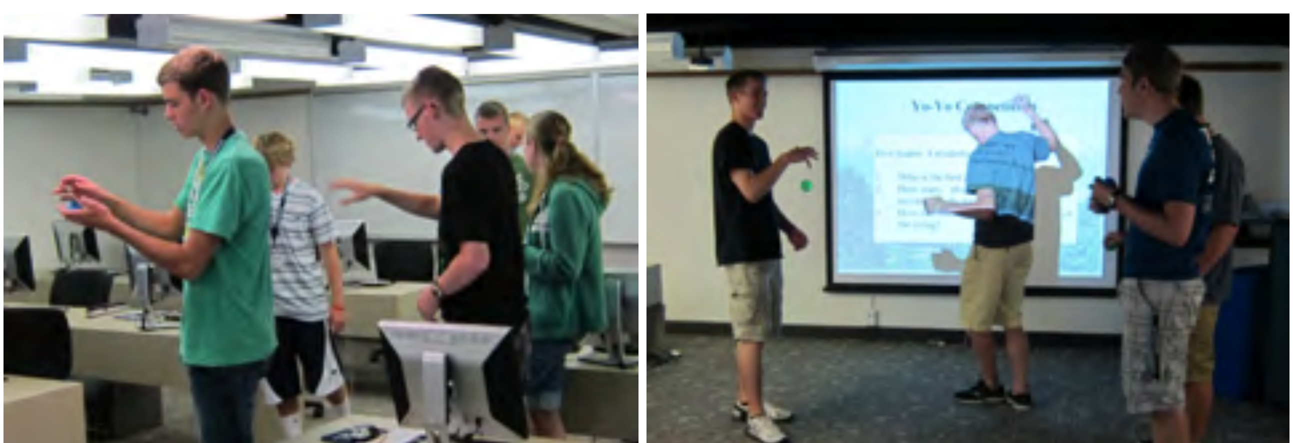

Figure 1. Students Played With Yo-Yos

team identified a physics concept incorrectly, or if a concept was a mathematics concept rather than a physics concept, that concept was not counted. The student team that identified the largest number of physics concepts won the contest.

Physics Concepts Identified by Students via Collaborative Brainstorming

Tables 1 and 2 show representative examples of the physics concepts identified by six student teams via collaborative brainstorming with yo-yos. The concepts listed in Tables 1 and 2 are re-arranged alphabetically by the first letter of each concept.

The numbers of physics concepts identified by each of these six representative student teams were: Team #1: 31 concepts; Team #2: 27 concepts; Team #3: 21 concepts; Team #4: 26 concepts; Team #5: 22 concepts; Team #6: 22 concepts. The total number of different physics concepts identified by all 30 student teams was more than 50.

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.

Team #1 (31 concepts)	Team #2 (27 concepts)	Team #3 (21 concepts)
Acceleration	Acceleration	Acceleration
Angular momentum	Centrifugal force	Air resistance
Center of mass	Centripetal force	Angular momentum
Centrifugal force	Density	Centripetal force
Density	Distance	Energy
Distance	Drag force	Equilibrium of forces
Energy	Energy	Friction
Friction	Friction	Gravitational potential energy
Force	Force	Gravity
Gravitational potential energy	Gravity	Heat
Gravity	Heat	Inertia
Impulse	Inertia	Inertia of rotation
Inertia	Kinetic energy	Kinetic energy
Kinetic energy	Mass	Linear momentum
Linear momentum	Motion	Newton's first law
Mass	Newton's 1st law	Oscillation
Mechanical energy	Newton's 2nd law	Potential energy
Momentum	Newton's 3rd law	Power
Newton's 1st law	Position	Rotational kinetic energy
Newton's 2nd law	Potential energy	Tension force
Newton's 3rd law	Power	Velocity
Particle	Speed	
Position	Tension	
Potential energy	Time	
Rotation	Velocity	
Rotational kinetic energy	Weight	
Speed	Work	
Time		
Torque		
Velocity		
Work		

Table 1. Representative Examples: Results of Brainstorming by Student Teams #1-#3

Team #4 (26 concepts)	Team #5 (22 concepts)	Team #6 (22 concepts)
Acceleration	Acceleration	Acceleration
Angular momentum	Angular velocity	Air resistance force
Centrifugal force	Angular acceleration	Angular momentum
Centripetal force	Centrifugal force	Conservation of Energy
Distance	Displacement	Distance
Energy	Force	Energy
Force	Gravity	Force
Friction	Kinetic energy	Frequency
Gravitational potential energy	Mass	Friction
Gravity	Momentum	Gravitational potential energy
Heat	Net force	Gravity
Kinetic energy	Newton's 1st law	Impulse
Linear momentum	Newton's 2nd law	Kinetic energy
Mass	Newton's 3rd law	Linear momentum
Momentum	Normal force	Newton's 1st law
Newton's 1st law	Potential energy	Newton's 3rd law
Newton's 2nd law	Projectile motion	Period
Newton's 3rd law	Speed	Potential energy
Position	Static friction	Static stability
Potential energy	Tension	Velocity
Power	Velocity	Weight
Speed		Work
Time		
Velocity vector		
Work		
Work and energy theorem		

Table 2. Representative Examples: Results of Brainstorming by Student Teams #4-#6

Positive Student Comments

At the end of the session, the students were provided with an open-ended questionnaire 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 their favorite sessions that they had attended in the Engineering State event. All students enjoyed "brainstorming with yo-yos" activities, and they expressed that 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 is a list of representative student comments:

- "This session gets me very excited about taking physics next year."
- "It made me think about physics for the first time since summer began."
- "It was my first exposure to physics and it made me really understand."
- "[I was impressed with] the yo-yo competition and thinking about all of the different aspects and concepts that act upon the yo-yo."
- "I liked the yo-yos. They are more hands-on, so I was able to test and see concepts I learned from school."
- "[I was impressed with] the challenge to come up with as many physics concepts [as possible] in playing yo-yo. It broadened our understanding of what things are considered concepts."
- "I liked how much interaction there was with the yo-yos."
- "I have learned more about physics here than I have ever done in school."
- "I liked [that] you made us aware of the physics that we see every day through the yo-yo."
- "I loved how many concepts were covered in just an hour and a half."
- "We came up with a whole bunch of physics concepts that have to do with an everyday thing like the yo-yo."
- "[We] learned about physics concepts in real situations."

The above comments indicate that "brainstorming with yo-yos" helped students see how physics is connected to real-world situations and helped increase students' interest in learning physics.

Discussions

Experiences and Lessons Learned

Although brainstorming is a powerful technique for creativity, a close examination of students' submissions of physics concepts reveals that students did not master the skill of brainstorming in the most effective manner. Figure 2 shows a representative example of original brainstorming results by a student team. As is seen clearly in Figure 2, students simply jotted down whatever physics concepts that came to their minds when they played with yo-yos. For example, the first concept in Figure 2 is "friction," followed by the second concept "velocity," then "air resistance," then "Newton's 1st law," and so on. These concepts were identified by students in a totally random manner, and no logical connections among those concepts could be found.

Therefore, the author of this paper suggests that instructors incorporate the mind mapping technique into brainstorming activities to make brainstorming more effective and simultaneously enhance student learning of physics concepts (Buzan & Buzan, 1996; Eppler, 2006). In mind mapping, a single word (text or idea) is placed in the center of a diagram, and associated words (texts or ideas) are added to the central word (text or idea). As more and more words (texts or ideas) are added, the diagram (i.e., mind map) becomes larger and larger and spreads in all radical directions like a spider's web. The following paragraph provides an example of how mind mapping can be used in "brainstorming with yo-yos" activities to not only maximize the number of physics concepts, but also help understand the relationships among various concepts.

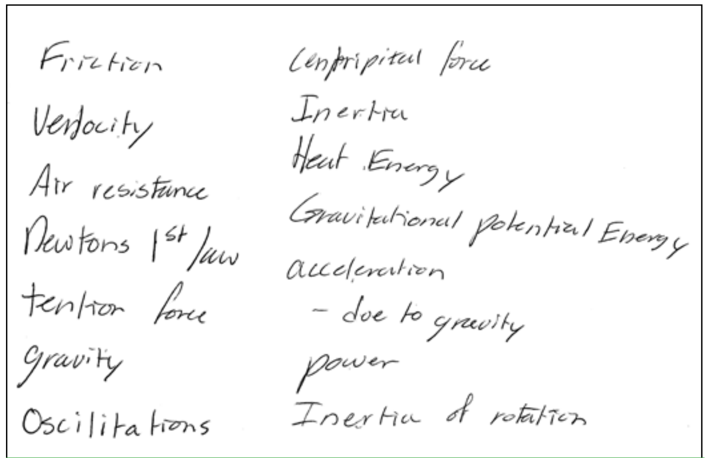

Figure 2. Representative Example: Excerpt From Original Brainstorming Results By a Student Team

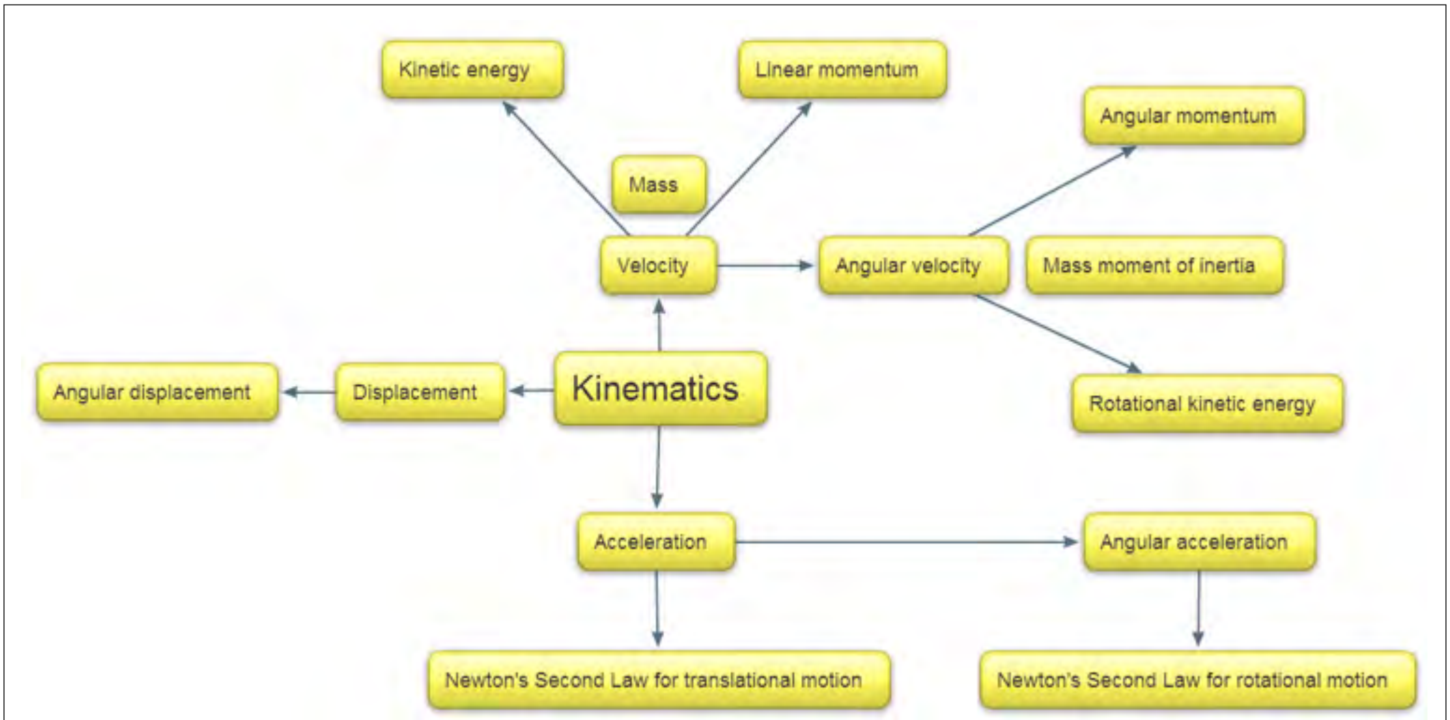

Figure 3. An Example Mind Map

One can start with a physics concept "kinematics." Write the word "kinematics" on a piece of paper (or one can use a computer software program to replace hand writing). Around "kinematics," there are three directly-associated concepts: "acceleration," "velocity," and "displacement." For a rotational motion, there are another three associated concepts: "angular acceleration," "angular velocity," and "angular displacement." When "mass" is added, "kinetic energy" and "linear momentum" will be generated from "velocity." When "mass moment of inertia" is added, "rotational kinetic energy" and "angular momentum" will be generated from "angular velocity." "Newton's Second Law for translational motion" can be generated from "acceleration" and "mass." "Newton's Second Law for rotational motion" can be generated from "angular acceleration" and "mass momentum of inertia." Figure 3 shows a mind map generated in the way described above. This mind map contains a total of 15 physics concepts. All of these concepts can be found in yo-yos. By using a different physics concept (such as "force" or "energy") from the initial, starting concept, one can develop many mind maps. During brainstorming, each student member on a team can contribute his/her own concepts to the mind map.

Another lesson learned from the present study was that some students confused physics concepts with mathematics concepts. For example, "radius," "diameter," "length," "axis of rotation," and "vector" are concepts that some students identified, but which are actually mathematics concepts, rather than physics concepts. In the final contest, the instructor corrected students' misunderstanding on the difference between physics and mathematics concepts.

Limitations of the Present Study and Future Work

The present study has one major limitation: "brainstorming with yo-yos" is designed as a recruiting tool to increase high school students' interest in learning physics and then pursuing postsecondary STEM education, rather than 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 from across the state, "brainstorming with yo-yos" covered more than 50 physics concepts. It was impossible to ensure that every student developed a deep understanding of each physics concept by the time the students left the room.

Therefore, future work will be collaborating with K-12 physics teachers to incorporate these "brainstorming with yo-yos" activities into 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. Longitudinal educational research involving a comparison of control and experimental groups as well as pre-test an post-test assessments will also be conducted to investigate how "brainstorming with yo-yos" improves student learning.

Conclusions

This paper has described an innovative approach – "brainstorming with yo-yos" – that was implemented in an outreach to high school event to increase high school students' interest in learning physics. An extensive literature review shows that there is no published literature reporting the unique use of yo-yos as a brainstorming tool for students to use by identifying as many yo-yo-related physics concepts as possible. Brainstorming has been primarily used as a technique for generating ideas, rather than as a catalyst to motivate learners' interest in learning science and consequently pursuing postsecondary STEM education.

The effectiveness of "brainstorming with yo-yos" has been validated by 1) more than 50 physics concepts that student teams identified, and 2) highly positive student comments. Many students used words and phrases such as "fun," "play," "hands on," and "real life," to describe their experiences with "brainstorming with yo-yos." Based on a close examination of students' submissions of physics concepts, it is suggested that instructors incorporate the mind mapping technique into brainstorming activities to make brainstorming more effective and simultaneously enhance student learning. Future work will include collaborating with K-12 physics teachers to incorporate these "brainstorming with yo-yos" activities into the formal K-12 course curriculum and conducting longitudinal educational research to investigate how "brainstorming with yo-yos" can be used to improve student learning (beyond increasing their interest in learning).

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Ning Fang is an Associate Professor in the Department of Engineering Education in the College of Engineering at Utah State University. He earned his PhD in mechanical engineering and has taught a variety of engineering courses, such as engineering dynamics, metal machining, and design for manufacturing. His research interests include computer-assisted instructional technology, curricular reform in engineering education, the modeling and optimization of manufacturing processes, and lean product design.