The Design and Optimization of a Lighted Kinetic Art Surface Display

(Technical Paper)

Developing Future Engineers at Home: A Deterministic Analysis of Various STEM Toys and their Effect on Learning and Enthusiasm in Children under Eight Years Old

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Introduction

Even at a very young age, children possess incredible problem-solving ability. Effective Science, Technology, Engineering, and Math (STEM) education for young children develops their problem-solving skills and can significantly impact critical thinking, interest, and general learning. Study of engineering education is rapidly increasing, and researchers are attempting to develop ways to teach STEM concepts and inspire effective learning in young children. While STEM labs and clubs are becoming prevalent at the elementary-school level, there has also been recent development of STEM toys that are used at home (Weiss, 2013). The research paper will provide a comprehensive evaluation of different types of STEM toys and will identify the most important elements for increasing learning and enthusiasm in children under eight years old.

The technical project is also motivated by a desire to increase interest in STEM fields in an educational setting. The capstone team will create a lighted kinetic art sculpture with optimized units to create a mystifying effect that will interest those traveling through the Mechanical Engineering building. In the future, we envision students programming their own functions into the sculpture as a fun way to visualize surfaces, waves, and vibrations. Like engineering toys, the technical project is intended to increase excitement about STEM fields.

Technical Topic

The capstone team, comprised of Megan Mazzatenta, Jack Purcell, and Philip Renkert, identified the need for a kinetic, programmable display that demonstrates mechatronic principles and increases excitement about Mechanical Engineering. From a design perspective, the iterative development of space-efficient and optimized systems is a concept integral to both engineering design and business decisions yet not typically covered in engineering curricula. The kinetic display will emphasize the importance of design optimization for minimizing manufacturing cost and time and create a lasting addition to the Mechanical Engineering (MEC) building.

The kinetic sculpture will consist of many small, lighted units, aptly named Voxels, that translate up and down to form surfaces or display images. The initial concept is inspired by the kinetic sculptures developed for the Bavarian Motor Works (BMW) Museum in Munich as well as the Build UP LLC design piece in Dubai ("Kinetic sculpture," 2018; *Kinetic sculpture timelapse*, 2015). These designs use string-and-pulley systems to lower metal and LED-lit spheres (see Figure 1a), respectively, which move in pre-programmed patterns to create surfaces, waves, and designs. These string-and-pulley systems, though simple and effective, are constrained by several limitations. First, because they rely entirely on gravity to lower the hanging spheres, they only work in one orientation, with the objects hanging beneath the pulley. Furthermore, because the hanging spheres are only constrained in one direction, nothing prevents the spheres from swinging or getting tangled. Therefore, these designs must be isolated from wind and other environmental factors.

However, the pin array configuration mitigates many of these issues. Researchers at the Massachusetts Institute of Technology (MIT) pioneered this configuration. Their Tangible Media Group has conceived of numerous designs, including Relief and inFORM (see Figure 1b), which use an array of sliding pins to create a digitally-configurable surface (Follmer, Leithinger, Olwal, Hogge, & Ishii, 2013). Stanford has a similar configuration in their shapeShift project (Siu, Gonzalez, Yuan, Ginsberg, & Follmer, 2018). The MIT design utilizes a compact linear actuator coupled with a slide potentiometer for feedback, while Stanford's design uses a screw drive (see Figure 1c). Both designs are limited by cost, difficulty of assembly, and limited linear travel for each pin.

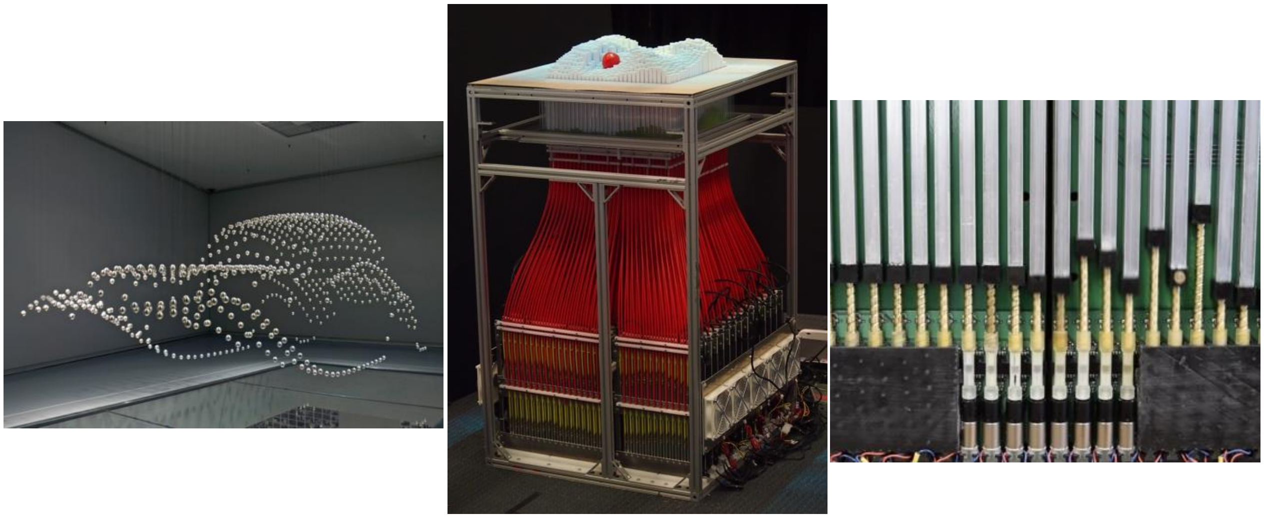

Figure 1 (a-c). Representations of prior art for extendable surface tables and suspensions. From left to right: (a) BMW Museum kinetic sculpture with hanging metal spheres, (b) MIT inFORM table with pin-array structure, and (c) Stanford shapeShift table with screw drive.

The team used these limitations to form considerations aimed to develop a similarly-captivating visual effect in the project and chose to design a rigid lighted structure in order to meet the project goals. A rigid structure allows the motor to both raise and lower each unit without relying on gravity for lowering, so the display can theoretically operate the same way when installed in any direction. When compared to string, the rigid structure also discourages students passing through the MEC building from reaching up to swat at the display. The system must be modular, inexpensive, and easily manufacturable to feasibly build a display of any size and orientation. Accordingly, the team focused on optimizing one unit of the design, and major design decisions were motivated by the objectives of minimizing both cost and manufacturing time while maintaining a captivating visual effect.

Overall, the optimized unit will create a versatile, mystifying visual display that can be expanded or modified with ease. Motion of the lighted acrylic rod will be large and controlled, and incorporating the motor into each unit provides a key advantage in modularity. If one unit breaks, or the user desires a larger display, units can be easily replaced or added on with minimal cost and manufacturing time. The inverted kinetic sculpture will be an attention-grabbing addition to the MEC building, and the team aims to give the display a greater purpose by allowing students to program in their own functions and use the sculpture as a fun way to visualize surfaces, waves, vibrations, etc. The project is set to be completed in the Fall 2019 semester with a budget of 20 dollars per Voxel, and future work on the project will focus on expanding user interaction with the kinetic sculpture.

STS Topic

Although created for young children with little to no engineering knowledge, STEM toys require both innovative and thoroughly-researched design. In the past twenty years, there has been an increase in development of toys intended to teach young children STEM concepts. There has been an uptick in the variety and popularity of STEM toys on the toy market as demand has increased for employees to fill engineering jobs. The innovators' hopes are that STEM toys will inspire critical thinking and encourage excitement about STEM careers in very young children (Weiss, 2013). Education researchers have recently taken great strides in investigating STEM education for elementary and middle school students in the classroom. However, the effect of individual engineering toys and games on STEM learning is underexamined despite their potential impact on children's skills and career choices later in life (Angeli & Valanides, 2019). There is currently very little research into the effectiveness of STEM toys and the "best" types of STEM toys for encouraging real learning. Further research must be conducted to determine how such toys are influencing children's development and impacting their role in society. The STS research paper addresses the impact of STEM toys on learning and excitement in children under eight years old, an age when they would not otherwise have exposure to engineering concepts.

Research findings collected throughout the fall and spring semesters will be used to guide more effective future development of STEM toys and will assess their potential impact on society.

The relationships between STEM-toy technology and society is complex. Concerning toy impact on individual students, the learning from each toy will change based on both the abilities and interests of each child and on the character of parent-child and parent-artifact interactions. Maruyama's evaluation of parental opinions regarding engineering education will be used alongside Inman's analysis of toy purchase to study the importance of appealing to parents through STEM toys (Maruyama, 2018; Inman, 2015). Engineering toys also affect the larger society – if successful in increasing interest in STEM study and careers, societal development may be concentrated in STEM fields to the possible detriment of progress in other disciplines. STEM toys also have the potential to perpetuate biases throughout society if particular artifacts are unintentionally designed to appeal more to children of one gender or nationality, for example. Conversely, it is possible that the toys could minimize the gender bias in the engineering profession by giving young girls more confidence in engineering concepts (Inman, 2015). Finally, the characteristics of the technology itself play a large role in its impact on both humans and society. This study will first identify traits of successful STEM toys using evaluations of different toys found in Yu's study of computational toys for children along with the Smithsonian evaluation of STEM toys (Donahue, 2017; Yu & Roque, 2019). The paper will then synthesize the findings in a short guide – aided by Zhou's analysis of engineering activities and design – that can be used to encourage successful development and use of STEM toys (Zhou et al., 2017).

The paper will explain the ability of STEM toys to impact both humans and society using the framework of technological determinism. Technological determinism refers to the theory that technology controls societal change (Smith, 1994). Canadian communications theorist Marshall

McLuhan played a key role in the development of technological determinism and argued that technology shapes societal achievement and values ("Technological Determinism," n.d.). In analyzing STEM toys with this framework, the paper will evaluate the ability of these toys to determine young children's skill development, success in school, and choice of higher-level study or career.

Broader societal effects of using STEM toys will also be analyzed through the lens of technological determinism. The theory will help identify how STEM toys affect learning environments and intellectual divides in schools. Use of engineering toys at home may change student-teacher and student-student relationships. The paper will also assess whether STEM toys are ever detrimental to real learning and understanding in a way that could significantly affect society. Another interesting component of the study is whether engineering toys contribute specifically to STEM learning or to general learning and problem-solving skills. The paper will evaluate the answer using de Paula's work on combining arts and computational thinking and Baratè's music-related study, which will help determine and predict the effect of STEM toys on societal goals and priorities (Baratè, Ludovico, & Malchiodi, 2017; de Paula, Burn, Noss, & Valente, 2018).

Critics of technological determinism, including British semiotician Daniel Chandler, have argued that the theory oversimplifies society and attributes too much power to technology alone. The critics argue that it is unacceptable to ignore the complexity of interactions between technology and society by reducing the problem to a mere cause and effect. Commenting on the effect of engineering toys on young children, STEM-toy reviewer Andrea Schwalm said, "I suspect that toys (in combination with books, movies, teacher expectations, and family attitudes) do help foster interests that can turn into hobbies that can turn into careers" (Weiss, 2013).

While recognizing the potential impact of engineering toys, Schwalm's remarks hint at a criticism of technological determinism by pointing out other factors that may also contribute to children's interest in STEM careers.

Research Question and Methods

This paper will answer the research question: "How do engineering toys affect learning and enthusiasm in children under eight years old?" The primary method for obtaining information will be documentary research. I will first divide collected sources related to engineering toys into three broader categories: background information, description of specific technology, and overall analysis and evaluation. Background will explain the importance of STEM toys and introduce the ramifications of their use. I will then split specific technologies into three subcategories of engineering toys: robotics, circuits, and traditional/simple mechanics. These subcategories represent the most common types of engineering toys.

The paper will investigate Angeli's work on robotics toys, Saenz's development of a circuit toy, and Korur's evaluation of simple machine innovations (Angeli & Valanides, 2019; Korur, Efe, Erdogan, & Tunç, 2017; Saenz, Strunk, Chu, & Seo, 2015). The paper will discuss defining elements, learning objectives, skill development, and overall strengths and weaknesses of each technology within the subcategories. Finally, the analysis section will evaluate the success of each technology based on its ability to inspire real learning and increase enthusiasm in STEM. The paper will then identify elements that contributed most to successful designs. Key results from analysis will be synthesized in a succinct guide for developing and identifying effective STEM toys. Toy market research will also be used to compare popularity of each STEM toy to its real learning benefit as evaluated by researchers ("STEM toys market research reports 2019," 2019). Finally, I will pull Cardella's and Papavlasopoulou's studies of engineering toys and gender into the analysis to evaluate gender biases present in STEM toys and to discuss how to avoid such biases in future designs (Inman, 2015; Papavlasopoulou, Sharma, & Giannakos, 2019). Documentary research will help shape the majority of problem formulation, background, and STEM toy evaluation in the thesis paper.

To gain insight into the human interactions with the STEM toys, I will conduct four interviews as a secondary research method. The first interviewee will be Samuel Giedzinski, a college student studying Mechanical Engineering who owned many STEM toys as a child. The goal of the interview will be to discover the extent to which these toys encouraged him to pursue engineering at the university level. Secondly, I will interview Caris Fagan, a ten-year-old girl who decided she wanted to become an engineer after playing with various STEM toys at a very young age. The paper will evaluate effectiveness of specific types of toys, aided by Caris's responses. The third interviewee will be Aileen Fagan, the mother of Caris, and the paper will use her answers to provide insight into the effect of parent-child-artifact interactions on the success of STEM toys. Finally, I will interview an engineering professional with no experience using STEM toys to define the control case. The four interviews will serve as case studies of the impact of engineering toys on learning and excitement as viewed from different stages of life.

Conclusion

The STS paper analyzes various engineering toys to address the lack of research regarding the effect of STEM toys on development of both children and society. The STS analysis of engineering toys is expected to demonstrate that toys increase learning and enthusiasm in STEM fields in combination with other factors. The STS deliverable will include a concise guide for developing effective engineering toys.

The technical deliverable for the capstone project is the kinetic art sculpture with units optimized for cost and manufacturing, which the capstone team will document in a technical thesis paper. The expected outcome is a 256-unit lighted piece installed in the Mechanical Engineering building that creates a mystifying effect with potential for future work in user interaction. Both the technical and STS portions of the project are intended to contribute to STEM education in an engaging way.

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