People's Sculpture Racing

Sculpture Racing
and the 2016 Massachusetts
Science and Technology Curriculum Framework
Grades 6-8

March 31, 2018

Contents

Sculpture Racing workshop at *David Lang's studio*

Introduction

Addressed here are ways that sculpture racing (SR) design challenges can advance and complement general principles and disciplinary core concepts of the Massachusetts Science and Technology/Engineering Curriculum Framework. The Framework emphasizes the importance of modeling in the sciences, technological advancement, and engineering. We consider sculpture racing to be a useful *type* of model, with special capacities for motivating, interdisciplinarity, and reaching beyond school walls to engage surrounding communities.

This conversation occurs in the context of a 2018 application for a Biogen Foundation STAR Initiative grant to create a STEM 'ecosystem' in Cambridge and Somerville in support of leading underserved, low-income, and less educated youth into STEM college trajectories and better representation in STEM fields. The grant's focus is on biology, chemistry, and mathematics in grades 6-12. *Sculpture Racing: Learning Math and Science through Design Challenges*, our grant proposal, is a collaboration between People's Sculpture Racing (PSR) and TERC (Technical Education Research Centers), a Cambridge consulting organization focusing on STEM education. TERC is the lead applicant, focusing on curriculum design and evaluation, and the development of kits to help make sculpture racing a powerful contribution to Massachusetts science curricula. PSR's role is to organize educational sculpture sessions and develop its curriculum in collaboration with TERC. (See grant application text in the appendices.)

Here, we focus on preliminary suggestions from People's Sculpture Racing for the role of the sculpture racing practice towards fulfilling the Framework for grades 6-8. Another text addresses grades 9-12.

About Sculpture Racing

Sculpture races are public races (1/2 to ¾ mile) of artful, human-powered, mobile (usually wheeled) contraptions raced on flat surfaces without obstacles. Trophies are currently given for first-to-finish, spectacle, and ingenuity, though awards can be designed for any category, or medallions and certificates can be given to all. Races are followed by exhibitions. We currently hold a Community Sculpture Race at Danehy Park as part of the Cambridge Science Festival each April, and a juried artist-focused race during the Cambridge Arts River Festival each June. We are in discussions about creating an annual schools-based science race near the end of each school year (after MCAS exams), in concert with afterschool programs.

Sculpture Racing is a revival after 30 years of a local 1980s project, founded by artists Geoffrey Koetsch and Kirby Scudder, which included kinetic sculptor Arthur Ganson. Ganson makes "mechanical art demonstrations and Rube Goldberg machines with existential themes. His kinetic sculptures, among the most beloved features of the MIT Museum, explore the nature of oiled surfaces, object manipulation, and slow explosions, and are created from a range of materials that he fabricates or finds." Early years also included the late Bill Wainwright, a celebrated public artist who worked with Buckminster Fuller. All were terrific designers and educators with engineering skills, who sought to create profound works through design and kineticism. Following that lead, PSR in this century attempts to expand sculpture racing's use of design and kinetics into the sciences, while still keeping the A for arts in STEAM (Science, Technology, Engineering, Arts, and Mathematics).

The 1980s project was open only to professional artists. PSR wanted to open it to the community at large. Shepherded by the MIT Science Museum, PSR discovered its community home in the sciences, and now participates in Cambridge's Science Festival with a community race open to all. In order to make sculpture racing open to non-engineers and community members, People's Sculpture Racing conducts STEAM workshops. We have held sculpture racing workshops at the MIT Museum, Artisan's Asylum, Parts & Crafts, Maud Morgan Arts, educators' studios, the Charles River Museum of Transportation and Technology, and in Rockland, Maine. The Sculpture Racing education team include parents, students, engineers, fabricators, architects, artists, and scientists who are expert in both the basic sciences and modeling. (See team in the appendices.)

Exemplary Science-Related Works

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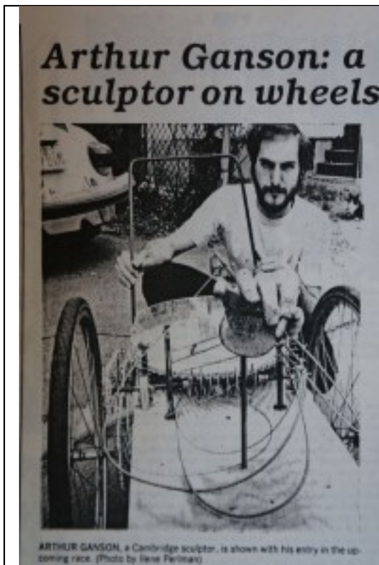

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Faster (1980s)
Arthur Ganson
An exemplary kinetic work, Faster! also goes high concept in that the work as a whole is a human-machine cyborg, i.e. a feedback loop between artist and work, human and machine. The faster the racer runs, the faster a mechanical hand on the sculpture writes the word "Faster." Theoretically it's an example of a potentially calamitous positive feedback loop. You can see this and other of Ganson's works in action at his permanent MIT Museum exhibition.

To focus on relevance, the STE [science technology/engineering] standards emphasize fewer core ideas over lists of discrete knowledge. For example, understanding the function of living systems includes understanding the role of feedback mechanisms – The Framework
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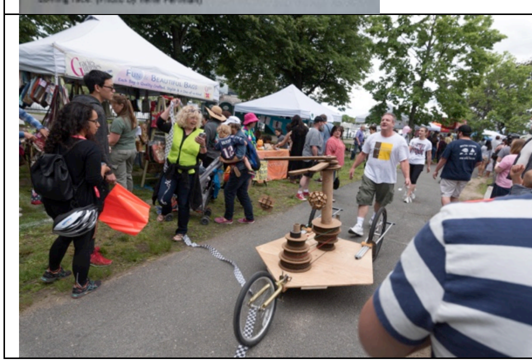
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Platonic Solid Orrery (2017)
Daniel Rosenberg
Daniel explored Johannes Kepler's explanation of the "number, magnitude, and periodic motions of the heavens [as being] established by means of the five regular geometric solids." The five solids rotate around the 'sun' in action motivated by the wheels.
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In grades 6–8, students can model complex and microscopic structures and systems and visualize how their function depends on the shapes, composition, and relationships among its parts. They analyze many complex natural and designed structures and systems to determine how they function. They design structures to serve particular functions by taking into account properties of different materials and how materials can be shaped and used -- The Framework

Beeline to the Finish Line **(2017)**
Shainker-Freywoht Family—Elizabeth (mom), Michael, 13, Isaac, 11, Caleb, 9

The bee was an opportunity to explore all aspects of the bee [said Elisabeth Schainker.] I think I checked out 50+ books from the library and spent countless hours learning about bees on the internet. In preparation I studied all aspects of structure. I had never looked so closely at all the different bee parts---legs proboscis, eyes. And in studying the structure I realized I didn't understand what some of the parts were so I delved further. I also looked at different types of bees and their markings. Again I had no idea of the complexity. I learned that people can identify bee species by their markings, like a fingerprint. I spent a lot of time learning about how bee flight works, and how the aerodynamics of it really should NOT work--making it even more amazing that bees can fly. I watched a lot of slow-mo bees flying. Again I realized my understanding was quite superficial- and how complex making bee wings move would be. [The late Kinetic Sculptor David Lang] really pushed me to think about how to incorporate [the bee's] figure 8 motion. In the end I was partially able to do this by moving the wings and weighting the smaller part of the wing so it rotated when it also moved up and down.

The first part of thinking through the idea was pretty independent work and I learned a lot. The second part was more communal. It was wonderful to team up… It helped because it was pretty hard work and I was thankful to have others who were just as challenged as I was, and also was fun to make new friends and be part of celebrating their success. Michael and Isaac helped the most. The project this year will be a kinetic school of fishes done as a group project, in which each person who participates makes a kinetic fish to add to the whole

Tsunami Wave Machine (Homage to Hokusai) **(2015)**
Steve Hahn

Steve Hahn explores how waves work. The main wheels crank a chain that turns cams fixed to vertical rods, in turn fixed to diagonal rods that create a wavelike motion.

Rocket Express 2.0. **(2016, redesigned 2017)**
Raquel Fornasaro and Family

The bubble-making atomic thruster functions through cams connected to the wheels. Raquel's daughters, now 7 and 9, thoroughly enjoyed the design and engineering process. When their mother said she wouldn't have time to create a racing sculpture for 2018, the girls objected and came up with a design. When Raquel told them how it would be engineered, the girls said, "No, that's not our plan."

	***Sisyphus*** **(2015)** **The Harvard Physics Team with Kim Bernard, Artist-In-Residence** This contemporary work moves along on *square wheels* driven by a rope on a pulley pulled by a 'sailor' standing *on* the 'sailboat'. (The tracks, however, require extensive team footwork!).
	**Uphill Sculpture Race (2017)** **Camden-Rockport Middle School with Kim Bernard, Artist-In-Residence** **Penobscot Bay Pilot, 5/26/17** (excerpts) “Twenty-three unique teams challenged Knowlton Street in front of the school as the student body watched from the sidelines cheering them on. Each team had three to five kids involved with the design, building and racing. "Kids were given a base for their sculpture," [teacher Kristen Anderson] said. "It could have been a set of wheels that were part of a stroller, or lawnmower, or bicycle.” "Only 10 percent could be new materials," [Kinetic Artist and PSR Education Team Member Kim Bernard] said. "The theme is recycling, upcycling. The teams had the task to problem solve and come up with a design, come up with a plan and make a sculpture, all within about a week and a half." “We all thought it would be a great interdisciplinary project,”[Anderson said.] “The kids are learning math, they're implementing math skills, and they'll use them in science class and study motion and how to make things faster. “ “Bernard said the kids were fabulous to work with. "They were high, high energy," she said. "Sometimes uncontrollable creative energy. Once they got past the brainstorming stage and decided what they were going to do, they all had responsibilities. One was a team leader, another was in charge of documentation, taking photographs, materials, everybody had a job to do, but once they knew their theme there was no holding them back."

As can be seen in the text accompanying the examples, sculpture racing turns kids on, and enthuses them to learn through problem solving, knowledge acquisition, and team building. The secret sauce of the project is the anticipation and excitement of the public race itself, which enchants and mobilizes youth even before a project begins!

Sculpture racing leads to spirited collaborations between family members, mentors and families, siblings, and adults, as persons of all ages and interests participate. It attracts a wide array of interests and learning styles, including youth who think of themselves as more interested in the arts and sport than in the sciences. Families attend workshops together and become friends. Participants become fans and attend each year; over time more people are attracted, and relationships build up. Teams from different schools, education programs, and communities join in. An ecosystem flourishes.

Besides engineering and math, we also see above explorations of life sciences, physics, and astronomy. ***Any scientific pursuit aided by modeling can deploy sculpture racing design challenges.*** Learning can focus on engineering; or modeling time or phase-based concepts; or movement in nature, as with the bee and orrery, which address structure and function. To whatever degree desired it can also deploy a non-moving 3D representation of something under exploration, attached to or resting upon pre-supplied moving parts. Mathematics is usefully employed throughout. Typically encountered in sculpture design and building are middle school topics in operations with rational numbers, and working with expressions and linear equations; solving problems involving scale drawings and informal geometric constructions; working with two- and three-dimensional shapes to solve problems; and topics in analyzing two and three dimensional space and figures using distance, angle, similarity, and congruence. structure and function.

The Massachusetts Curriculum Framework

Students should be able to analyze and solve problems in real-worlds context using both science and technical reasoning to support, critique, and communicate scientific and technical claims and decisions – The Framework

The Framework gives technology and engineering the same status as the basic sciences, as each complements the other. The sculpture racing team members are experts in modeling both basic core ideas and detailed disciplinary content using a wide array of methods: schematics; simple and composite materials; and modeling software, including CAD laser cutting and 3D printing.

Disciplinary Core Idea Progression Matrix

To focus on relevance, the STE [Science Technology/Engineering) standards emphasize…core ideas over lists of discrete knowledge – The Framework

In the below table are included in the first two columns the Framework's core ideas for middle schools. The third column focuses on modeling. There are many dozens of ways each concept has been modeled by scientists and in schools. Here, we include a few extant and brainstormed models. Our project includes examination of such models to determine which may be interestingly adapted for sculpture racing, such as those in the fourth column, which also includes extant and brainstormed works. Note that each grade level has specific disciplinary topics not detailed here. Orange highlights are areas Biogen focuses on: math, biology, chemistry (chemistry is only studied in grades 10-11).

Earth & Space Science			
Core Concept	**Text**	**Models**	**Sculpture Racers**
ESS1.A The universe and its stars	N/A The solar system is part of the Milky Way, which is one of many billions of galaxies.	A **black hole** somehow swallowing up information so that, once it falls into the black hole, it cannot escape.	
ESS1.B Earth and the solar system	The solar system contains many varied objects held together by gravity. Solar system models explain and predict eclipses, lunar phases, and seasons.	Orrery (1) The relation of Earth and Moon, with a light source, to show the **phases of the moon**. (2) **Gravity** and the contour of space near an object of great mass. This has been done with a rubber sheet stretched into a sort of vortex, with the	Example: Daniel's Orrery (see examples)

		object falling into it. A sculpture should show the greater the mass, the larger vortex.	
ESS1.C The history of planet Earth	Rock strata and the fossil record can be used as evidence to organize the relative occurrence of major historical events in Earth's history.		
ESS2.A Earth materials and systems	Energy flows and matter cycles within and among Earth's systems, including the Sun and Earth's interior as primary energy sources. Plate tectonics is one result of these processes.		
ESS2.B Plate tectonics and large- scale system interactions	Plate tectonics is the unifying theory that explains movements of rocks at Earth's surface and geological features. Maps are used to display evidence of plate movement.		

Life Sciences

Core Concept	Text	Models	Sculpture Racing
LS1.A Structure and function	All living things are made up of cells. An organism can be made of one cell (unicellular) or many cells (multicellular). Within cells, specialized structures are responsible for specific functions. In multicellular organisms, cells work together to form tissues and organs that are specialized for particular body functions.	Molecular modeling, 3D and computer application	**Protein synthesis**. Amino acids could come along in the sculpture, lose H and OH to form a peptide (synthesis). The water could break the peptide bond (hydrolysis). In synthesis, each turn of the sculpture could bring in another amino acid to be linked in a peptide chain.
LS1.B Growth and development of organisms	An organism's structures and behaviors affect the probability of successful reproduction. An organism's growth is affected by both genetic and environmental factors.	Animal locomotion Exploring the organic: how & why mechanical wings and bee wings work differently.	Elizabeth's bee's wings.
LS1.C Organization for matter and energy flow in organisms	Matter cycles between living and non- living parts of an ecosystem. Plants use the energy from light to make sugars through photosynthesis. Within individual organisms, food is broken down through cellular respiration, which rearranges molecules and releases energy.		

LS2.A Interdependent relationships in ecosystems	Organisms and populations are dependent on their environmental interactions both with other living things and with nonliving factors, any of which can limit their growth. Organisms compete for resources within ecosystems; typical interaction patterns include competitive, predatory, parasitic, and symbiotic relationships.		
LS2.B Cycles of matter and energy transfer in ecosystems	The matter that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. Food webs model the transfer of energy as well as matter among producers, consumers, and decomposers within an ecosystem. The Sun provides the energy for most ecosystems on Earth.		
LS2.C Ecosystem dynamics, functioning, and resilience	Ecosystems are dynamic; their characteristics vary over time. Changes to any component of an ecosystem can lead to shifts in all of its populations. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.		
LS3.A Inheritance of traits	Organisms reproduce, either sexually or asexually, and parents transfer their genetic information to offspring. An individual's traits are largely the result of proteins, which are coded for by genes. Genes are located in the chromosomes of cells.		(1) **DNA** molecule shown as a double-helix sculpture winding and unwinding. (2) **Mitosis** or (more complicated) meiosis as a kinetic sculpture
LS3.B Variation of traits	In sexual reproduction, each parent randomly contributes half of its offspring's genetic information, resulting in variation between parent and offspring. Genetic information can be altered because of mutations, which may result in beneficial, negative, or no change to traits of an organism.		
LS4.A Evidence of common ancestry and diversity	The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history. Comparisons of anatomical similarities among both living and extinct organisms enables the inference of lines of evolutionary descent.		

LS4.B Natural selection	Both natural and artificial selection result from certain traits giving some individuals an advantage in surviving, reproducing, and passing on genes to their offspring, leading to predominance of these advantageous traits in a population.		
LS4.C Adaptation	An adaptation is a trait that increases an individual's chances of surviving and reproducing in their environment. Species can change over time in response to changes in environmental conditions through adaptation by natural selection acting over generations.		

Physical Sciences

Core Concept	Text	Models	Sculpture Racing
PS2.A Forces and motion	The role of the mass of an object must be qualitatively accounted for in any change of motion due to the application of a force.		**Work** (that is, force x distance) could be the basis of sculptures built of levers, gears, etc to increase the mechanical advantage. Pushing uphill is hard. **Conservation of energy** could be the basis of a sculpture involving momentum or pedaling a generator to keep a light bulb lit.
PS2.B Types of interactions	Forces that act at a distance involve fields that can be mapped by their relative strength and effect on an object. Solutes can change the properties of solvents by creating charged particles.		
PS3.A and 3.B Definition and conservation of energy and energy transfer	Kinetic energy can be distinguished from the various forms of potential energy. Energy changes to and from each type can be tracked through physical or chemical interactions. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter.		
PS3.C Relationship between energy and forces	When two objects interact in contact or at a distance, each one exerts a force on the other, and these forces can transfer energy between them.		

PS3.D Energy in chemical processes and everyday life	Sunlight is captured by plants and used in a reaction to produce sugar molecules, which can be reversed by burning those molecules to release energy.		

Engineering & Technology

Core Concept	Text	Models	Sculpture Racing
ETS1.A Define design problems	The precision of criteria and constraints is important to an effective solution, as are considerations that are likely to limit possible solutions.	Picking realistic designs.	Needs of sculpture racing as productive design constraints.
ETS1.B Develop solutions	Parts of different solutions can be combined to create new solutions.	Deploying found mechanisms.	
ETS1.C Optimize solutions	Systematic processes are used to iteratively test and refine a solution.	Build it, break it; you can predict when something will break. Computer modeling, and refinement using mathematics.	
ETS2.A Materials and tools	Materials used in technologies are chosen based on the material properties needed for a particular purpose. Physical processing can change the particulate structure of materials and their properties.	Material strengths; how and why they vary. (See also Framework materials education table in appendices.) Found & recycles materials. Life cycle of materials. Where do they come from and why are they made as they are. Different materials to bring different characteristics to different parts of model. Compromising.	
ETS2.B Manufacturing	The design and structure of any particular technology product reflects its function. Products can be manufactured using common processes controlled by either people or computers.		
ETS3.A Analyzing technological systems	Generally, technology systems are built to accomplish specific goals, rely on defined inputs, carry out specific processes, generate desired outputs, and include feedback for control. Major systems are often designed to work together.		Ganson's "Faster" (shown above)

ETS3.B Technological systems society relies on (examples)	Three critical systems society relies on are communications, transportation, and structural systems. Components of a communication system allow messages to be sent long distances. Transportation systems move people and goods using vehicles and devices. And structural systems allow for physical structures that meet human needs.		
ETS4.A Using, transferring, converting energy and power in technological systems	Machines convert energy to do work. [Content found in PS3.A and 3.B]	Simple machines and combination.	Animated elements: cranks, gears.
ETS4.B Thermal systems	[Content found in PS3.A and 3.B]		
ETS4.C Electrical systems	[Content found in PS2.B]		Lighting & sound have been used in sculpture racers.

Mathematics Progression Table

Repeating a paragraph from above--Typically encountered in sculpture design and building are middle school topics in operations with rational numbers, and working with expressions and linear equations; solving problems involving scale drawings and informal geometric constructions, working with two- and three-dimensional shapes to solve problems; and topics in analyzing two and three dimensional space and figures using distance, angle, similarity, and congruence.

Math/modeling ideas for sculpture racing:

MATH: (1) Operations with logarithms shown by means of a kinetic-sculpture slide rule.
STATISTICS: (1) Probability A large upright board with wire brads in it, glassed in, so that dropping BBs or shot from the top falls to the bottom and describes a normal curve.

Progression of Pre-K–8 Domains										
Domain	**Grade Level**									
	PK	**K**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Counting and Cardinality	■	■								
Operations and Algebraic Thinking	■	■	■	■	■	■	■			
Number and Operations in Base Ten		■	■	■	■	■	■			
Number and Operations – Fractions					■	■	■			
The Number System								■	■	■
Ratios and Proportional Relationships								■	■	
Expressions and Equations								■	■	■
Functions										■
Measurement and Data	■	■	■	■	■	■	■			
Geometry	■	■	■	■	■	■	■	■	■	■
Statistics and Probability								■	■	■

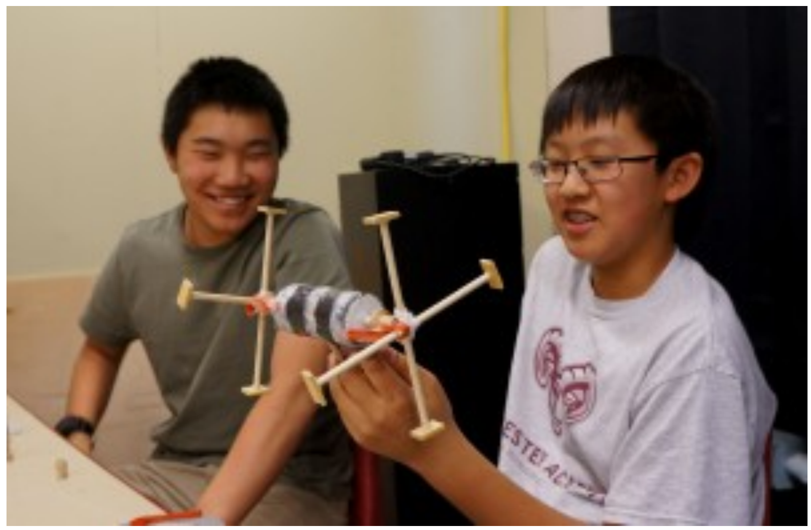
Appendices

A Few Images of PSR Outreach Events and Workshops

Initial concept design at an East Cambridge STEAM event.

Initial concept design at the Cambridge Science Festival Carnival

Building at Parts & Crafts



Modeling at the MIT Museum

Building at Maude Morgan Arts

Material Properties Progression Table

Material Properties

Different properties of materials are specified and used throughout the standards. The table below shows the grade span at which each property is introduced. Once introduced at one grade level, the property may be used, referred to, or expected in any later grade. A check mark (✓) indicates that the property is specified again in the later grade span.

Pre-K–2	3–5	6–8	HS
Absorbency			
Color	✓	✓	
Flexibility		✓	
Hardness	✓	✓	✓
Texture			
	Electrical conductivity	✓	
	Response to magnetic forces		
	Reflectivity		
	Solubility	✓	✓
	Thermal conductivity	✓	✓
		Boiling point	✓
		Density	✓
		Ductility	
		Flammability	
		Melting point	✓
			Elasticity
			Plasticity
			Reactivity
			Resistance to force
			Surface tension
			Vapor pressure

PSR Education Team

- **Kim Bernard, MFA**, Kinetic Artist; Educator
- **Mike Dawson***, Designer & Builder; Owner, Dawson Design Build LLC
- **Jeff Del Papa**, Interdisciplinary Science Education Evangelist; Director, N.E. Model Engineering Society
- **Raquel Fornasaro**, Artist; mother of two ardent pre-teen sculpture racing designers
- **Lisa E. Freed, MD, PhD**; Research Scientist at MIT's Media Lab (biomechatronics); life-long member of the MIT community; mother of two daughters pursuing college educations in STEM fields.
- **Christian Herold, MA**, Educator; Director, People's Sculpture Racing
- **Daniel Rosenberg**, Director, Physics and Chemistry Lecture-Demonstration Services, Harvard University
- **Robert Ross, Ph.D.,** medical and science writer interested in improving science education
- **Elisabeth Schainker, MD**, Associate Chief Medical Officer, Franciscan Children's Hospital
- **James Weaver, Ph.D.,** Senior Research Scientist at Harvard's Wyss Institute for Biologically-Inspired Engineering, where he runs the Wide Field Electron Optics Laboratory, and is the go-to person at Harvard for 3D printing. He has a BA in Aquatic Biology and a Ph.D. in Marine Science and completed postdoctoral studies in Molecular Biology, Chemical Engineering, Physics, and Earth Sciences.

Modeling at the MIT Museum

More Building at Parts & Crafts

*Not the same Michael Dawson of Innovators for Purpose.

Biogen STAR Initiative Grant Application

Sculpture Racing:
Learning Math and Science through Design Challenges

February 23, 2018

TERC’s mission is to improve mathematics and science education. TERC, the prime applicant, works at the frontiers of theory and practice to contribute to a deeper understanding of learning and teaching; enhance instruction through teacher professional development; develop applications of new technologies to education; create curricula and other products; and support reform in both school and informal settings.

Sculpture Racing: Learning Math and Science through Design Challenges engages middle and high school students and teachers in designing 3-D representations (mobile sculptures) that illustrate biology, chemistry, and mathematics content; presenting the thinking underlying their design; and racing them in proof-of-concept races. For a start, we have organized collaborations with the Rindge School of Technical Arts (9-12) in Cambridge, and the Kennedy School (K-8) in Somerville, as well as nonprofit educational organizations. Research and development will be conducted as a collaboration between Technical Education Resarch/TERC and People's Sculpture Racing (PSR), its subcontractor (see page 4).

PSR's role is to ramp of expansion of the use of its learning model, which is project- based, collaborative, accessible, adaptable, and fun--and additionally highly flexible it its capacity to teach different science topics--to new schools, non-profits, communities, and underserved populations (see "About Sculpture Racing" addendum).

TERC's role will be to ensure that PSR's science teaching is rigorously planned and evaluated. TERC will develop modules for each content area, each with solution- focused design thinking, such as defining a problem, conducting research, formulating a solution, creating and implementing a prototype, and learning from it. Deliverables will be module toolkits, including MA state science and math standards alignment, walk-through of the design process, embedded assessments, a student workbook, building materials, CAD software, and access to a discussion web site.

The project can positively impact STEM education in the two towns, because its underlying design thinking provides opportunities to develop skills, tools, and content knowledge needed for the workplace and civic life. It will stimulate interest in STEM, encourage collaborative learning, and result in teachers incorporating new STEM educational opportunities.

Outcome 1: Students will know the biology, chemistry, or mathematics content and concepts that underlie their sculpture. Measures for comprehension of specific grade level content and concepts as specified in MA state science and mathematics standards for biology, chemistry, and mathematics will be created from observation, interview, and survey data collected during conceptualization, building, and presentation of the sculptures.

Outcome 2: Students will demonstrate the ability to apply skills of design thinking. Measures for defining a problem, conducting research, formulating a solution, creating and implementing a prototype, and learning will be created from observation, survey, and interview data collected during conceptualization, building, presentation, and racing of the sculptures.

Outcome 3: Students will demonstrate interest and engagement in STEM. Data from observations and interview responses will be used to probe participants science learning in terms of interest and engagement.

The project has the potential to positively impact STEM education in Cambridge and Somerville as the design thinking that underlies the approach provides opportunities for students to develop skills, tools, and content knowledge that are needed to participate in a society where problems are increasingly complex.

Additional benefits are that it may also broaden participation and interest of middle grade and high school students in STEM, encourage collaborative learning, and result in teachers incorporating new STEM educational opportunities that include technology.

TERC's relationship with the Cambridge and Somerville schools is currently mediated by People's Sculpture Racing. The project begins its first year with collaborations, described in the attached letters, with the John F. Kennedy School (K-8) in Somerville and the Rindge School of Technical Arts in Cambridge (high school). We will discuss with them their learning needs for 6th & 7th grade and 9th & 10 grade, respectively, in math, chemistry, and biology. We will hold fall and spring semester-long after-school programs at both schools, pairing PSR instructors with school instructors. There will be vacation camps and weekend workshops with PSR's three non-profit collaborators. TERC staff will collaboratively design the instructional materials with PSR and school instructors and observe and evaluate.

In our second year, integrating the insights and evaluations of the first year, we will continue the above initiatives, add more organizations, and produce inter-school and organization races, and start working towards our third year goal of bringing sculpture racing into the in-class curriculum. Year four will continue all of the above initiatives, while TERC develops and completes its deliverables.

TERC's main source of revenue is grants. Staff's research and development efforts are supported as funding opportunities align with the research. Staffing is typically available within the organization to support such efforts or hired as needed. Staff tend to stay at TERC for many years as there are opportunities across the organization's work to match their expertise.

PSR has been to date a voluntary organization with limited bandwidth. Biogen's grant monies used for program and administrative salaries will allow very active outreach, collaboration, and project development-more instructors, sites, outreach, and STEM community building.

As an educational research and development organization that strives to make improve STEM education and learning for all, TERC collaborates routinely with other nonprofits, including Concord Consortium and EDC. These collaborations are intentionally designed to create synergies that take advantage of the strengths of TERC and its partners to create more robust and effective STEM teaching and learning in formal and informal settings.

For the proposed project, TERC will collaborate most closely with PSR, which teaches STEAM workshops and holds public sculpture races. PSR collaborates closely with Parts & Crafts and the Somerville High School Fabville educational innovation spaces in Somerville and arts making space Maud Morgan Arts in Cambridge. Our instructors have worked with both organizations to bring youth and families together to build racing sculptures. They taught PSR about the accessibility of the project to younger people, and more than anything else transformed the organization into a community project. PSR has also had close collaboration with the Cambridge Science Museum in its first year, and on a continuing basis with the Cambridge Science Festival, which hosts PSR during it's the festival in multiple events, including a race. The Cambridge Arts Council has acted as PSR's fiscal umbrella and has hosted it during its summer art festival. Catalyst Conversations, another collaborator, continues to build important conceptual connections between the arts and sciences. PSR participates in all of the Somerville STEAM Socials and Cambridge's EL STEAM Network events. It holds outreach demonstration events in East Cambridge Schools, as organized by Cambridge's STEAM Coordinator.

For more than a decade, the TERC team has been dedicated to increasing access to STEM opportunities and preparedness for students typically under-represented in STEM college and career pathways. Specifically, our research and development of universally designed signing dictionaries has provided access to signed STEM vocabulary for students who are deaf and hard of hearing and use American Sign Language to communicate. Each signing dictionary contains a 750+ content- specific, core-based terms and definitions, most including an illustration or example and virtual characters-avatars-that sign.

Evaluation of the impact of these resources in classroom and informal science settings reveal they are effective in helping deaf and hard of hearing children to sign, explain the meaning of, and use STEM terms integral to their science learning. The dictionaries' interactive features promote individualized instruction for a wide range of learners and standardize signs used throughout their education. TERC's Signing Math & Science body of work demonstrates the project team's success in effectively serving and engaging students behind grade-level academically and who have other barriers to graduating high school.

When People's Sculpture Racing started offering workshops in creating and building racing sculptures, it became clear that diverse youth delighted in the model. As there are many parts to each project, participants collaborated with each other on challenges they found difficult. Youth not normally interested in focusing on technical elements were captivated. PSR instructors easily customized lesson plans to different skill and education levels, bringing pre-made materials as helpful. Because there is a real-world performance element, PSR's teachers have easily seen missed components of sequential learning, e.g. a H.S. student not able to find ¾ measurements on a ruler.

We will incorporate the Biogen Foundation logo and a short description of the Foundation's contribution to the project on all of the materials developed for the project including instructional materials, project websites, press releases, publications, and promotional materials. Additionally, we will hold an annual sculpture race called the Biogen STAR Initiative Sculpture Race, with participants from all of our programs.

Attachments

- Budget
- TERC organization information
- CVs of key staff from TERC and PSR
- Letters of support from partnering schools: Rindge School of Technical Arts; Kennedy School (K-8); Somerville Public Schools Superintendent
- Other letters: City of Somerville (re Fabville); Parts & Crafts; Cambridge Arts Council
- About Sculpture Racing