"The Spiro Inquiry": exploring the application of an inquiry structure for learning science content to teaching with a digital design fabrication tool

Paula Hooper
Exploratorium Institute for Inquiry
Piers 15/17
San Francisco, CA 94111
phooper@exploratorium.edu

Natalie Freed
Exploratorium New Media Studio
Piers 15/17
San Francisco, CA 94111
nfreed@exploratorium.edu

ABSTRACT
This paper describes the design and implementation of the "Spiro Inquiry," an initial exploration into the development of a digital design fabrication based activity structured as a science inquiry and targeted at museum educators and professional development providers. We describe the development of a new software tool for exploring the properties of "spirograph" geometry, both on-screen and with digitally designed, physically fabricated gears. We then share the initial design and implementation of a workshop around this tool that is explicitly structured as a science inquiry.

Categories and Subject Descriptors
K.3.1 [**Computers and Education**]: Computer Uses in Education

General Terms
Design, Human Factors

Keywords
STEM education, digital design fabrication, inquiry learning

1.INTRODUCTION
Our work is motivated by the question: what kinds of learning experiences can support both formal and informal educators in learning about the affordances of digital design fabrication (DDF) for learning STE(A)M content? In this paper we describe the design and implementation of the "Spiro Inquiry," our first effort to explore the development of workshop with DDF for museum educators and professional development providers who work with K - 12 students and teachers.

Learning through inquiry is an accepted approach to learning STEM content that is embedded within Exploratorium exhibits as well as professional development experiences for both formal and informal educators [1][5]. Our conjecture is that a similar format to the inquiry structure used for professional development at the Exploratorium's Institute for Inquiry (IFI) could provide a structure for learning with a digital design fabrication tool that supports flexibility and explicit awareness and access to ideas that are learned in making.

Exploring scientific phenomenon through the inquiry structure makes the questions the learner asks themselves along the way and the strategies and hypotheses they come up with to investigate these more explicit and visible to the learner. The inquiry structure that we used provides points in time for reflection, for communicating/expressing ideas to others in an incremental and iterative way (one-on-one or in small groups, then a larger group).

The emerging "maker movement" has highlighted how tools to make physical things are quite motivating for learners of all ages and professions. In "maker spaces" and projects, "makers" often delve deeply into investigation of mathematical ideas in the service of the things they want to build and share [4]. There are often tensions in the design of these environments about explicitness in identifying and designing for learning of STEM content, the role of teacher/facilitator in guiding the work of learners/makers, and the goals for learners to take away from their making experience about their learning.

We adapted an established inquiry structure in two ways:
1. creating a palette of materials that includes technological tools in the form of software and fabrication output devices along with physical materials. We designed this new palette of materials to engage learners in wondering about the phenomena involved in creating spirograph-like designs using physical and digital gears. This palette of materials also evokes a wide range of questions that learners can investigate.
2. extending the goal of learners answering their own questions about scientific phenomenon, to that of accomplishing personal design goals - in other words, going through the process of inquiry to build/make a personally meaningful object.

Our goals for the Spiro Inquiry were to:
- Use an inquiry structure to design a workshop where participants engaged in making using DDF in order to explore their own questions. How did participants use the process of making as a tool for exploring the mathematical ideas embedded in this form of making?
- Observe the types of inquiry that participants framed for themselves. How did they use making to find answers to their questions? What did they find out in order to make personally meaningful designs and tools?
- Examine the professional significance that this group of museum educators found in the experience of a structured inquiry using DDF.
  - Discover what potentials participants see for this type of workshop as a form of immersive professional development (where educators are the learners and use their experiences to reflect on learning and teaching)?
  - Ask what other directions the participants would like to explore with DDF and pedagogical designs in their work with both children and adults.

2. BACKGROUND

2.1 Adding New Pathways to Constructionism

The Spiro Inquiry is an effort that lies within the tradition of constructionist theory, design and practice. Constructionism extends constructivist theory to emphasize the potential for making meaningful artifacts with computational tools to become a process of learners constructing new ideas.

Papert (1980) described how his childhood play with gears helped him to form new intellectual models that he used to learn mathematical ideas and points out that his love for the gears was key to using them as cognitive tools. He described his vision for "turning computers into instruments flexible enough so that many children can each create for themselves something like what the gears were for me." In early forms of Logo programming, turtlegraphics was a microworld that was accessible to children and novice programmers to use the computer to draw meaningful pictures using ideas such as body syntonic reasoning and procedural thinking. The flexibility and accessibility of turtle graphics commands allowed learners to explore complex graphical designs that supported an intuitive understanding of mathematical ideas such as variable, recursion and the geometry of polygons.

In these early days of computer graphics, it was incredibly motivating to "teach" the computer to draw simple or complex line drawings on the screen. Logo progressed to include a variety of microworlds and family of programming environments that make it possible to create a wide repertoire of pictures, stories, games, and new kinds of interactions possible on the screen. Each with the quality of being shared, used, played - personally meaningful and embodying the use of STEM ideas in the process of making. Now it seems we are in similar place to the days of early Logo with the twist of exploring the potentials of making things from the digital into the physical world - combining Papert's vision of a computer as a metaphor for an adaptable version of his beloved gears, while also making possible a return to the gears' tactile nature.

The Spiro Inquiry is a project to explore the potential for learners to become personally connected and intellectually productive in the process of investigating questions that combine creation within and across worlds of existing physical objects, digital representations and fabricating new objects into the world. All of these objects can be shared, used, gifted, and displayed, making them personally meaningful.

2.2 Digital Design Fabrication Tools in Education

As rapid prototyping tools - both software and hardware - become increasingly accessible to makers and educators, a greater variety of interfaces are becoming available for moving from software designs to physical creations. These innovations provide a lower barrier to creating new tools customized to specific interests, goals, and audiences.

Among the larger world of CAD and fabrication tools, we situate our work in the space of digital design fabrication tools combining aesthetic and personal applications with educational purposes, and which are designed for children or novice audiences.

The Craft Technology Group at the University of Colorado has produced a number of systems for children's "mathematical craftwork" combining a CAD software environment for designing certain types of objects connected to fabrication output devices., and emphasize the possibility of producing objects with social affordances - the ability to share creations with others - and of building aesthetically motivating creations with personal meaning and relevance. These objects include mechanical automata, origami, plush creatures, paper sculpture, fabric decals, sliceforms, and mathematical string sculptures [2]. Expansions on this theme are also suggested, each with unique relevance to a particular community of crafter and with its own potential educational affordances: string color printers, frames for soap bubbles, and spirographs in custom shapes, these last described as having the potential to become "an expandable set of curve-drawing artifacts."

With more of a specific focus on programming as the educational goal, Jacobs and Buechley developed "Codeable Objects," a code library supporting the layering of computationally designed geometric patterns over parametrically defined structures such as lamps or scarves, and the fabrication of these items [6].

We situate our work as the creation of a new DDF tool with its own novel affordances for creativity and STEM exploration. We also contribute an exploration of a specific pedagogical approach applied to our tool, in which facilitators help students express their fabrication goals and articulate their process and discoveries.

2.3 Spiral Drawing Toys: Aesthetically Motivating and Mathematically Investigable

We began this project with the idea that combining the inquiry learning structure and the affordances of digital design fabrication technology could provide a fruitful learning environment, particularly for more abstract STEM topics such as mathematics. After brainstorming various possibilities, we chose as our object of inquiry a "spiral drawing" toy most commonly known by the trademarked name Spirograph.™ This toy consists of a kit of flat shapes with gear teeth that guide a pen's movement to create looping, spiraling geometric line drawings (mathematically, in the family of 'hypotrochoids' - a circle rolled inside another circle - and 'epitrochoids' - a circle rolled around another circle) [8].

We chose to focus on this toy in part because its beautiful, complex, yet simple to make patterns have stood the test of time: the gear-based version has been around since the 1960's, and older mechanism-based tools that draw similar shapes have been around much longer [9]. This pointed to opportunities for creative and aesthetically motivated engagement.

Secondly, we chose this toy because it embodies a variety of interesting mathematical ideas that can be explored at multiple levels of explicitness: the tactile experience of the flow of a pattern repeating over time, building intuition about factorability and other properties of and relationships between integers, the geometric equations that define the placement of the curves. While we are still in the process of exploring the specific educational opportunities, we intuit that the mechanism can support thinking about variables and relationships between them that change together over time based on their respective constraints in geometric space. It may also support making connections between the geometry of a system and concepts learned outside of geometry. Understanding, for instance, the number of "petals" that will be formed by a given set of gear parameters is a result of the functional relationship between components of the system. A learner may observe that the location of the pen point on the small gear does not impact the number of petals (unless it is at the center of the gear, collapsing the shape altogether), discover how a "petal" is formed each time the smaller gear makes a full rotation around itself, and predict when the shape will repeat itself based on the least common multiple of the number of teeth in the outer and inner gears.

2.4 An Inquiry Structure for Learning Science Content, Making the Pedagogical Approach Explicit

The conceptual framework for using an explicit structure to design the inquiry are both philosophical and practical. Teaching is an intricate dance of helping students to engage their ideas with new experiences in order to develop new ideas. David Hawkins makes the eloquent philosophical argument that there is a triangular relationship between I, thou, it (teacher, student, subject matter) that is always present in a learning activity. He argues that the teacher's role in this relationship is to get to know students and facilitate their learning based on what they learn about students. The teacher's role is not to try to control students' connection with new knowledge but to figure out how to design materials and learning environments that encourage learners in making their own connections with subject matter [3]. This philosophical view highlights the practical reality that a pedagogical structure, an "I, thou, it" relationship is always present, whether it is made explicit or not. We think that this type of foundational view of teaching gives some insight into resolving tensions about the role of the "teacher" and types of facilitation that nurture learning through making. Whether in the context of a tinkering activity or a science class, learners either perceive or are told explicitly how they are encouraged to engage with materials, questions, and ideas.

The design of the Spiro Inquiry is based on the conjecture that being explicit about pedagogical structure can help to scaffold interactions between teacher/facilitator, students, and in this case STEM content. The three-phase inquiry structure is designed to help students take ownership of their own ideas and questions. This pedagogical design encourages facilitators to come to understand learners' interests and support them in making artifacts that have STEM content embedded within the process of making. The level of explicitness about pedagogical structure is important for both learners engagement with making that involves inquiry and teachers' facilitation of inquiry that involves making.

3. DESIGNING THE SPIRO INQUIRY

3.1 Design Principles

3.1.1 Technology, "just another investigation material"

We knew that the technology component would make this inquiry activity different in many ways from existing inquiries taught at the Exploratorium. However, existing non-technological inquiries are also quite varied. An inquiry involving observation of snails must necessarily differ in materials used, preparation needed, and type of scientific process emphasized from an Inquiry about investigating shadows. With this in mind, as much as possible we approached the software and technology design as simply the design of another investigation material that would be provided during the workshop, with its own special affordances and implications for facilitator preparation.

We drew an analogy, for instance, between including colored pens in the kit of physical gears, and including a color picker in the software. Both support aesthetic exploration while also acting as a flexible tool for scientific inquiry, making it easier for learners to compare designs created with different gears.

3.1.2 Making versus measuring: fabrication as a tool for scientific investigation

When using "making" as a tool for science inquiry, especially using computational tools, it is possible to systematically explore the relationship between variables and results without the tediousness of *measuring*. Instead, you specify values and *create* an object with specific properties, and then observe the results. For instance, learners do not need to *cou*nt gear teeth in their spirograph gear, but rather they can make one with the number of teeth they are interested in exploring. We designed our tool to leverage this idea by making it very easy not only to dynamically explore the effects of changing parameters (eg. with sliders), but also to input specific values directly.

3.1.3 Inquiry-Supporting Parametric Design

In support of both creative expression and scientific exploration, we made sure in the design of the workshop materials that the means of creation enabled investigation and comparison. For example, gears in the software tool are created by the user using mathematical functions (wrapped in accessible and easy to modify parameters) rather than free-hand drawing. Designed appropriately, an input interface like this doesn't limit creativity and can support learners as they explore aesthetic objects they would like to make, but can simultaneously support moments of focus on investigating the mathematical relationship between parameters and resulting shapes.

3.1.4 Balancing between supporting personal agency and imparting specific knowledge

One place we particularly thought the inquiry approach would benefit the digital design fabrication space is in its careful balance of imparting specific knowledge - such as that required by school curriculums - while enabling open-ended exploration and personal agency of learners.

The goal of an inquiry and in engaging in inquiries over time is for facilitators to help learners immerse themselves in owning their own investigations and taking progressively more responsibility for their own learning. The physical environment and materials can be designed to help learners find their way into exploring new ideas.

Inquiry and DDF have in common the emphasis on supporting learners in delving into "*my* idea" or "*my* question" about the concepts that the materials are designed to represent. In this case, learners come up with their own ideas for generating spirograph-like designs and the math and science questions motivating creating the designs and the gears that generate them.

3.2 Spirogator: Digital Design Fabrication Tool

We describe the implementation of the digital design fabrication tool itself, comprised of a software interface and of its interactions with fabrication machines.

The software, "Spirogator," has two modes. The first is the simulator, in which the user can create live drawings while modifying the parameters of two animated gears.

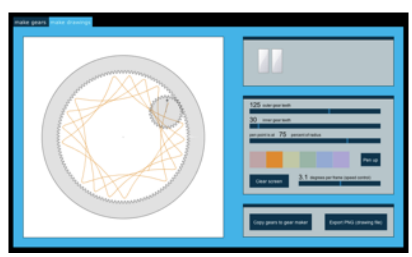

Figure 1. Spirogator in simulator mode

The simulator outputs a bitmap image that can be printed on a color printer or cut out on a cutting plotter. Figure 2 shows patterns created in Spirogator and cut out on a craft plotter. Here they were made from paper, but one could also make fabric decals, stamps, stencils, stickers, copper tape circuits, draw with a pen rather than a cutting blade, and other craft applications.

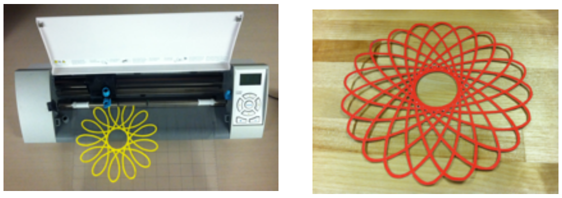

Figure 2. Exported patterns fabricated using a craft plotter

The second mode is the gear creator, in which the user can customize gears to be physically fabricated on a lasercutter by specifying the number of teeth in the gear, overall size of the gear, whether it is an outer ring or an inner mobile gear, and the location of the pen holes. These gears can be exported from the simulator, or can be created from any set of parameters.

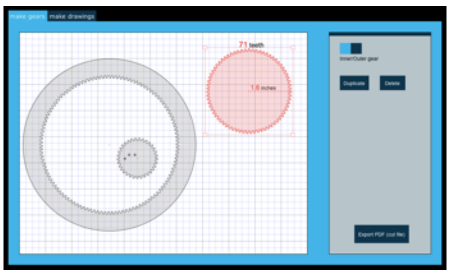

Figure 3. Spirogator in gear designer mode

The gear creator outputs a vector graphic designed to be cut out on a lasercutter. Figure 4 shows gears exported from Spirogator and cut out of acrylic, a material chosen for its hardness, translucency, and for immediately clean edges when lasercut.

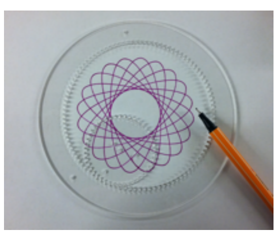

Figure 4. Exported gears fabricated on lasercutter from clear acrylic, here being used to draw a shape

3.3 Target Audience and Immersion Strategy for Professional Development

At the Exploratorium, inquiry education workshops are taught to educators from both formal and informal learning environments, and to professional development providers who will in turn bring the material to their institutions and classrooms. This was the target audience for our workshop. The workshop was a prototype where the 11 participants included educators from a variety of settings (including museum extended learning, after-school programs, university, K - 12 professional development, museum volunteers, and exhibit designers). Most of the participants had previous experience with inquiry approaches for a variety of audiences.

The model of inquiry that we used is considered an immersion strategy for professional development approach. This approach to professional development immerses participants in their own learning of STEM content in a way that relates to the process that might be use with the populations they serve as teachers/facilitators. But the form of inquiry in the workshop is designed for their own authentic learning as adults. This approach is well-documented in math and science professional development literature as effective in supporting shifts in pedagogical content knowledge for teachers [7].

Given the prototype nature of the workshop, we hoped to gather evidence for proof of our concept and refinements for future design iterations of the workshop. We would learn from documenting and observing participants' engagement in the material, their expressed interest and ideas about modifying the inquiry for use in their own education contexts.

3.4 Workshop Structure

The workshop was designed to follow the structure of other activities taught by the Institute for Inquiry, as in Figure 5.

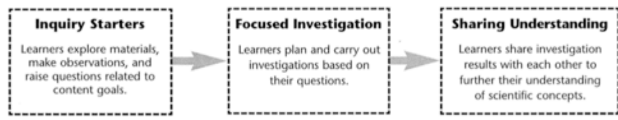

Figure 5: Inquiry Structure for Learning Science Content [5]

3.4.1 Inquiry Starters

In the first stage of an inquiry, learners are introduced to one or more activities including a collection of materials. They are asked to form small groups and are given time to explore these materials while thinking of questions their explorations elicit. Each of these activities makes up a "starter station." Following engagement with each starter station, learners write down their questions and post them up in the classroom. Some examples of questions participants posed included:

What would a gear within a gear look like?
How do we create a flower with 9 petals?
Does the pattern always meet itself? Something to do with multiples?
How can I keep the design between two radii from the center of the circle?
Why is it harder (on inside gear) to turn with pen closer to edge (in hole) rather than near center? Counter-intuitive!
Is there an inner/outer relationship where it makes a straight line?

Figures 6, 7, and 8 show the three starter stations in our workshop.

Figure 6: At the first starter station of the Spiro Inquiry, learners paired up and explored physically drawing with a kit of 7 different sizes of lasercut gears that were pre-selected to exhibit a variety of interesting properties.

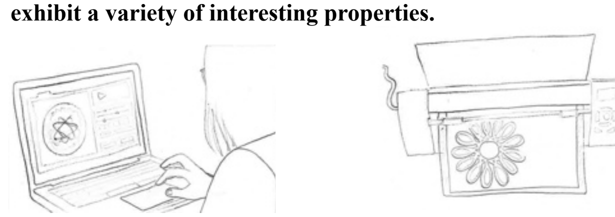

Figure 7: At Starter Station 2, pairs used the software to make digital drawings by changing the properties of on-screen

moving gears. They were then shown how to export their designs and cut them out using a scrapbooking cutting plotter.

Figure 8: At Starter Station 3, learners used the software to design gears with custom properties (including size, number of gear teeth, position, and position of holes), then were shown how to cut their gears out using a lasercutter.

3.4.2Focused Investigation

In the Focused Investigation stage of an inquiry, learners choose a question they are interested in to delve into more deeply. This question can be one of their own, or one from the shared question board. They form new pairs based on shared interest in a particular question. Then, they are given time to investigate their question using the tools and materials from any of the starter stations, other materials laid out, or specific materials they request.

During this stage in the Spiro Inquiry, learners had access to all three starter stations, including the fabrication tools, and a variety of other craft materials.

3.4.3Sharing Understanding

In the final stage of an inquiry-structured workshop, each pair shares what they have learned with the rest of the group. Then, facilitators "synthesize understanding" by bringing together the group's developing understanding and some of the key concepts in the science or math underlying the activity.

In this initial pilot, we asked participants to share what they wanted to find out and what they made in order to discover it. We also asked them to reflect on what they learned about the process of investigating through digital design fabrication, and how this inquiry informed their thinking about the work that they do.

4.PROFILES OF PARTICIPATION

We describe a few participants in our pilot workshop whose explorations were representative of a variety of styles of participation.

4.1Aesthetic Exploration

Participant A, an industrial design student, used the simulator feature of the software to create layered spiral patterns, then used the craft cutter to cut out her favorite shape. She brainstormed diverse art and design application ideas for the patterns that she was interested in - in particular, a mechanism attached to a bicycle that could trace out the spiral patterns with a point of light - while appearing to feel conflicted about not being drawn to explicit engagement with the mathematics: "This idea would be cool...but I guess it would not be about the math..."

4.2Mathematical Focus

Participant B (an educator with a mathematics background), by contrast, seemed to be primarily absorbed by systematic investigation of a mathematical question. In the first starter station, she iterated through combinations of the physical gears, annotating her drawn patterns with information about the gears that were used to create it. After being introduced to the simulator tool, she continued her investigations primarily in the software, which enabled more rapid iteration through inputs.

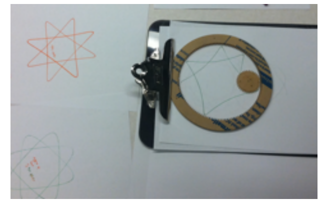

Figure 10. Participant B's annotated explorations

4.3Kit Design and Education Investigation

Participant C: This participant, an educator, experimented with rolling an "inner" gear around another "inner" gear, creating overlapping patterns in different colors.

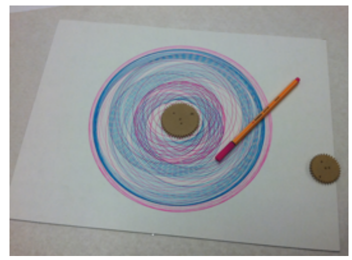

Figure 11. Participant C's layered explorations

She asked the facilitators if it was possible to design an "outer" gear with teeth on the outside using the gear designer software, and worked with us to understand that she could layer "inner" gears to create rings with teeth on the inside and outside. She used this technique to create her own physical gear kit with the parameters she was interested in exploring, then cut out her set on the lasercutter.

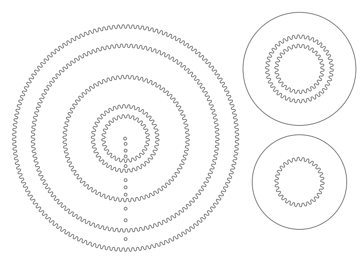

Figure 12. Exported file for the stacked gears that participant C created and lasercut to explore inner and outer variations

Participant C then took this set of gears home with her, and the next day conducted her own inquiry with friends using both the physical gears and the simulator software. She has since expressed interest in making more sets to prototype her own version of this inquiry in a classroom.

5. DISCUSSION: IMPLICATIONS FOR FUTURE DESIGN

The experiences of all the participants in the workshop affirmed our belief that this type of workshop has productive potential to be plumbed for professional development and working with a variety of learners. Overall, the software tool, physical gear mechanisms and drawing tools along with fabrication machines supported participants in engaging with making. The inquiry structure supported the explicit articulation of questions and the ownership of paths to pursue those questions.

The profiles described above are representative of both the general observations and some important clues to teasing out the nuances of learning in the workshop and implications for the next iteration of the workshop. Each of the profiled participants grounded their investigations in a feature of the materials that caught their interest and mathematical thinking was more or less salient in the projects that they defined for themselves. Some questions emerged from from the physical material, some questions that came from digital explorations and some were strongly connected to both digital and physical/fabrication. For example, Participant A used the feature of designing the complex curves in the app to find a design that she imagined would make an interesting pattern in motion through bicycle spokes while riding. She was apologetic that her inquiry was not explicitly mathematical. Her case raises the issue of whether the inquiry structure that we used implied a preference for mathematical investigations. In the future, we can consider how to explicitly value all types of investigations.

The investigations of participants B and C were both framed on systematic mathematical explorations. But each had a distinct approach to creating representations for patterns in the designs that suggest ideas about functional relationships. Participant B was intent on carrying a progression of designs that she found in working with the set of gears that was provided in the initial kit. She wondered when the curve would change "from convex to concave" and was pleased when the software version of the tool would allow her to quickly progress through the method of mapping out the numerical relationships between the gears that would make the types of curves along the progression that she was interested in. For her, the physical to digital was a tool of convenience. While Participant C defined an investigation that was driven by aesthetic appeal, modeling in the software and fabrication of her own set of gears. She created her own pathway of inquiry where the making of her design led to making a set of gears that was possible with the process of fabrication but nothing that we as facilitators had imagined. And it is a significant component of her engagement as a learner that she fabricated a set of gears that she could take home and explore further.

This is just the beginning of many fruitful directions for analysis that can inform our future designs. We are eager to further investigate evidence to suggest that the multiple learning pathways afforded by the physical-digital-fabrication cycle being open for participants to define their own inquiries at any point on the cycle. What is evocative about the way that the designs form the relationship between the variables? How to characterize a particular kind of dynamic visual representation of mathematical relationships?

There are implications in this web of pathways for refocusing the inquiry structure to emphasize toward explicit mathematical thinking, make the artistic nature of investigations more explicit and figure out how to articulate a blending of the two qualities. There will be more time in the next workshop to have participants discuss their approaches and findings with each other which will also further utilize a strength of reflective dialogue that is included in the inquiry structure for professional development. We believe that the prototype also supported the possibilities of the tool set to be used to explore the characteristics that can make the inquiry well-designed for helping kids learn variables.

There are a vast number of possible additions we could make to the software itself, but we have a few preliminary guiding principles in mind. First is to ground the features in what is possible physically (even if very difficult manually, such as moving a gear around the outside of another gear, or moving a gear inside an outer gear that is itself moving inside an outside gear) to maintain the ability to test an idea in both its digital and physical representation. Second is to maintain that gears are created using parameters that support investigation and comparison, as we described in the design principles for the workshop.

The variety of productive paths that even this small number of participants took also suggests that it could be productive to shape another kind of workshop structure that is even more open-ended. The tools themselves seem to be able to sustain a variety of kinds of making. What if exhibit designers wanted to play with creating interactive gear mechanisms that somehow created patterns controlled by microcontrollers? What would need to be changed so that the physics of the gear mechanisms could become a more accessible feature for investigation?

5. ACKNOWLEDGMENTS

Thank you to Bill Meyer for giving us the "design challenge" that started this project. Many thanks to the Institute for Inquiry for supporting the project, and to the New Media Studio for great software and UI feedback. Forrest Green contributed some wonderful debugging and computational geometry knowledge. Danielle Stanton advised us on spiro-math and pedagogy. Marilyn Austin provided her pedagogical wisdom. We really appreciate the Tinkering Studio generously sharing their lasercutter for the workshop. Thank you also to the participants in our first Spiro Inquiry workshop and Jennifer Paquette for the great documentation.

Finally, thank you to Lawrence Sass and Michael Eisenberg for being inspirations!

6. REFERENCES

[1] Duschl, R., Schweingruber, H., & Shouse, A. (Eds.). (2007). "Participation in scientific practices and discourse." in *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.

[2] Eisenberg, M. (2002) Output Devices, Computation, and the Future of Mathematical Crafts. *International Journal of Computers for Mathematical Learning.* 7(1):1-44.

[3] Hawkins, D. (1974). "I, Thou, It" In *The informed vision: Essays on learning and human nature.* New York: Agathorn Press.

[4] Honey, M. and Kanter, D. (2013). Design, Make, Play: Growing the Next Generation of STEM Innovators. Taylor and Francis: New York, NY.

[5] Institute for Inquiry (2006). "Pathways to Learning: A Design for Teaching and Learning through Inquiry". Available at www.exploratorium.edu/ifi/about/philosophy.

[6] Jacobs J., Buechley, L., " Codeable Objects: Computational Design and Digital Fabrication for Novice Programmers." 2013. In forthcoming Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, Paris, France, April 2.

[7] Loucks-Horsley, S., Stiles, K., Mundry, S. E., Love, N. B. & Hewson, P.W. (2010). *Designing professional development for teachers of science and mathematics (3rd ed.)*. Thousand Oaks, CA: Corwin

[8] Wikipedia. "Spirographs." 26 March 2013. Retrieved from <http://en.wikipedia.org/wiki/Spirograph>.

[9] Windsor, H. H., Ed. The Boy Mechanic. Chicago: Popular Mechanics Press, 1913. 436-439.