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Exploring Algorithm Building through Designing and Making Kinetic Sculpture

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Abstract: Algorithm building, creating a step-by-step procedure to carry out a solution, is a challenging concept for youth to learn and practice. Kinetic sculpture is a novel context for examining how students may learn algorithms through designing and making. As part of a larger study, we collected and analyzed a total of 18 student pre- and post-tests on computational thinking, physical computing, and arts. To examine how students build algorithms in the process of designing and making a kinetic sculpture, we analyze two vignettes from two small groups in a STEAM-based workshop. Findings show that while designing and building kinetic sculpture, students learned computational thinking and applied algorithms by incorporating inputs, outputs, and variables during the process. This study offers a springboard to investigate how students create and apply algorithms in designing and making kinetic sculpture and provides empirical evidence on how students learn algorithms in a STEAM learning context.

Introduction

Computational thinking (CT) includes conditional logic, debugging, distributed processing, and algorithm building (Wing, 2006). In computer science, algorithms are step-by-step responses to problem-solving and used to generate solutions as well as serve as heuristics to design processes to solve complex problems. Additionally, algorithms are identified as a required concept to learn in K-12 computer science (CS) education (CSTA, 2020). Applying algorithms allows learners to create a suitable output for a given input (Denning, 2009). Furthermore, algorithms are primarily explored within CS courses in K-12 schooling (Ciccone, 2021), which creates missed opportunities for developing students' algorithm building in other disciplines or multidisciplinary contexts. In this paper, we define an algorithm as the practice of creating a step-by-step sequence of procedures for carrying out a solution or process.

Studies have examined how students learn CT and algorithm building in robotics and STEM (Ioannou & Makridou, 2018). However, recent studies have shown how students can learn CT more effectively in STEAM-based learning environments than traditional programming activities due to participation of design-based activities (Wang et al., 2022). Kinetic sculpture is a promising application for learning complex concepts in arts, STEM, and computing for college students (Yilmaz, 2014). Sculptures take three-dimensional space, requiring both visual and structural balance. Kinetic sculpture may be designed and programmed to interact with nature, using wind or water to exert force, or it may incorporate technologies like simple crank motors or preprogrammed servo motors and LEDs. As such, interacting with a kinetic sculpture supports the learning of complex CT concepts, such as parallelization (Chowdhury, 2015). However, it was unclear how students learn CT, particularly algorithms, through the process of making and designing a kinetic sculpture. Therefore, we argue that it is compelling to investigate how students learn and build algorithms through designing and making a kinetic sculpture in a STEAM-based learning environment. In this study, we ask: 1. To what extent do students learn CT in making a kinetic sculpture? 2. How do students apply and build an algorithm in the process of designing and making a kinetic sculpture?

Workshop Design

Grounded in a constructionist approach to learning through hands-on designs (Papert & Harel, 1991), we understand learning of CT to be both an individual and social process mediated by the design and sharing of external artifacts (Kafai & Proctor, 2022. Additionally, this study is guided by Wing's foundational work defining algorithm building to identify targeted key practices of algorithm building in action in a classroom setting. Kinetic sculpture was chosen because of its promising application for applying complex concepts in arts, STEM, and computing. In our lessons, fifth- and sixth-grade students designed sculptural movement using inputs like sensors, buttons, and potentiometers, and preprogrammed outputs like servo motors and LEDs. Over the course of a 4-day workshop, students started by learning and programming inputs and outputs of their kinetic sculpture with varied variables. Later in the workshop, we gave students freedom to create any abstract or representational design they wished. Creating kinetic sculptures required students to think across multiple domains and apply CT and algorithms to building an original design that moves.

We designed the lessons in this study with consideration of both media arts standards (NCAS) and engineering design standards (NGSS) as well as California computer science standards in two core concepts: 1) Decompose problems and subproblems into parts to facilitate the design, implementation, and review of programs; and 2) Seek and incorporate feedback from team members and users to refine a solution that meets user needs. According to the standards these two concepts centered on algorithms which students create and build step-by-step procedures to solve a problem or carry out a solution. In this paper, we focus on the ways students apply algorithm building by using the components and concepts like inputs (e.g., potentiometer), outputs (e.g., servo motor), and variables (e.g., speed, time) as well as design materials during the process of designing and making a kinetic sculpture. Over the course of the workshops, objectives were sequenced around learning arts concepts through kinetic sculpture and physical computing with the Grove Beginner Kit for Arduino and a block-based Arduino coding platform, Grove Blockly, designed by the research team. Students worked collaboratively to design and create kinetic sculptures by using computational and electrical (e.g., Grove Blockly, servo motors), structural (e.g., cardboard, foamboard), and aesthetic materials (e.g., feathers, colored felt). Students apply and create algorithms, step-by-step procedures (sequencing), in order to solve the problem they identified in iterative design processes. Table 1 shows the workshop sequence and duration.

Table 1
Lesson Sequence and Duration

Day 1	Day 2	Day 3	Day 4
Pre-Test Administered 30 minutes	Group A: Physical computing and coding lesson (identify the inputs and outputs, program LED and servo motor with push buttons and potentiometer) 1 hour, 15 minutes	Group A: Art and design lesson 1 hour, 15 minutes	Combined making: All students making kinetic sculptures (coding, connecting, building); Post-Test Administered 2 hours, 20 minutes
	Group B: Art and design lesson (identify elements and features of kinetic sculpture, plan and design using servo motor or sensor with LED) 1 hour, 15 minutes	Group B: Physical computing and coding lesson 1 hour, 15 minutes	

Methods

This study was conducted in spring 2022 at a charter school in Orange County, California in a combined 5th-6th grade classroom. A total of 25 students participated in the study (and a near equal split of students that identified as girls and boys in the classroom). Based on the results of pre-survey from students, 9 students were White, 6 were mixed race, 2 were Latinx, 2 were Asian, and 6 were other. Most students (over 70%) had no prior experience with physical computing but reported prior arts experiences (e.g., painting, crafting) before the workshop. We used 360° cameras placed next to students in small groups and collected a total of 15 hours and 44 minutes of video across four focus groups (3 dyads, 1 triad). The lesson sequence occurred over four days (see Table 1).

A total of 25 students participated in the workshop and seven were removed from the analysis due to absent consent and incomplete pre- or post-test. To answer the research question, we analyzed 18 students' (M =7, F =11) pre- and post-test to examine the learning of STEAM concepts, focusing on physical computing, CT, and arts on the topic of kinetic sculpture. Particularly, this paper will focus on the results of physical computing and CT to examine students' learning gains on algorithm building. The pre-test included demographic questionnaires and questions regarding prior knowledge on physical computing and arts for researchers to better understand students' backgrounds. We applied paired sample t-tests to examine if there were learning gains from pre- to post-test. Building on the results from pre- and post-test, we then included two vignettes to unpack the ways in which students applied and built step-by-step algorithms with outputs and variables from the processes of design and making. The vignettes included one dyad and one triad group. In this paper, we chose to focus on these groups because, as we reviewed the collective video data, we noticed the unique ways they negotiated sequential design choices for their sculpture including sophisticated decisions around sequencing and problem solving. The video selected is from the final day of instruction where students were finalizing their designs and building their sculptures with minimal teacher-led direction.

Findings

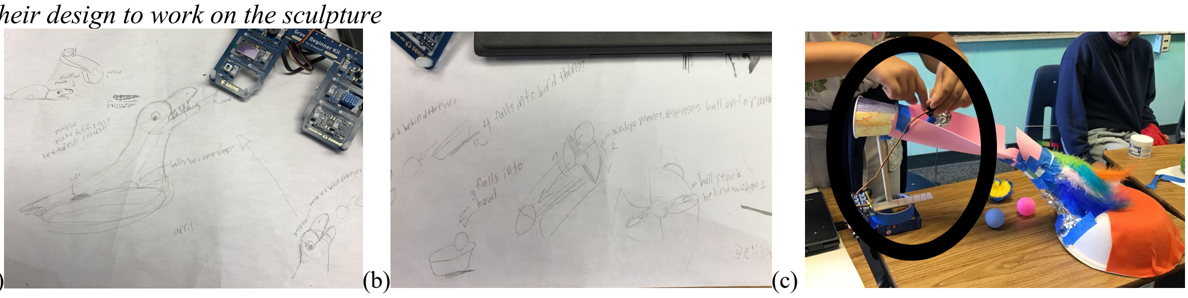
In this study, we explored how students build, develop, and modify algorithms during a co-design process including the use of inputs, outputs, and variables. First, the paired sample t-test results showed that students improved significantly from pre- ($M = 3.83$, $SD = 3.92$) to post- ($M = 17.11$, $SD = 5.32$) test $t(17) = 10.19$, $p < .001$. Particularly, students showed improvement on the questions of CT and physical computing from pre- to post-test. The results indicated that students had better understanding on electrical components and concepts (e.g., servo motor, input, output), computational (e.g., loops, conditional logic) and arts concepts (e.g., shape, form, texture) from pre- to post-test. Ten out of 19 questions focused on CT and physical computing also indicated students' learning on algorithm building, including – describe an output of an algorithm, create step-by-step procedure with inputs, outputs, and variables, and identify inputs and outputs from a step-by-step procedure. The results of the paired sample t-test inform the qualitative analysis to further examine how students apply algorithms with inputs, outputs, and variables during the designing and making processes.

Applying Algorithms in Design

To understand how students incorporated inputs, outputs, and variables in building an algorithm, we include two vignettes as examples to show how these elements were used in the process of design and making a kinetic sculpture. First, the dyad group with Dolores and Amber (pseudonyms), considered revised their sculpture design for balance and functionality, considering how they could use the motor (output) to "feed" ping pong balls to a bird sculpture, filling its stomach. Vignette 1 shows how the group decided to use the servo motor (output) in their design and then used planning and testing to solve a problem in making the sculpture.

Figure 1

(a)The group modified design drawing of the kinetic sculpture for balance and movement, (b)planned a step-by-step motion of ping pong balls by applying an algorithm with motor design, and (c)finally tested and adapted their design to work on the sculpture



(a) (b) (c)

Vignette 1

Line	Transcript
1	**Dolores**: It was originally just going to be the head but then it wouldn't balance great, so then we decided to do the body of it
2	too (see Figure 1 left). When you put ping pong balls up to the motor it goes like right there (indicates the top of the cup shoot;
3	see Figure 1 center, drawings numbered 1 and 2) and then the ball gets, it's like right there, and then when you turn it, it goes in
4	(see Figure 1 center, drawing numbered 3).
5	……..
6	**Dolores:** (picks up a structure made with a wooden base, 6 inch dowel, paper cup attached on its side, bottom cut out) This is
7	where these (the balls) are gonna come out (moves a ping pong ball to the cup opening). We're going to have a motor and it's
8	going to go through (see Figure 1 right).

Dolores explained to the researcher that they planned to feed balls into the bird's mouth using a separate tower structure with the servo motor releasing the balls as it moved (Line 1-4). However, during the making process, they realized that there was a balance problem with their sculpture, and they decided to give the bird a wider stomach as the base. From there, they designed a step-by-step motion plan as building an algorithm (Figure 1 center; numbered 1, 2, and 3 in the drawing) to illustrate how the servo motor will move and spin, so ping pong balls will fall into the bowl and then tested and adapted their design as they built (Line 6-8). This vignette indicated how the group incorporated a servo motor (output) in their design by applying a sequence algorithm based on the motion of the servo motor in an iterative design process.

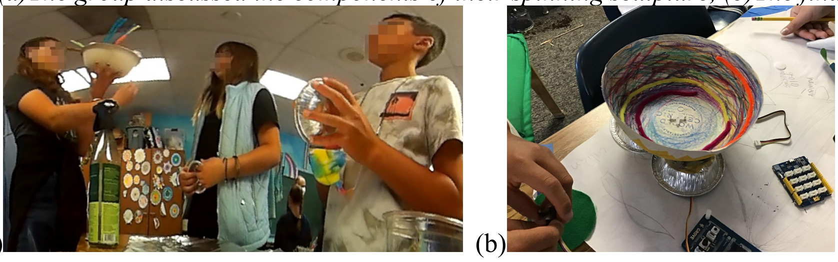
Building Algorithms in Making

In Vignette 2, the group discussed what design materials (e.g., paper bowls, cups) to include for the sculpture and how they incorporated the output components (LED light and servo motor) into the design.

From Line 1-6, Naia identified a problem (weak base) of their sculpture, and Simon provided his opinions regarding the size and weight (variables) of the sculpture design. Linda asked a question about the materials they used which led to the conversations regarding where the servo motor can be placed in the sculpture. Line 9-18 shows how the group made a step-by-step design decision by incorporating the servo motor, LED light, and variables like the size of the materials. Using the servo motor to drive the design of sculpture, the group created a sequence of decision-making in the process of making.

Figure 2

(a)The group discussed the components of their spinning sculpture, (b)The final look of the sculpture

(a) (b)


Vignette 2

Line	Transcript
1	Naia: I don’t think this is strong enough for the base.
2	Simon: It’s not like we’re making something big and heavy though, the servo motor is really tiny.
3	Linda: Yeah, we just need it to be big enough to support the (picks up the paper bowl and indicates the sides) (see Figure 2 left).
4	Are we using this for the whole thing?
5	Simon: Yeah, that’s what I was thinking.
6	Naia: Um yeah. So this (picks up the paper bowl) would be on top of this (puts it over the small pie tin)?
7	Linda: And then this would spin. [Linda demonstrates the spinning motion]
8	Naia: But then how would that work?
9	Linda: Let’s take everything out [Linda dumps balls and pipe cleaners from the bowl] and we could try going like this but then I
10	think that's (a single small pie tin) too small. Oh wait, but then we could go like this, put them all together [Linda places three
11	pie tins in a triangle formation for the base] and then this one would go like [Linda places the paper bowl on top].
12	Naia: Yeah, all of these three can be together.
13	Linda: Yeah but then how do we get the servo motor through there.
14	Naia: We could have the motor going though these (indicates the center of the base) like this.
15	Linda: Yeah I guess that would work.
16	Naia: [picks up the bowl] Or instead of having it spin we could make it with lights.
17	Linda: Simon doesn’t want lights.
18	Naia: Really? I think it would look really cool. Okay, Let’s start by hot gluing these (indicates the three pie tins) together first.

Discussion

This study aims to explore how students create and apply algorithms in the process of designing and building a kinetic sculpture. At first glance, algorithms seem to be a linear, one-way direction in building a step-by-step instruction toward a problem solution. However, the layer of algorithms can be complex regarding the elements and variables that are used as part of the algorithms. Particularly, the process of design and making are iterative and it is critical for students to review and modify the proposed algorithms to ensure they achieve the desired outcomes. This study not only offers a springboard to understand how students incorporated inputs, outputs and variables in building the algorithm through design and making, but also includes empirical evidence on learning CT and algorithms in a STEAM-based workshop.

References

Ciccone, M. (2021). Algorithmic Literacies: K-12 Realities and Possibilities. In *Algorithmic Rights and Protections for Children*. https://doi.org/10.1162/ba67f642.646d0673

Chowdhury, B. T., Blanchard, S., Cameron, K. W., & Johri, A. (2015). SeeMore: An interactive kinetic sculpture designed to teach parallel computational thinking. *Association for Engineering Education - Engineering Library Division Papers*, 26.1360.1–14. https://doi.org/10.18260/p.24697

Computer Science Teachers Association (2020). CSTA Standards for Computer Science Teachers. Retrieved from https://csteachers.org/teacherstandards.

Denning, P. J. (2009). The profession of IT Beyond computational thinking. *Communications of the ACM*, *52*(6), 28-30.

Ioannou, A., & Makridou, E. (2018). Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work. *Education and Information Technologies*, *23*(6), 2531-2544.

Kafai, Y. B., & Proctor, C. (2022). A revaluation of computational thinking in K–12 education: Moving toward computational literacies. *Educational Researcher*, *51*(2), 146-151.

Papert, S., & Harel, I. (1991). Situating constructionism. *constructionism*, *36*(2), 1-11.

Wang, D., Luo, L., Luo, J., Lin, S., & Ren, G. (2022). Developing Computational Thinking: Design-Based Learning and Interdisciplinary Activity Design. *Applied Sciences*, *12*(21), 11033.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33-35.

Yilmaz, B. (2014). Art Engineering and Kinetic Art. *Journal of Arts and Humanities*, *3*(12), 16-21.