A Study On The Design And Manufacturing Of Mechanical Sculptures: The Blooming Flowers Automata

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This study provides the documentation and methodology necessary for designing, testing, and manufacturing advanced automata using widely available materials while utilizing design engineering principles. The automata have no electrical pieces such as motors or sensors, focusing on simple machines, specifically gears and levers to automate the mechanical sculpture. A modified Engineering Design Process (EDP) is created to cater to high school students and utilize CAD environments for high-fidelity prototyping [9], as well as compensate for the problems in estimating engineering quantities without experience [3]. On that branch, the curricula for gear theory and fundamental law/s are adapted to the high school level for users with rudimentary to no grasp of mechanics as a proper understanding of gear theory is necessary. A laser cutter is used for the quick prototyping of the automata, however, the design can be manufactured by hand with plywood or MDF and easily accessible tools such as hand saws and wood files. Making bevel gears is challenging and timely without a machine like a CNC because of their conical-shaped teeth. To compensate for this, cage and peg gears are used. Additionally, the gears are developed for the sculpture using gear theory to achieve peg gear trains with nonparallel axes of rotation. The real-life constraints of mechanical design engineering are dealt with by utilizing the mod. EDP and gear theory in the following study.

Keywords *Design Engineering, Gear Theory, Computer-Aided Design, Computer-Aided Manufacturing, Engineering Design Process*

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1 INTRODUCTION

Makers and artists have incorporated movement into sculptures and artwork since the early 20th century. This was done mechanically, statically, or mobile [1]. The use of motors was classified as mechanic while exploiting natural phenomena such as hydraulic or aerodynamic movement was classified as mobile art. The movement was imitated through static means by utilizing optical illusions in static art, also called op art. Recently, however, achieving kinetic art with simple machines alone has become increasingly popular. The development of the mechanical sculpture in this study relies exclusively on the interactions of simple machines, more specifically the gear. In this showcase, I will be presenting a bloom automaton kinetic sculpture which was developed with the proposed EDP and serves as a proof of concept. I wanted to modify the traditional EDP in a way that allows students to experience and figure out the process in an organic way as opposed to passively absorbing information [2].

2 BIO

I am a student at Hisar School and have worked in the fabrication laboratory ideaLab since middle school. My academic interest is physics, mechanical engineering and mechanics specifically, and I mainly work on prototyping in R&D projects. My areas of interest are kinetic sculptures, biomimetics, education, and clockwork.

3 MODIFIED ENGINEERING DESIGN PROCESS

Currently, a lot of people in the maker environment have trouble incorporating real-life constraints into their designs like when to use certain materials and when not to, taking accessibility into account, they have trouble operating the machines, and such. The students have difficulty understanding the design process and fail to think of the aforementioned constraints during the research, ideation, and feasibility, bypassing any relevant physics knowledge that should be thought of. Steps that are implied in traditional EDP (Engineering Design Process)– for example, topology optimization– are disregarded because of students' lack of experience [5]. Other vital skills like estimating engineering quantities are similarly underdeveloped due to a lack of hands-on experience [6]. While this issue is fairly dated [6, 9], it has become prevalent after the covid pandemic, as makers were only able to work on their skills online. So while working in CAD (Computer-Aided Design) prevailed no work could be done with manufacturing tangible prototypes, causing these specific issues.

As a student, I propose a modified EDP that is targeted toward student-makers facing these difficulties, shown in Fig. 1.1-2.

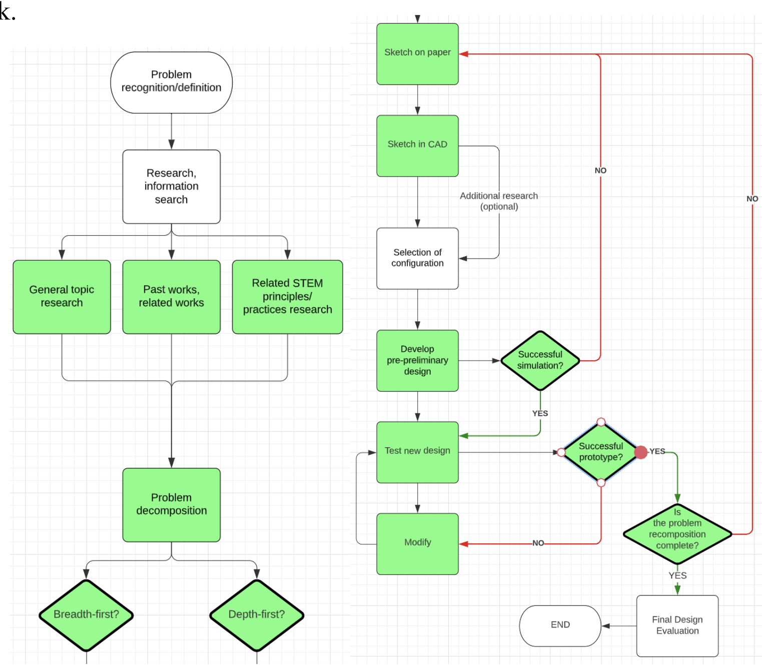

Fig. 1.1-2 proposed EDP flowchart

A method that aims to utilize the familiarity with CAD [9] engines most student makers gained to bridge the gap of the lack of hands-on experience, and to integrate high-fidelity prototypes [3] within the CAD environment at the student level.

The process starts by identifying the problem and doing research on it, as per the traditional model. In the mod. EDP, the research stage is modified to explicitly include identifying relevant practices or principles, and understanding them in addition to general research and research of past works. While a professional would take them into account regardless, a student most likely wouldn't have sufficient information or experience for this. To design the automaton, I learned rotational motion, gear theory, torque, friction, mechanics, and the very basics of material science as well as common joinery, gear types and their uses, and linkage.

The mod. EDP expands the design requirements and brainstorming stage into systematic problem decomposition [5] where either a breadth-first or depth-first approach is used according to the problem. Afterward, possible designs are sketched on paper, then in the most appropriate CAD environment, doing additional research if necessary, and testing until the desired outcome is achieved. The problem is recomposed, with each recomposition iterating the aforementioned steps, until the project is finalized.

After identifying problems in the prelim, modifications must be made directly to the prototype. The prelim almost always doesn't work so it should be used to test in real-life what does work and be used as a solid foundation for the details design. This stage is added to the EDP because it's usually skipped by student makers who want prelims to be their final design and stop working on them if they fail [9] rather than work on them because they fail. A specific case in the mod. EDP is called for at the drive mechanism: frame, base, and support. Here supports, frame, and base required for the working prototype are another stage with their own EDP iterations, as shown in Fig. 2.

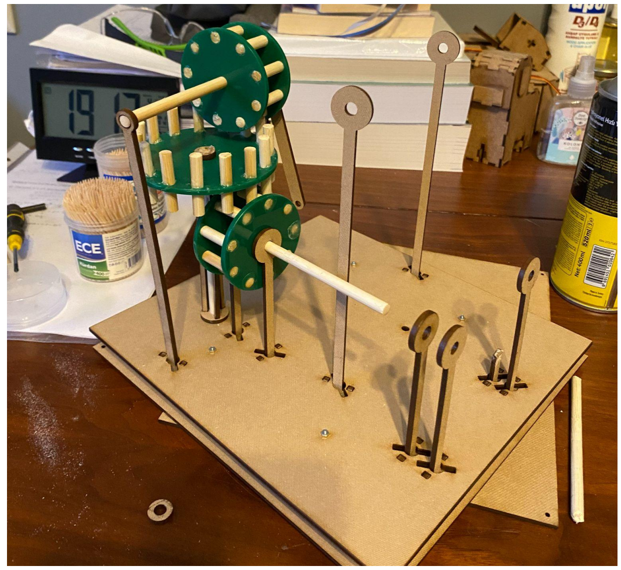

Fig. 2 supports-frame-base

4 AUTOMATA

4.1 Flower Documentation

For the bloom, I broke down the automaton into two parts: the flower itself and the blooming mechanism. Since the driver would be done according to the final design of the flower I started decomposing the flower. The smallest part of the flower was the leaf. I wanted the upper segment of the leaf to "bloom" faster than the lower segment and to do this automatically in response to the movement of the lower segment.

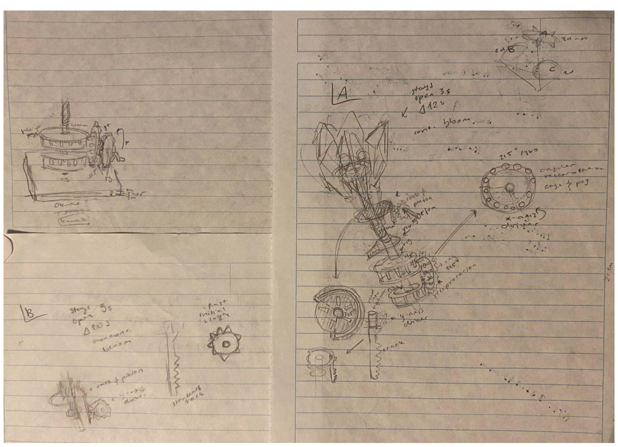

Fig. 3 Initial sketches

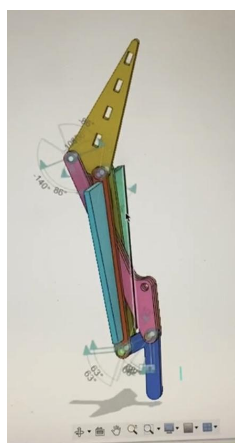

Fig. 4 CAD design

Fig. 5 Versions 1-3 of flower

I sketched out possible designs with estimated measurements, as shown in the figures above, and eliminated them according to feasibility, accessibility to materials, and my research on mechanics. I needed to be able to simulate joint relations and solid body interactions so I picked Fusion 360 and started the design. As a part of the mod. EDP, I put the appropriate real-life constraints into the CAD design, which in this case was setting a thickness variable by utilizing user parameters. I used a laser cutter for this project for its quick results and the vast array of materials but that meant that its constraints were my constraints as well.

After completing a high-fidelity model, I treated it as a pre-preliminary design, testing and optimizing the way I would a tangible prototype [9]. After slight adjustments, I made the actual preliminary design and tested it. I settled on a final design for the leaf after one prelim and for the entire flower after three prelims, as shown in Fig. 4. The first bloom mechanism was clunky and the joints pulling the top plate bumped into each other, so I switched out the linkage mechanism with wire.

That version turned out to be overly mobile as the wires were too thin to fix the plate about its vertical axis, and eventually, I settled on clamping ∅2mm hinge pieces with M2 screws. This let it be disassembled and reassembled as needed which allowed me to calibrate and make slight adjustments without damaging the leaves. I decided to use cast acrylic for the petals and was able to quickly adjust the spacing on the leaf frame by changing the numerical value of the thickness parameter that I had set previously.

4.2 Gear Design

I had recomposed up to the first decomposition and started working on the driver mechanism iterating the EDP steps for it as well. When picking a CAD engine I actually picked OnShape, for spur gear simulations, and Fusion 360, for peg gear simulation, as that depends on solid body interactions where as OnShape works better with visual simulations. I also decided to use acrylic to decrease friction between meshed gears. There are four iterations required for the gears of the automaton: *actuator gear and pair*, *reciprocating cage-peg gears*, *cage-peg gear train*, and *blooming rack and pinion* as shown in the figures below.

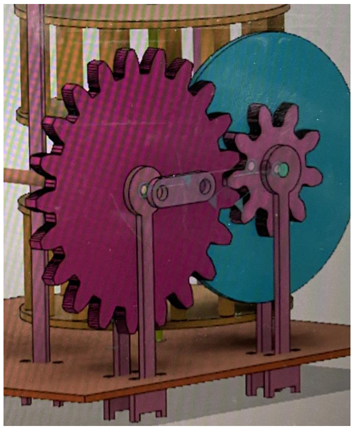

Fig. 6 Actuator and pair

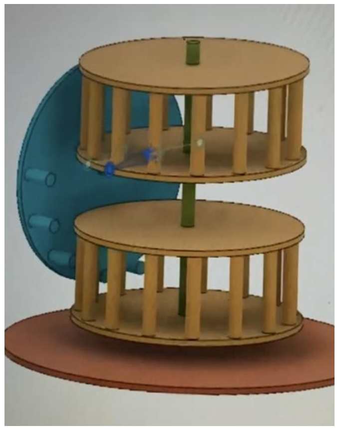

Fig. 7 Reciprocating pegs

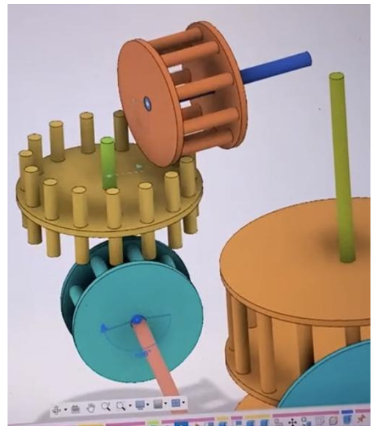

Fig. 8 Gear train

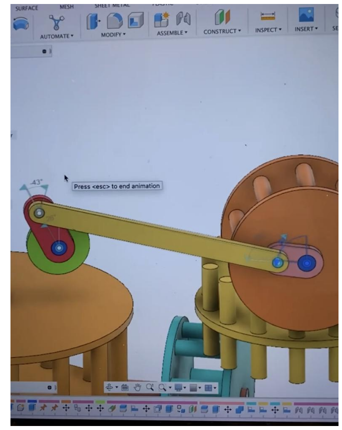

Fig. 9 Pinion linkage

The actuator gear and its meshed pair are a set of ordinary spur gears, with a 2 to 5 velocity ratio. The actuator spur is the pinion which is powered manually by rotating a crank, fixed about its axis of rotation. It provides rotation for the bloom, which is motion in the upwards direction y, as well as torque to rotate *the reciprocating gears*. The meshed pair of the actuator gear is fixed to the peg with M2 screws. The dowels attached to a 270° circular segment of the peg rotate the top cage in a clockwise direction and vice versa. The dowel fixed to the top plate of the flower is attached to the cages allowing it to rotate on the horizontal plane with 0° to 270° revolute joint limits. *The peg gear train* utilizes two small cage gears, one with a parallel rotation axis to the actuator and the other driving the pinion of the rack, and one double-sided peg gear. With this train, I was able to change the direction of torque without having to manufacture bevel gears, which would be impractical as bevel gear teeth are angled and laser cutters trace 2-dimensional paths. *The blooming pinion* is driven with a linkage mechanism where the crank is fixed to the top cage of the gear train and the follower to the pinion, allowing an unchanging rotation direction to the cage while limiting the revolute joint of the pinion between -43° and 34°, abs. 77°. The pinion converts rotational motion into translational motion via the rack, essentially a gear with an infinite radius, to push the bottom plate upwards closing the petal and vice versa.

5 CONCLUSION & DISCUSSION

In this study, a student-centric modified EDP is presented along with its proof of concept, methodology, and documentation. Unlike the traditional method, the mod. EDP approach encourages the students to build up their own knowledge from practical applications while utilizing the mentioned modifications to its model to bridge the gap of experience between a professional and a student. While the study and proof of concept, the final sculpture shown on the right, are sufficient in forming an ideal case with the mod. EDP, more data is required; especially from individual, group, classroom, and mentee students. The implications of constructivist and student-centric EDP models must be explored in future work according to the data that is collected.

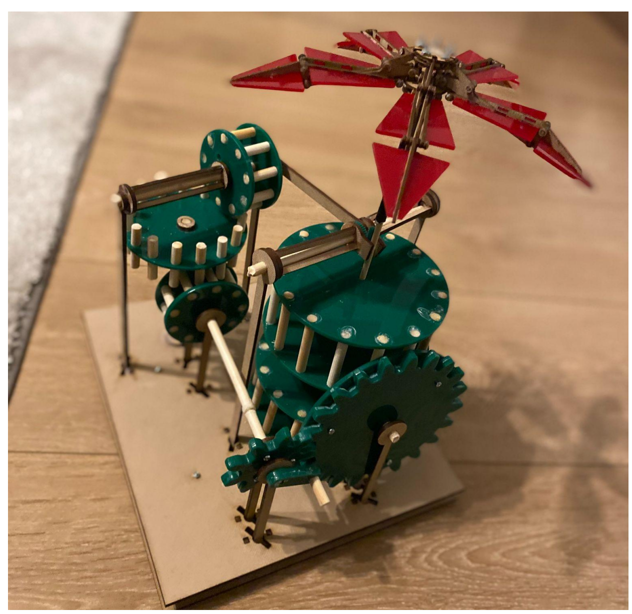

Fig. 10 Final blooming flower sculpture

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