Bridging Theoretical And Applied Mechanics by Integration of Augmented Reality: Automata

A short introduction to understanding of mechanical systems for K-12 students

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Abstract

In the scope of the new technological era we live in, creative learning, prototyping and innovative problem solving are increasing in value day by day. However, newcomers in K12 laboratories find it quite challenging to take on new projects by themselves. Our observations in STEM projects and robotics competitions revealed a significant gap between theoretical knowledge and practical applications in mechanical systems. Aiming to find a constructive way to fill this gap, we prototyped kits labeled “automata”. Creativity can enhance the hands-on multidisciplinary learning experience by drawing interest in the process of creating a unique outcome[3]. The kits we designed in total have 6 models which we produce in our fablab consisting of a farm of 20+ 3D printers. The kits illustrate core concepts of cams, cranks and gears which are the most used and base of all mechanical systems. Each model has its own original design which illustrates systems we constantly face in our daily lives but fail to realize. When finalized with the design of the kits, to encourage innovative and creative thinking, we enhanced them with augmented reality (AR). As users interact with these models, movements are mirrored by corresponding AR animations on their mobile devices. For instance, geneva stop automata have jellyfishes rotating in correlation to the rotational movement of the gear. We had the opportunity to test this kit on K12 students, each workshop resulting with high accuracy of learning when comparing our before-after forms’ feedbacks. We believe this workshop is a great contribution to constructionist and innovative learning since by connecting physical building with digital visualization, the kit offers an interactive approach to learning mechanics, helping K12 students to bridge the gap between theory of mechanics and the practical technological application.

Keywords and Phrases: Mechanical Systems, Interactive Learning, Hands-On Kit, Augmented Reality (AR), Creativity

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1. 1. INTRODUCTION

Mechanical systems are fundamental to engineering and robotics, yet many K-12 students struggle to bridge the gap between theoretical knowledge and practical application. In order to bridge this gap and allow them to apply the necessary skill sets that are embedded within STEM areas we created the Automata Kits, covering areas from 3D design, mechanics, to augmented reality. Mechanical systems or figures that mimic any motion found in nature, especially human motions, continue to entertain us and capture our imagination [6]. We created a bridge between mechanics and technology by integrating our kits with augmented reality (AR). Our kits consist of six models, each reflecting a fundamental mechanical principle such as gears, cams and crank systems. These models, which are designed and 3D printed by us, develop a better understanding in mechanical systems and make it engageable when integrating augmented reality (AR) elements. This dual integration of AR aims to create more interactivity and enhance comprehension, particularly in complex mechanical systems.

Figure 1:

Also, during our time in mentoring our FIRST Tech Challenge (FTC) team and struggles we observed of newcomers to our FIRST Robotics Competition (FRC) team, we realized a significant gap in apprehension and application of mechanical systems.

1.1 Accessibility

Aiming to maximize our kits' accessibility, we are working on an open-sourced website. We have prepared all of our kits' 3d designs documentation to make them open to the public, making anyone able to download the kits and print them out from a 3d printer therefore assemble all the kits on their own, breaking the barrier of requirement of face-to-face teaching and being able to reach the kits anywhere from the world. We also have assembly videos of the kits within the 3d designs of the kits. Furthermore, we are working on an Udemy lesson about these kits to make them accessible to all who want to learn how to create, assemble and customize their own automata. Our Udemy account (@HisarCS) is currently reaching over 34.770 students around the world. Moreover, we are working with the School Support Foundation (Okul Destek Derneği) (ODD) who are helping us to reach students in all 81 provinces of Türkiye, guiding us to ship the kits and give workshops to students through online sessions. The foundation especially focuses on earthquake affected areas, due to the Maraş earthquake in February 2023, still affecting millions' lives. We have reached 18 from 81 provinces of Türkiye. Overall, we have produced 300+ kits.

1.2 Related Works

Handcrafting or artistic activities were decided to be the essentials of education. In search of merging art and education, we were first introduced to automata by the Cabaret Mechanical Theatre, based in Hastings, UK, who have been entertaining and inspiring visitors & makers with our collection of automata since 1981 [2]. They have many designers who are working on collections of contemporary automata that can be seen in museums & galleries around the world. Moreover, we have an alumni at Carnegie Mellon University, which introduced us to a similar ongoing project. CMU has a class dedicated to automata making from wood [5]. Moreover, there is a research paper about AR generated automatas, AutomataStage. AutomataStage utilizes a video see-through interface to support the creation of InteractiveAutomata [3]. However there are no hands-on activities, being only visible through AR/VR. A similar research project creates an interactive design system that allows non-expert users to create animated mechanical characters [7] [8].

Unlike these, our Automata Kits combine physical assembly with AR, allowing students to build and interact with real mechanical models, use AR overlays to enhance conceptual understanding and customize both physical and digital components. This hybrid approach bridges theory and practice in mechanics, making our work distinct from prior AR-based automata research. By combining hands-on construction with AR, our project fosters a deeper, constructionist learning experience in mechanical education.

2. Design Approach

During the design process of the kits, our primary goal was to create a design such that all K12 students would be able to grasp the mechanical system dedicated to the kit with ease. Our kits focus on cam systems, different gear systems- like geneva stop and crank systems. These are the systems we observed that were used most commonly in our daily lives and the ones students struggled with the most. We searched for a way to teach these systems in an interactive, tangible way which led us to prototyping hands-on kits. Through our long trial and error method, as our kits evolved, we were able to finalize all 6 kits within one year, making them as simple and minimized as possible. We are currently working towards getting the patent for these kits. All the design process was through Autodesk Fusion360. Fusion's comprehensive toolset, especially its capabilities for parametric design, was pivotal especially for optimizing. Learning to use such advanced 3D design applications and teaching the context of it throughout our workshops helped to dive more deeply into STEM subjects such as technology, computer science and engineering.

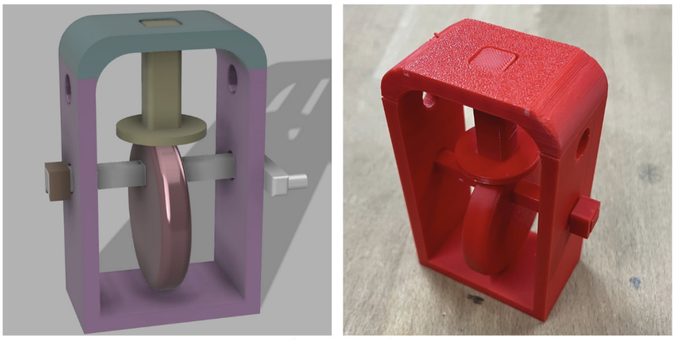

Figure 2: Cam-A

Our first kit: Cam-A, illustrates how cams convert rotational motion into linear oscillatory motion. Cam: The cam is a rotating or sliding piece in a mechanical linkage that drives the follower. The cam's surface can be contoured in various ways (such as circular, elliptical, or even complex custom profiles) to create different types of motion in the follower as the cam rotates. The cam mechanism operates on the principle of direct contact and force transmission between the cam and the follower. The specific path that the follower will take is determined by the shape and contour of the cam's surface. Throughout the design it is thought that the cam mechanism's ability to produce controlled, precise, and complex motion profiles from a simple rotational input makes it an invaluable component in mechanical design, enabling the execution of a wide array of functions with high efficiency and reliability. Cam mechanisms are used as the control system in machines of several fields such as internal engines, filling and packing machines, etc.

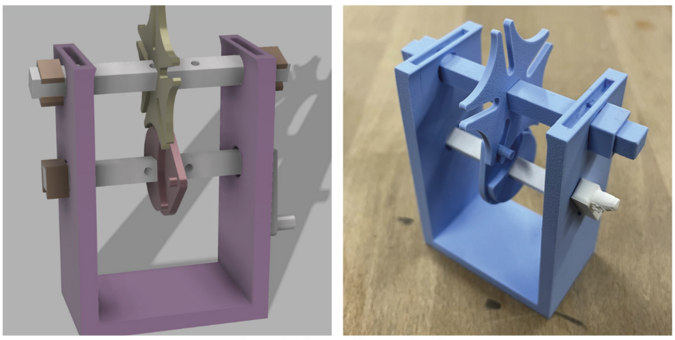

Figure 3: Cam-B (Geneva Stop).

Our second kit: Cam-B (Geneva Stop), illustrates how cams convert rotational motion to arranged paused motion, which is intermittent motion [4]. The mechanism consists of a rotating drive wheel, driver, with a pin that engages with slots in a driven wheel, The mechanism operates through direct mechanical engagement between the driver pin and the Geneva wheel's slots. The number of slots determines how many steps occur per full rotation of the driver. When in motion, the pin transfers rotation, and between steps, the Geneva wheel remains locked in place causing stability. The Geneva mechanism is widely used in machinery requiring precise timing and indexing, such as clockwork systems, film projectors and automatic assembly lines. Its ability to deliver controlled, intermittent motion from continuous input makes it a valuable tool in mechanical design.

Our third kit: Crank, illustrates how the crank mechanism converts rotational motion into linear reciprocating motion. The crank is a rotating arm attached to a shaft that has a connected link, known as the connecting rod. As the crank rotates, it pushes and pulls the rod, creating a back-and-forth, reciprocating, motion. This simple yet effective design allows rotational movement to be transformed into controlled linear movement, without any loss of energy. The mechanism works through direct mechanical linkage, with the crank's circular motion guiding the movement of the rod. The length of the crank and rod determines the range of motion, while the rotation speed controls the frequency of movement. This consistency of rotation and reciprocation makes the crank mechanism a core element in many machines. Crank mechanisms are widely used in engines, pumps, and presses, where converting rotary motion into linear motion is the key.

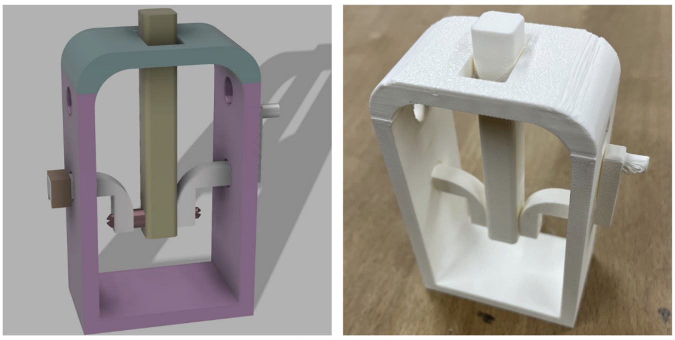

Figure 4: Crank.

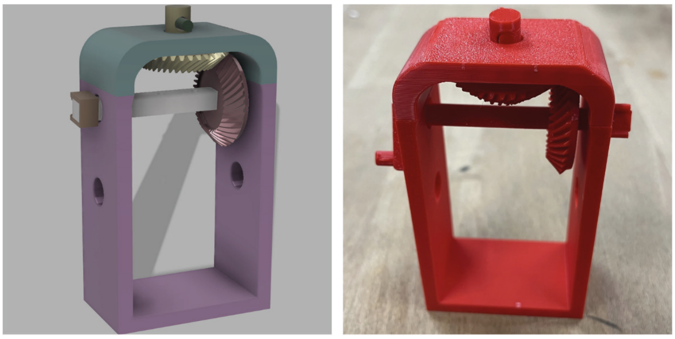

Figure 5: Gear-A.

Our forth kit: Gear-A, illustrates how bevel gears transfer rotational motion between perpendicular shafts. It transmits horizontal circular motion to vertical. Bevel gears are a type of mechanical linkage that changes the direction of rotational motion. They have cone-shaped teeth that mesh at an angle, usually 90 degrees, allowing torque and speed to transfer efficiently between intersecting shafts. As one gear rotates, it drives the other, redirecting motion while maintaining smooth power transmission. The gear ratio and tooth design determine the speed and torque output, making bevel gears adaptable to different applications. Bevel gears are widely used in machines requiring precise power transmission at an angle, such as automobiles, industrial machinery, and hand drills.

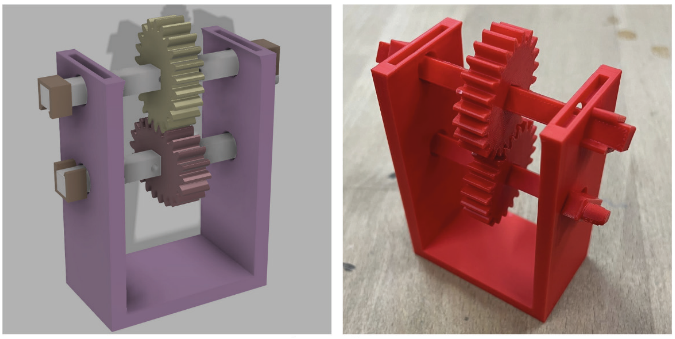

Figure 6: Gear-B.

Our fifth kit: Gear-B, illustrates how gear alignment and shape affects torque and speed, even when the driver rotates at a constant rate. These may seem like normal spur gears but unlike traditional gear trains, this mechanism causes continuous variation due to the shifting alignment of the gears. As the driver turns, the positioning of the gears alters the load distribution, leading to dynamic changes in speed and torque. This results in an output that doesn't maintain a steady speed but instead accelerates and decelerates depending on the gear alignment at any given moment. Their ability to create fluctuating motion patterns makes them useful for specialized engineering challenges. Weird gear mechanisms are used in applications requiring variable torque and non-uniform motion, such as adaptive transmission systems and experimental drive mechanisms.

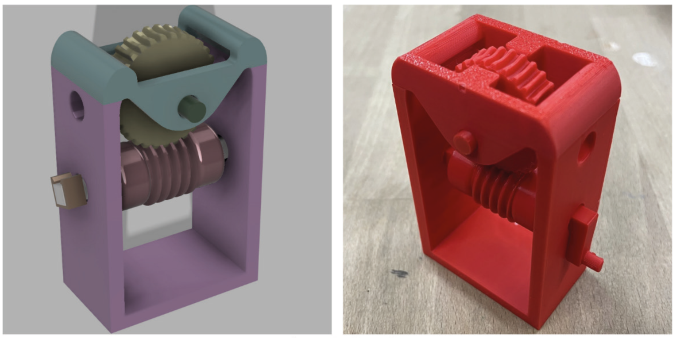

Figure 7: Gear-C.

Our sixth kit: Gear-C, indicates how a worm gear system converts rotational motion while significantly reducing speed and increasing torque. A worm gear consists of a screw-like worm that connects to a toothed wheel (worm wheel). As the worm rotates, its threads drive the worm wheel, transferring motion at a 90-degree angle. The design allows for smooth power transmission with high gear reduction in a compact space. The mechanism operates through continuous sliding contact between the worm and wheel. This setup provides a high torque output and an important self-locking feature, meaning the gear can't be back-driven, making it useful for safety-critical applications. Worm gears are commonly used in elevators, conveyor systems, and tuning mechanisms, where controlled motion and torque multiplication are essential.

3. Findings and Limitations

3.1 Workshops

We gave many workshops, Coding Summit' 24 '25, FabEducators' 24 '25, ACS' 24 '25... The workshops we gave began with the introduction of automata and 3D design. Every student in the workshop is given the unassembled kits and the booklet we designed for each. They piece the kit themselves, learning the basics of that mechanical system along the course. We gave 12 workshops, 8 in the annual Coding Summit that we held in our school as ideaLab and 4 in the ACS Summit. Total, we had 200+ participants. In our workshops, the participants' ages varied from 6 to 14.

The first phase of our research included surveys among K12 students to analyze the gap in understanding mechanical systems. The surveys included questions about the mechanical systems we constantly used in our STEM projects and robotic competitions, or frequently faced in our daily lives. Feedbacks were essential to us in order to improve our kits. We included two open-ended questions in our post-tests in order to improve our kits. Receiving 30+ guided the kits' growth.

To assess the impact of the Automata Kits, a pre-test and post-test approach was implemented across 4 workshops. A total of 83 students participated, and each completed an 8-question multiple-choice test before and after using the kits. The questions varied from what the general purpose of the kit students assembled is to the name of key components of the mechanisms to how to use the interfaces which were used to design the kits and customize them with AR. In our final workshop, the accuracy rate was 43% in the pre-test, which improved to 86% in the post-test results, with %78 percent of the students scoring more than half of the questions correctly. Especially for the workshops dedicated to 5th and 6th graders, we observed the highest rate of change of rate of accuracy.

Figure 8: Workshops

3.2 Sustainability

Through ongoing feedback from participants, we identified areas for improvement, which led us to make the kits more customizable and engaging. The kits first design involved many individual components which were put together by screws. It was hard for students to assemble the kits and there was a significant waste in screws and filament. We removed the screws and added clips designed by us. However, still aiming to minimize our usage of filament to produce more sustainable kits, we arranged the tolerances and got rid of many clips. We also merged the individual components to decrease the complexity. We arranged all the kits to be set on the same base so the base would not have to be printed out 6 times, which helped the students focus on the mechanism.

At first, we gave the students drawings they could cut and stick on top of the kit. For instance, for Gear-,A we drew a ballerina, printed it out and gave it to students so they could visualize the system's transmitted movement in real-life. 2D being insufficient, we shifted to origami, which was inspired from the constant use of it in space technologies. To illustrate, with a tutorial on how to make it, we put an origami boat on top of the crank automata visualizing a ship travelling in the sea. Still not satisfied, we finalized our kits' real-life connection with the integration of augmented reality (AR).

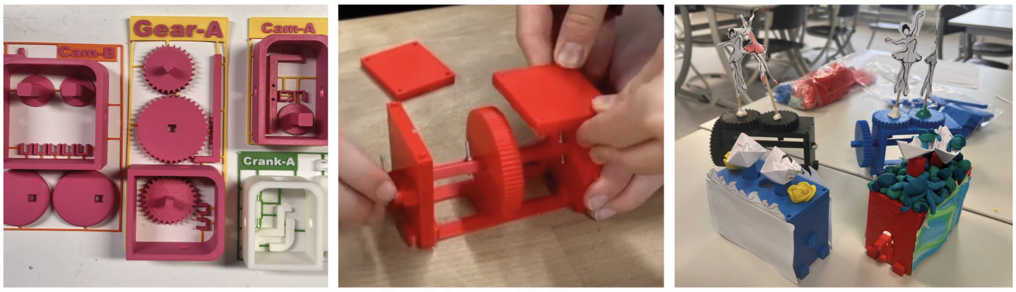

Figure 8- Evolution of the Kits

Figure 9: Evolution of the Kits.

3.3 Why AR?

In several research projects, AR is used to make a tangible interaction and projected information enable the iterative and rapid creation [9]. Augmented information and accompanying tangible parts help users to fabricate mechanisms [10]. Overall, prototyping and designing with AR was increasing in value day by day. How would you make a mechanical toy that magically makes characters come to life, moving up and down and turning round and round [1]. The question stuck with us, guiding us to improve on our creativity with integrating our kits with AR. WE believed that AR was the most innovative way to enhance this constructivist learning, hence creating a bridge between theoretical and applied mechanics by technology. This new approach both gathered the attention of many students and helped them grasp the motion transmitted throughout the systems the best way possible. The visuals for the ARs were developed from Meshy AI. The AR animations were developed by us creating our own app, allowing real-time tracking and interactive overlays that correspond to the mechanical automata's movement with object detection and aruco codes. This integration ensures that students can visualize mechanical motion both physically and digitally, reinforcing conceptual understanding and improving on STEM subjects such as technology guided by their own creativity.

To further enhance engagement, the AR models are thematically designed around marine life conservation, reflecting the United Nations' Sustainable Development Goals (SDG 14: Life Below Water). Animals are always known to be liked by kids. Marine life constantly faces endangerments, such as the threat of microplastics or viruses being spread below water, attacking many specific marine species, for instance, corals. Not only enhancing the learning experience with newly improving technologies, we also wanted to raise awareness on how valuable marine life is by putting small informative texts in our app for each AR object (type of species, status, etc.). Each kit's AR has its own story in the background, all including individual marine species which were endangered or faced with a threat, mostly human-based. Normally, there are 30+ AR animation designs available so that kids can mix and match, have the thrill of putting aruco after aruco, searching for different types of octopuses to come or face endangered species of eels. Here are the main 6 ARs we normally dedicated per kit:

Cam-A is integrated with an AR visualizing a manta ray swimming through the depths of the ocean. Manta rays became endangered due to a combination of overfishing, habitat destruction, and slow reproduction rates. Cam-B (Geneva Stop) is integrated with an AR visualizing three jellyfish intermittently swimming around. Jellyfish are key to nutrient cycling. When jellyfish die and decompose, they release nutrients that support marine food chains.. Crank is integrated with an AR visualizing a shark attacking above. Sharks prevent overpopulation, maintain a healthy ecosystem by removing sick and weak animals. Gear-A is integrated with an AR visualizing a couple of fish circling around. Overfishing and netting causes many fish species to significantly decrease in population. Gear-B is integrated with an AR visualizing two dolphins swimming around.Some species of dolphins are endangered such as Yangtze River Dolphin and Maui's Dolphin because of habitat destruction and loss and due to bycatch in illegal fishing nets.. Gear-C is integrated with an AR visualizing a sea turtle slowly swimming around, a caretta-caretta to be precise. Caretta-carettas are endangered due to habitat loss since coastal development and tourism disturb nesting beaches, reducing successful egg-laying and hatchling survival. Also pollution, plastic waste, oil spills and chemical pollutants harm their health.

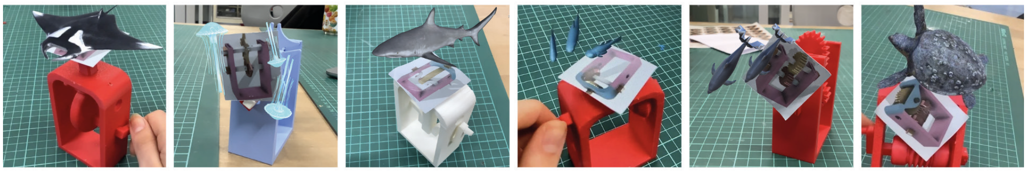

Figure 10: AR Integration of Each Kit Respectively.

3.4 Future Goals

Our primary goal is to make this project completely open-sourced, making our kits be a part of the K12 education globally and accessible. We are currently designing a website to put all of our sources, 3d design folders and instructional videos. We are aiming to successfully finish the shipment or our kits all around Turkey. We have yet to reach a couple of provinces, hoping to reach all 81 provinces. To help with our open-sourced learning, we are preparing Udemy videos from our account @hisarcs. To encourage creativity, we are aiming to design an app for AR, specialized for our kits. The AR application will include an interactive tutorial mode, allowing students to visualize the movement of gears and cams in real time before physically assembling them. Additionally, our open-source website will provide step-by-step assembly instructions, troubleshooting guides, and an interactive forum where educators and students can share their experiences. This digital expansion aims to create a collaborative ecosystem for STEM learning through hands-on engagement. This would help us dive more deeply into STEM subjects, including coding and creating an app, developing customizability. The app would be a whole library for AR stories for automata, enabling all to collaborate with many other people, demonstrate and improve their ideas, and contribute to the STEM community by creating our own AR development community for automata kits. In addition to making the kits more accessible, future research will focus on conducting large-scale controlled studies across multiple educational institutions. By analyzing long-term learning retention and engagement metrics, we aim to develop a standardized curriculum integration model for Automata Kits in K-12 education. Furthermore, we plan to collaborate with educational researchers to publish findings on the impact of augmented reality (AR) in mechanical learning. Going forward by handling each obstacle, we are working at our fastest pace possible to accomplish these goals.

4. Conclusion

By integrating augmented reality (AR) with hands-on mechanical assembly, Automata Kits bridge the gap between theoretical knowledge and practical application, offering a scalable and interactive approach to STEM education, helping students to dive into mechanics with ease. AR and hands-on learning offer distinct experiences: AR provides interactive digital simulations, while hands-on activities offer physical engagement with real mechanisms. The kits combine both approaches, making mechanical systems more engaging and innovative for students. This study highlights the impact of combining hands-on mechanical assembly with augmented reality to enhance STEM learning. Automata Kits bridge the gap between theory and practice, offering an interactive and engaging learning experience that surpasses traditional static models. We believe our kit, which brings a new approach to AR and innovative education with constructionism, would be a valuable contribution since it provides new constructionist technologies and hands-on experiences within the theme of "Making and Innovation in Constructionist Learning".

References

[1] Maselle, M. (2024) *Build a Bird Automaton*. STEM Powered Family, 146

[2] Alexander, S. Alexander, G. Alexander, M. Patrick, B. (2024) *Cabaret Mechanical Theatre Learning CIC*. Hastings, UK

[3] Jeong, Y. Cho, H. Kim, T. and Nam, T. (2023) *AutomataStage: an AR-mediated Creativity Support Tool for Hands-on Multidisciplinary Learning*. In Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23). Association for Computing Machinery, New York, NY, USA, Article 732, 1–16.

[4] Brown, H. T. (1868) *Five Hundred and Seven Mechanical Movements*.

[5] Zhang. Y, Finger. S, Behrens. S, (2009) *Introduction to Mechanisms*. Carnegie Mellon University (CMU), 77-115

[6] Ceylan, D., Li, W., Mitra, N. J., Agrawala, M., & Pauly, M. (2013). *Designing and fabricating mechanical automata from mocap sequences*. ACM Transactions on Graphics (TOG), 32(6), 1-11.

[7] Stelian Coros, Bernhard Thomaszewski, Gioacchino Noris, Shinjiro Sueda, Moira Forberg, Robert W. Sumner, Wojciech Matusik, and Bernd Bickel. 2013. Computational design of mechanical characters. ACM Trans. Graph. 32, 4, Article 83 (July 2013), 12 pages.

[8] Stelian Coros, Bernhard Thomaszewski, Gioacchino Noris, Shinjiro Sueda, Moira Forberg, Robert W. Sumner, Wojciech Matusik, and Bernd Bickel. 2023. Computational Design of Mechanical Characters. Seminal Graphics Papers: Pushing the Boundaries, Volume 2 (1st ed.). Association for Computing Machinery, New York, NY, USA, Article 87, 839–850.

[9] Jeong, Y., Kim, H. J., Yun, G., & Nam, T. J. (2020, October). *WIKA: A projected augmented reality workbench for interactive kinetic art*. In Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology (pp. 999-1009).

[10] Jeong, Y., Kim, H. J., & Nam, T. J. (2018, April). *Mechanism perfboard: An augmented reality environment for linkage mechanism design and fabrication*. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (pp. 1-11).