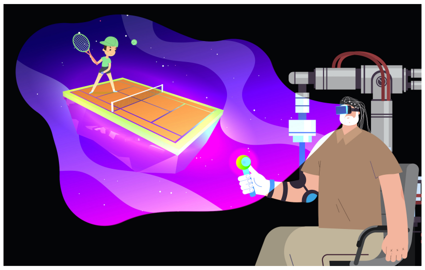
Madi Babaiasl – Research Statement

Summary of the Proposed Projects

Project 1

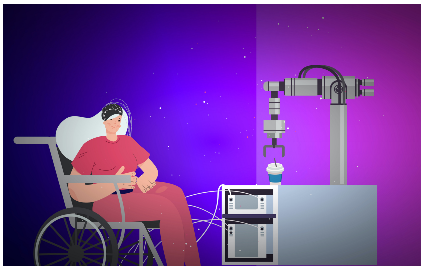
Specific Aims: In order to improve rehabilitation exercises' intensity and repeatability, new interventions such as robot-assisted rehabilitation are needed. Through this project, my research team and I will develop a game-based rehabilitation robot that will not only make rehabilitation exercises more intense and repeatable but will also motivate patients and improve the human-robot interaction experience.



Aim 1: Developing a robotic rehabilitation system that integrates Virtual Reality (VR) technology and Machine Learning (ML) algorithms
Aim 2: Improving human-robot interaction experience through developing ML-based control strategies that acquire patients' data and then predict and respond to human intentions

Project 2

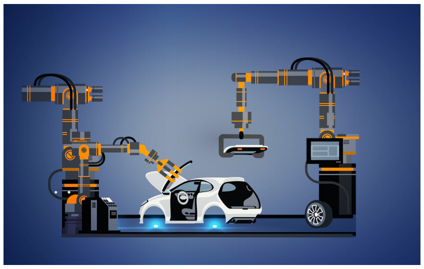
Specific Aims: To help senior citizens and citizens with disabilities to perform activities of Daily Living (ADL) independently and with dignity, we need to teach robots to assist these patients. In this project, my research group and I will develop a robotic device to assist people with paralysis or elderly people with basic tasks such as eating, drinking, dressing, shoe fitting, brushing, and bathing, with high priority given to drinking and eating.



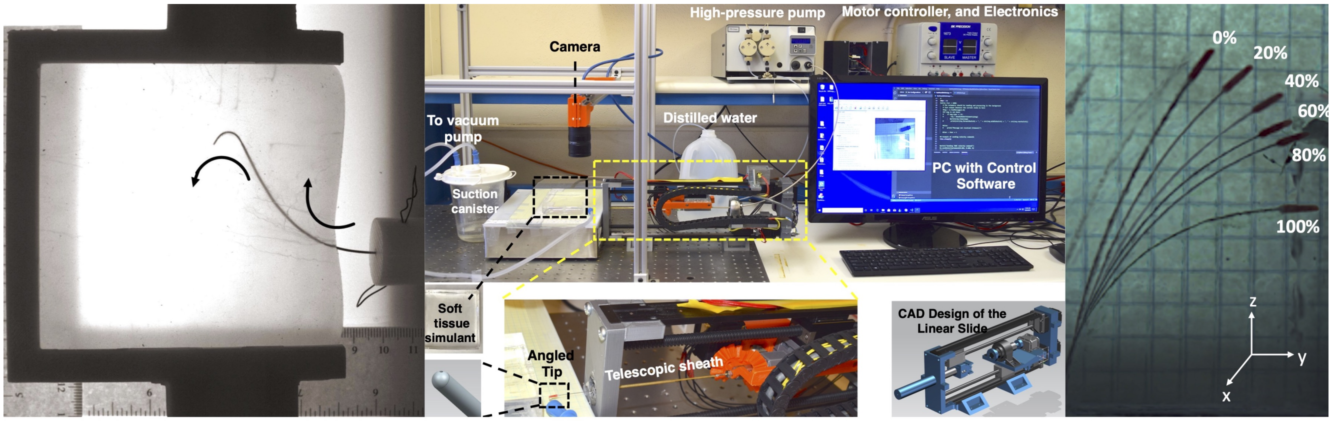
Aim 1: Developing a robotic system with a custom-designed gripper and a vision-based control system to identify the task given
Aim 2: Developing online learning frameworks to teach the robot to accomplish the assisting task
Aim 3: Teaching the robot to detect the patient's intention and appropriately respond and learn

Project 3

Specific Aims: With the increasing need for robotics and artificial intelligence (AI) experts in today's world, promoting and contributing to robotics and AI education seems essential. In this project, my research team and I will develop kits and models to support robotics, mechatronics, and artificial intelligence education and research from elementary school to graduate school and then the job market.



Aim 1: Developing better robotics and AI education curricula that facilitate experiential learning and practical experience (kits, models).
Aim 2: Developing models to help robotics researchers to test their algorithms in their lab settings (for instance, a smaller version of an autonomous vehicle)



(a) (b) (c)

Figure 1: Fracture-directed steerable needles research during my research @ WSU, Pullman, WA. (a) Small radius of curvature attained by stylet-and-tube steerable needle [1], (b) Waterjet steerable needle system [2], (c) Variable radii of curvature attainable by waterjet steerable needle [3]

Introduction

From surgery rooms to hospitals to homes, we envision a future where robots can help clinicians, health-care professionals, caregivers, patients, and the elderly safely and efficiently in a myriad of tasks to reduce patient care work and strenuous/repetitive manual tasks. Ideally, the robots should be safe to work near humans, humans should accept them, the cost should be reasonable so they are widely available, and the robots should not be complicated to avoid confusion for the patients and the caregivers.

There is, however, a long way to go before we reach this ideal. Based on the findings of my past research [4], optimal restoration of arm and hand function after a neurological disorder such as stroke is essential to perform activities of daily living (ADL) independently and to maintain human dignity. On the other hand, my research showed that the type of therapy matters less than the exercise intensity so the main goal of robot-aided therapy is to provide a means for increasing exercise intensity. Moreover, research [5] clearly demonstrated that current rehabilitation robots can not satisfy the needs of patients, especially senior citizens who require social interaction for emotional support and some sort of control over the machine to preserve their dignity. Therefore, a question arises here. Is it possible to develop robot-aided rehabilitation systems that increase the intensity of rehabilitation exercises safely while also addressing the emotional needs of patients? Is it possible to have rehabilitation robots that can acquire patients' data and learn their movement characteristics to provide safe and effective training?

Meanwhile, the aging population requires assistance both physically (i.e., handing over objects, eating/drinking assistance, etc.) as well as mentally (motivating, supporting emotionally, etc.) from caregivers, and considering the caregiver shortage, robots can play a key role here. Independently performing these tasks can enhance the dignity of the elderly and people with disabilities. The second question is: can we teach robots to assist these patients in independently performing Activities of Daily Living (ADL) in order to improve their quality of life?

My other area of interest is education and how we can promote STEM education, especially robotics and AI education. Due to the COVID-19 pandemic and the need to automate repetitive tasks, there is an increasing need for people who are trained in robotics, machine learning, mechatronics, and artificial intelligence. As a result of the shortage of experts in this field, companies had to spend lots of money on training their employees before hiring them. Additionally, research into areas such as autonomous cars is a current trend, but it is virtually impossible to have such cars in the lab to test algorithms developed. A friend of mine who is now an engineer at NVIDIA once told me that while he was working on his

Ph.D. research, he wished he could test his algorithms on a smaller version of an autonomous car. The third question of my research arises from this. Is it possible for my research team and I to develop kits and models to support robotics, mechatronics, and artificial intelligence education and research from elementary to graduate school and then the job market?

At Saint Louis University, I want to build a strong group focused on robotics in healthcare and education. In this research statement, three programs are described that aim to develop robots that can be used in healthcare and education. The first project is aimed at developing a rehabilitation robotic system to help people suffering from neurological diseases regain their motor functions (Fig. 3 - a). This project emphasizes on using Virtual Reality to increase motivation and intensity of rehabilitation exercises and Machine Learning algorithms for intention recognition, progress assessment, and safe human-robot interaction. The second project will be on training a robot to assist elderly people or people with disabilities in performing activities of daily living. To accomplish this, we will develop an assistive robotic system that responds to the intentions of the patient and can perform according to those intentions. In this way, the patient can somehow control the robot, giving them a sense of control and dignity. (Fig. 3 - b). The third project involves developing models and kits that support informal and formal robotics, mechatronics, and artificial intelligence education (Fig. 3 - c).

Research to Date

Fracture-directed Steerable Needles

The central goal of my Ph.D. thesis was to propose a new type of steerable needles for surgical applications that compensate for the disadvantages of traditional steerable needles, such as constant curvatures and buckling. In order to accomplish this goal, we proposed two methods. The first method is called "stylet-and-tube fracture-directed steerable needles," where the direction of the tissue fracture is controlled by an inner stylet and later by the hollow needle [1]. This method achieved a radius of curvature as low as 6.9mm across a variety of tissue stiffnesses (Fig. 1-a). This reduced radius of curvature allows the needle to avoid anatomical obstacles, such as nerves and bones, giving superiority to these needles compared to existing methods like bevel-tip steerable needles.

The second proposed design was a waterjet steerable needle that is directed to the desired soft tissue location by a waterjet cutting a channel in the tissue and then followed by the superelastic needle. This is the first time in the scientific literature that waterjet technology has been incorporated into steerable needle design [6]. We developed a needle insertion system consisting of a custom waterjet nozzle attached to a Nitinol needle (Fig. 1-b) that resulted in variable curvatures unattainable by traditional steerable needles (Fig. 1-c). We also studied the effect of tissue stiffness, flow rate, and needle diameter on the depth of the waterjet needle cut, and we could solve a fundamental physics problem of waterjet, and soft tissue interaction [2]. This allows the waterjet steerable needle to do the selective cutting, meaning that the parameters can be chosen so that the waterjet needle only cuts the intended tissue and not more than that. Furthermore, the buckling issue is non-existent here because the cut is already done by the waterjet and not the needle.

During this research, we also manufactured soft tissue simulants using the mineral oil-based synthetic polymer styrene-ethylene-butylene-styrene (SEBS) gels, whose stiffnesses could be adjusted by altering the mineral oil to powder ratio. As a result, we could validate our steerable needles with a wide stiffness range of soft tissue substitutes [7].

This research is nationally and internationally important in terms of reducing surgical mortality rates. In 2009, the CDC estimated the U.S. surgical mortality rate to be approximately 160 people out of every 100,000 patients aged 45 and older. In order to reduce this number and improve the success of surgeries in the US and the World, new techniques for these operations are required. My Ph.D. research has supplied two new means of employing steerable needles in surgical applications, designating this research as nationally important and of inherent interest to improving healthcare in the United States and the

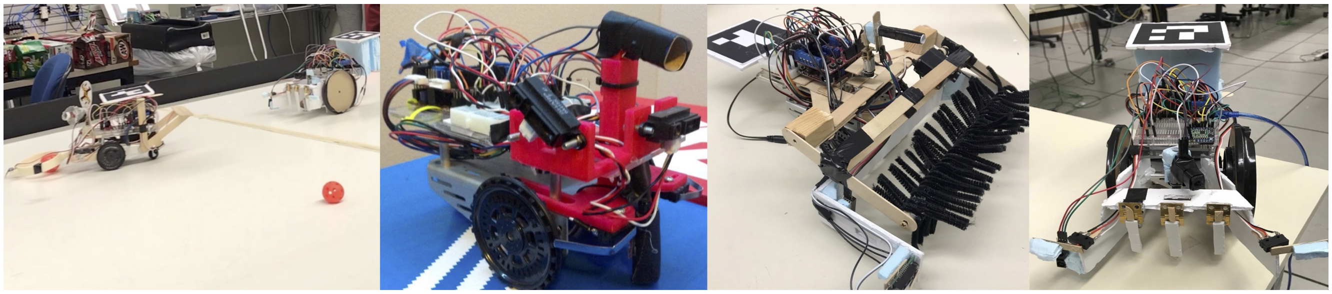


Figure 2: Some of the projects that students could accomplish during the two semesters that I was a teaching assistant for the Mechatronics course.

World. This research led to the US Patent 11103278 (Fracture-directed steerable needles).

Assistive & Rehabilitation Robots

While completing my master's degree, I designed an exoskeleton robot for shoulder rehabilitation and arm movement recovery following a stroke [8]. This robot accounted for rotational and translational arm movements. Furthermore, the robot's design was lightweight and had a special mechanism for the third joint that also allowed for translational shoulder motions. I also proposed and developed several nonlinear control methods for rehabilitation robots that rejected disturbances to the system enabling the patient's arm to follow the desired path [9, 10].

During my Master's degree, I worked with the Mechatronics Scientific Association to develop a hand tremor suppression device to eliminate the hand tremors of people with this disorder. I came up with the idea for this project when my father, a computer whiz who was working with delicate computer motherboards, asked me as an engineering student if I could design a device so he wouldn't have to suffer from hand tremors while working on these delicate motherboards. Our method was based on getting feedback from the muscle's abnormal activity using an accelerometer sensor and Electromyography (EMG) electrodes and then using MATLAB to analyze the data in order to determine tremor signal features. Finally, based on the measured features, we designed a control system that applied a new signal to the muscle to oppose the underlying cause of the tremor resulting in a steady hand for the sufferer. During a trial, the system successfully eliminated the hand tremors of a Parkinson's disease sufferer.

Robotics & Mechatronics Education

Though this part appears to fit within the Teaching Statement, it is also close to one of the projects outlined here. When I was a teaching assistant for two semesters for the Mechatronics Course, I co-developed educational kits and designed projects that significantly improved the students' course retention by learning through doing. By the end of the semesters, the students developed a Pac-Man Robot, System Automation projects using PLCs, and a Scavenger Race Robot using the hands-on knowledge of LabView, Data acquisition, Signal Filtering, Microcontrollers, Servo motor control, color sensing, IR sensors, state machines, DC motor control, PLC control of electro-pneumatic systems and vision-based control of robotics systems (Fig. 2). Students reported better job offers as a result of taking this class and the use of educational kits for teaching. Moreover, they said that abstract ideas now came to life and could be experienced.

Future Directions

I plan to continue developing robots for healthcare and education purposes. While my previous research had focused on designing robots for surgery and rehabilitation, in my future work, I would like to addition-

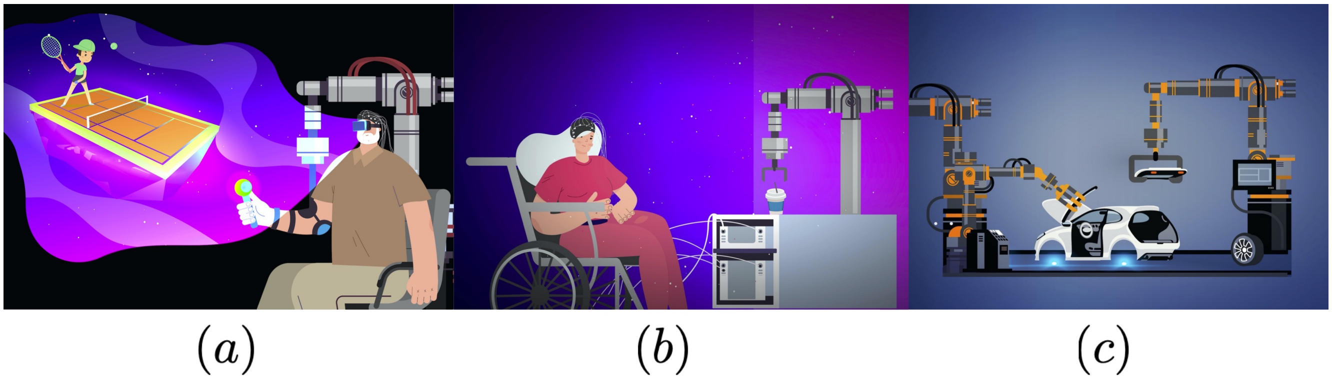


Figure 3: Proposed research projects. (a) Game-based Rehabilitation Robot, (b) Intention-based Assistive Robot, and (c) Robotics, Mechatronics, and AI Education.

ally focus on integrating technologies such as Augmented Reality (AR), Virtual Reality (VR), Machine Learning (ML), and Artificial Intelligence (AI) in rehabilitation and assistive robots to solve the known challenges in these robots such as safe human-robot interaction, intention detection, developing games that are highly relevant to rehabilitation, and better assessment of the rehabilitation process.

All of the research projects presented below are interdisciplinary in nature and reflect the philosophy of my future research group. Students will be exposed to a variety of problems to solve and will gain insight into robotics in healthcare and education from different perspectives. The cooperative nature of an interdisciplinary laboratory will be reinforced through cooperative interactions among students. Synergy will be the key principle in my lab, which means acknowledging and utilizing the differences between students in order to complete an interdisciplinary project that could not have been done by any of those students alone.

Game-based Rehabilitation Robots

To answer the first research question in the introduction part of this research statement, my research group and I will develop a robotic rehabilitation system that integrates Virtual Reality (VR) technology and Machine Learning (ML) algorithms (Fig. 3 - a). Virtual reality games not only increase the intensity of rehabilitation exercises, but they can also provide social interaction for the elderly through shared games in a network with possibly loved ones (See an example of a shared game through a network in virtual reality that we developed in Mecharithm at this link). For a safe and effective human-robot interaction, a robot must acquire patients' data and then predict and respond to human intentions. These intelligent algorithms can learn from past experiences, adapt better to dynamic conditions and unknown robotic models, and can objectively assess the rehabilitation process. In order to quantify the patient's intention, we can use two approaches: (i) using Machine Learning Algorithms to estimate muscle force and joint torque from physiological signals

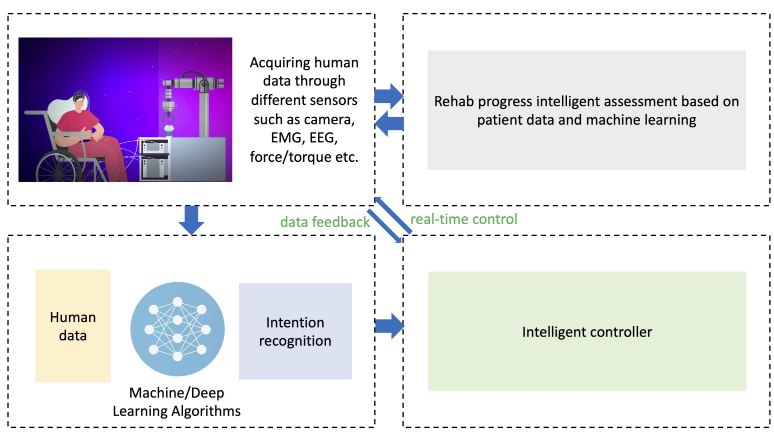


Figure 4: Possible ML-based Robot-aided Rehabilitation System

(EMG, EEG, etc.) (ii) using the human-robot kinematic and dynamic data such as force and position and then finding a mapping model to quantify the intention. After quantifying the intention, the rehabilitation robot should be able to adjust trajectory or force based on the patient's intentions in order to provide personalized training. In order to achieve this goal, it is crucial to develop suitable human-robot interactive control strategies. A possible ML-based robot-aided rehabilitation system is depicted in Fig. 4.

Intention-based Assistive Robots

This project is closely related to the previous project, but here the goal is to develop a robotic device to assist people with paralysis or elderly people with basic tasks such as eating, drinking, dressing, shoe fitting, brushing, and bathing. A high priority will be given to drinking and eating (Fig. 3 - b). A robotic arm with a custom-designed gripper and a camera that can identify food/drink and an online learning framework can be used to accomplish this. Algorithms should converge quickly, and solid and liquid foods should be taken into account. Vision-based control algorithms combined with force control should be used here. Similarly to the previous project, the robot must detect the patient's intention and appropriately respond and learn.

Robotics, Mechatronics, and AI Education

For this research direction, my research team and I will develop kits and models to support robotics, mechatronics, and artificial intelligence (AI) education and research from elementary school to graduate school and then the job market. This research direction is also aligned with the National Science Foundation's (NSF's) programs to spread robotics and AI education. I mentioned some funding opportunities for this research area in the funding section. This research direction is important because we are currently experiencing the largest workforce transition in history. The use of robotics and artificial intelligence is transforming all industries, leading to the elimination of some jobs and emerging of other high-tech ones. One billion people are predicted to need re-training by 2030, and among the skills they need are robotics, AI, and machine learning/deep learning. In order to adapt to this change, there is a need for better robotics and AI education curricula that facilitate experiential learning [11]. Imagine a scenario where students need to gain a thorough understanding of everything related to automation. Rather than abstractly discussing this idea through PowerPoint presentations, the instructors could use a model of a car factory with robots. The students will program robots to build the car and learn about automation concepts along the way (Fig. 3 - c).

Impact and Funding

My research goals are aligned with national, international, and industry efforts to advance the development and use of robots for healthcare and education. The National Science Foundation (NSF) offers several funding opportunities for education and rehabilitation/assistive robotics research, such as the Foundational Research in Robotics (FRR) program, Advancing Informal STEM Learning (EHR/DRL/AISL) program to support research and practice focused on the range of informal STEM learning experiences and environments that comprise life-long learning, Discovery Research PreK-12 (EHR/DRL/DRK-12) for research related to formal STEM education, Innovative Technology Experiences for Students and Teachers (EHR/DRL/ITEST) for research in which pre-K through 12th-grade youth engage in robotics in formal or informal settings, Research on Emerging Technologies for Teaching and Learning (RETTL), and Disability and Rehabilitation Engineering (ENG/CBET/DARE) program that supports research in neuroengineering and rehabilitation robotics. Robotics funding is also available from NIH, DARPA, NASA, HHS, and the NIOSH. For instance, rehabilitation robots that can help soldiers with PTSD or other disorders can be supported and funded by DARPA. Leading medical robotics companies like Intuitive also have medical robotics-related grants like Technology Research Grants. Hence, there are increasing opportunities for my research to be financed by both governmental agencies and industrial collaborations.

References

[1] Fan Yang, Mahdieh Babaiasl, and John P Swensen. Fracture-directed steerable needles. *Journal of Medical Robotics Research*, 4(01):1842002, 2019.

[2] Mahdieh Babaiasl, Stefano Boccelli, Yao Chen, Fan Yang, Jow-Lian Ding, and John P Swensen. Predictive mechanics-based model for depth of cut (doc) of waterjet in soft tissue for waterjet-assisted medical applications. *Medical & Biological Engineering & Computing*, 58(8):1845–1872, 2020.

[3] Mahdieh Babaiasl, Fan Yang, and John P Swensen. Duty cycling of waterjet can improve steerability and radius-of-curvature (roc) for waterjet steerable needles. In *2020 International Symposium on Medical Robotics (ISMR)*, pages 50–56. IEEE, 2020.

[4] Mahdieh Babaiasl, Seyyed Hamed Mahdioun, Poorya Jaryani, and Mojtaba Yazdani. A review of technological and clinical aspects of robot-aided rehabilitation of upper-extremity after stroke. *Disability and Rehabilitation: Assistive Technology*, 11(4):263–280, 2016.

[5] Maria Kyrarini, Fotios Lygerakis, Akilesh Rajavenkatanarayanan, Christos Sevastopoulos, Harish Ram Nambiappan, Kodur Krishna Chaitanya, Ashwin Ramesh Babu, Joanne Mathew, and Fillia Makedon. A survey of robots in healthcare. *Technologies*, 9(1):8, 2021.

[6] Mahdieh Babaiasl, Fan Yang, and John Paul Swensen. Robotic needle steering: state-of-the-art and research challenges. *Intelligent Service Robotics*, pages 1–33, 2022.

[7] Yao Chen, Jow-Lian Ding, Mahdieh Babaiasl, Fan Yang, and John P Swensen. Characterization and modeling of a thermoplastic elastomer tissue simulant under uniaxial compression loading for a wide range of strain rates. *Journal of the Mechanical Behavior of Biomedical Materials*, 131:105218, 2022.

[8] Mahdieh Babaiasl, Ahmad Ghanbari, and Seyyed Mohhamad Reza Noorani. Mechanical design, simulation and nonlinear control of a new exoskeleton robot for use in upper-limb rehabilitation after stroke. In *2013 20th Iranian Conference on Biomedical Engineering (ICBME)*, pages 5–10. IEEE, 2013.

[9] Mahdieh Babaiasl, Saeede Nazari Goldar, Mojtaba Hadi Barhaghtalab, and Vahid Meigoli. Sliding mode control of an exoskeleton robot for use in upper-limb rehabilitation. In *2015 3rd RSI International Conference on Robotics and Mechatronics (ICROM)*, pages 694–701. IEEE, 2015.

[10] M Babaiasl, A Ghanbari, and S Noorani. Anthropomorphic mechanical design and lyapunov-based control of a new shoulder rehabilitation system. *Engineering Solid Mechanics*, 2(3):151–162, 2014.

[11] Maki K Habib, Fusaomi Nagata, and Keigo Watanabe. Mechatronics: Experiential learning and the stimulation of thinking skills. *Education Sciences*, 11(2):46, 2021.