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An Educational Test Rig for Kinesthetic Learning of Mechanisms for Underactuated Robotic Hands

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Abstract: Teaching robotics requires interdisciplinary skills and a good creativity, providing instructions and hands-on experiences, exploiting different kinds of learning. Two kinds of learning methods are commonly used: the 'visual learning' and the 'auditory learning', recognizable by the preference of an approach for images, rather than for texts, or oral explanations. A third possible learning style is the 'kinesthetic learning', based on tactile activities, which is generally least exploited, both by teachers in the classroom and by students during individual study. In this perspective, the use of educational test rigs is a good practice and adds an opportunity to share a passion for robotics. The paper focuses on the realization and application of an educational test rig aimed at explaining how a differential mechanism works and how it can be applied to robotic underactuated soft grippers to move multiple robotic fingers independently of each other using just a single actuator. The differential test bench was realized by 3D printing and mounted with the help of students in high school seminaries oriented to encourage students towards robotic or mechatronic studies. This activity was very thrilling for the students and helped them to approach robotics in a natural way, exploiting kinesthetic learning as it is demonstrated by test results.

Keywords: differential mechanism; underactuated robotics; robotic hand; soft robotics; gripper; educational robotics; robotic manipulation

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1. Introduction

In the coming years, robotics is going to be an essential ingredient for the success of many educational activities [1–3]. For instance, educational robots can be fruitfully used in early childhood to pursue the development of computational thinking and skills [4–7]. Furthermore, the opportunity to face technical activities applied to robotic tools during educational sessions makes students learn without difficulty and naturally even complex mechanical matters [8,9]. In addition, not only the use of robotic educational devices helps students enhance their skills, but most of all, the possibility of building parts of robotic tools themselves, touching with their hands to learn how they work [10,11]. With this approach based on experiments and manual experiences, students learn faster and better and gain the ability to solve even complicated issues [12,13]. Different learning styles have been exploited and used over time, and they have been categorized by educational models. One of the most widely accepted and used theoretical models is Neil Fleming's VARK (visual, aural, read/write, and kinesthetic) model [14,15], which assumes three macrotypes of learning: visual, based on visual supports, such as figures, diagrams, written texts, and so on; auditory, based on listening oral lessons, audio tracks, conversation, and so on; and kinesthetic, based on "doing" and "moving", through tactile activities typical of experiments, projects, and manual exercises.

All these learning styles usually coexist within the same individual, who will have a preference for or preponderance of one of them, also depending on the experienced learning activity.

There are also other approaches to learning that complement the macrosubdivision operated by Fleming; this is Howard Gardner's theory of "multiple intelligences" [16], which is categorized into: naturalist, linguistic/verbal, logical/mathematical, visual/spatial, bodily kinesthetic, musical/rhythmic, interpersonal, and intrapersonal.

This paper is focused on an investigation of how visual, oral, and kinesthetic teaching can improve the interest of 13- to 14-year-old students in robotics.

In particular, the aim of the paper is to demonstrate that laboratory activities focused on the construction and use of an educational test rig help students to learn the principles of actuation in underactuated robotics, enhancing their interest in such subject, encouraging them towards further robotic or mechatronic studies [17,18].

This experimental and manual approach was used to teach high school students the working principle of differential mechanisms for robotics and their application to underactuated robotic hands.

Underactuated robotic hands commonly use tendons to propagate the actuation to the joints, which is a very simple solution but with a unidirectional actuation [19,20]. The use of differential mechanisms allows for moving multiple fingers with a single actuator [21], enhancing the compactness of the device [22].

Differential mechanisms, like many other mechanical systems, are difficult to explain to high school students devoid of technical background using just a blackboard and visual/oral approaches, while the best way to attract and engage students is to show them how the mechanisms work and make them touch with their hands [23,24].

In this paper, an educational test rig of a differential mechanism for underactuated robotic grippers is presented and was realized and mounted by students with simple commercial components and 3D-printed elements. The use of the differential test rig allowed the students to understand how different robotic fingers can be moved independently of each other by a single actuator in underactuated robotic grippers, improving the grasping ability and the compliance of the contact between the finger and the object to manipulate [25,26].

The students could also use a 3D-printed underactuated robotic gripper to test the functionalities of the studied differential system grasping real objects. This activity thrilled all the students and allowed them to face challenging robotic matters with a simple approach that made them learn naturally and without effort [27,28]. Results demonstrated that the test rig and the approach proposed in this paper could facilitate the learning of robotics, making unskilled students deal with technical issues [29,30].

The paper is organized as follows: Section 2 is focused on the description of all the teaching methods—visual/oral and kinesthetic—and of the contents of the lectures and laboratory activities. This section also contains the contents of the survey taken with the students with the aim of appreciating their interests and learning preferences. Section 3 reports the results of the survey and the discussion of the achievements. Section 4 is dedicated to conclusions and future perspectives.

2. Materials and Methods

Twenty-two students aged 13–14 at the high school level were invited to participate in a summer activity focused on differential mechanisms for underactuated robotics.

The teaching method was based on different approaches:

- Frontal lectures;
- Laboratory activities;
- Experimental applications

Frontal lectures were given for 6 hours, and they were characterized by an oral and visual approach, through videos, presentations, drawings, and oral explanations, while the students listened to the lectures, watched video demonstrations, asked questions, and took notes.

Laboratory activities were focused on a tactile approach throughout the realization of models and 3D-printed samples of the test rig's components to build it and practice with a differential mechanism according to a kinesthetic approach. The students were involved in all the activities and had the possibility of drawing, building, and assembling all the components.

Experimental applications regarded the use of a real underactuated robotic gripper mounting a differential mechanism similar to the one realized with the test rig and used to grasp real objects. This final experience allowed the students to enhance their comprehension of the utility and functionality of a differential mechanism and to have an approach with underactuated robotics.

At the end of the summer course, a survey was taken to appreciate the learning results due to the oral, visual, and kinesthetic approaches and investigate the learning preferences of the attending students.

2.1. Frontal Lectures: Oral and Visual Teaching

The contents of the frontal lectures were focused on the generalities and typologies of differential mechanisms and their applications in underactuated robotics.

Here, the main topics were shown and treated in the frontal lectures.

When talking about differential mechanisms, the differential gear train used in automotive comes to mind immediately, but the use of gears is just one of the different design solutions to realize a differential system.

In general, a differential is a two-degrees-of-freedom mechanism that can transfer the input of a single actuation to two outputs or vice versa [31], and the connection of multiple differential systems is a solution to obtain more than two outputs with a single input [32], as represented in Figure 1.

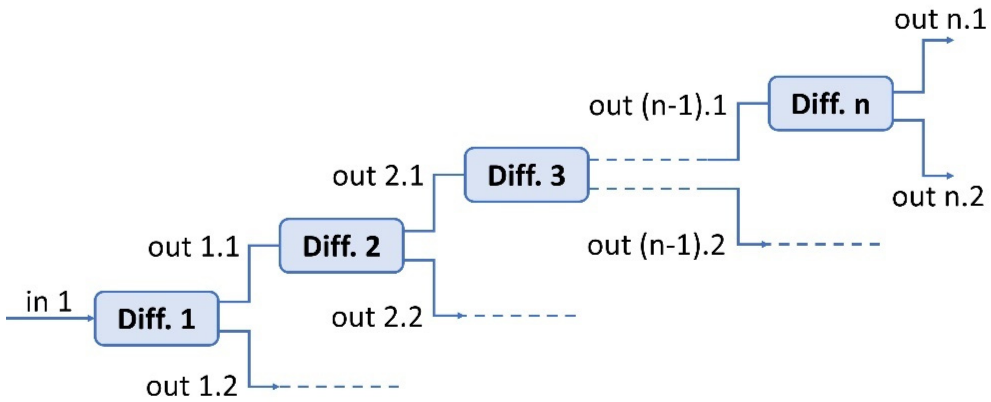

Figure 1. Serial differential systems.

Several design solutions are possible to realize a differential mechanism, as Figure 2 reports by showing four typologies. The most known differential systems are based on gear trains with different configurations: based on bevel gears, as shown in Figure 2a, or planetary gears. Although these mechanisms are mainly used for automotive applications, they were also used for underactuated robotic hands [33].

Figure 2b shows a differential mechanism based on a seesaw system aimed at adjusting the different positions of the two outputs by rotation. The same principle governs the differential mechanism based on movable pulleys, as represented in Figure 2c. This design solution is maybe the most known and frequently used in mechanics and robotic grippers due to its simplicity of realization [34]. Movable pulley and seesaw mechanisms are very useful to transmit the motion in a mechanical system driven by two tendons, and for this reason, they are widely used for robotic hands and manipulators [35].

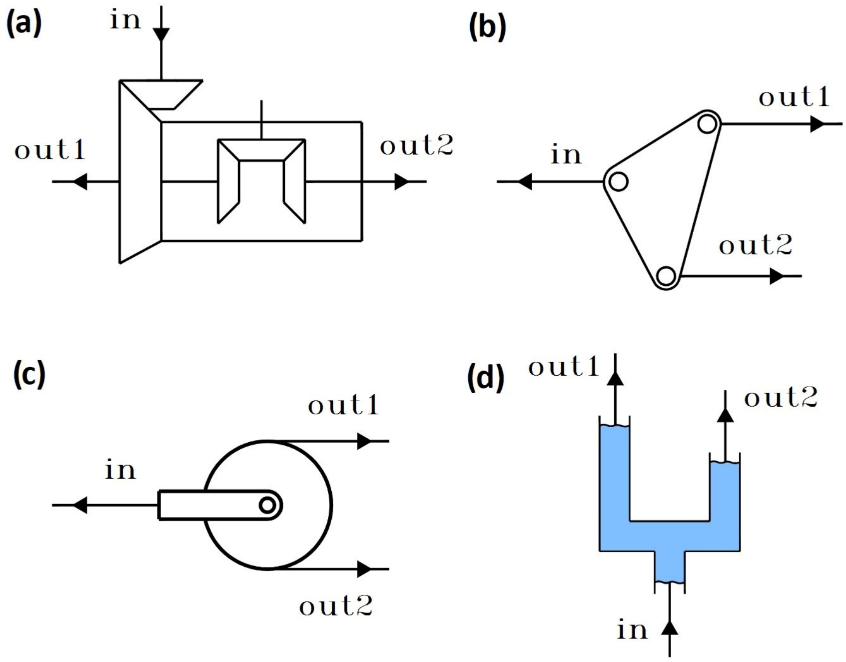

Figure 2. Some typologies of differential mechanism: (**a**) bevel gear, (**b**) seesaw system, (**c**) movable pulley, (**d**) fluidic system.

Another possible design solution to realize a differential system that splits one input towards two outputs is to use a T-pipe fluidic stage, as represented in Figure 2d.

Differential mechanisms are fundamental components of underactuated robotic devices moved by tendons and cables, for example, robotic hands and grippers, which are devices having a number of fingers greater than the number of actuators. The most challenging aim of underactuation is to transmit an independent motion to several fingers using a single actuator. This purpose can be achieved by means of differential mechanisms that are also fundamental to ensure a reliable and compliant grasping, allowing the motion of each finger, even when the others are stuck, after collision with an obstacle [36] and allowing for completing the closure of all the fingers until the object is caught, as represented in Figure 3.

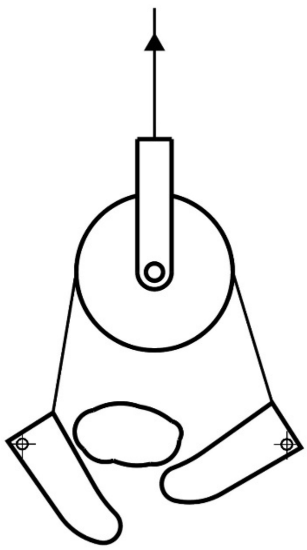

Figure 3. Importance of the differential mechanism to ensure a compliant and reliable grasping.

Using an underactuated system improves the cost-effectiveness and the versatility of the device, which results in it being lighter and less cumbersome, which can be also miniaturized for designing wearable haptic devices [36,37].

An underactuated gripper with two fingers and six phalanges, actuated by a single tendon, and one scoop driven by three phalanges is represented in Figure 4. In this device, there are two actuators, one for the scoop and one for the two fingers, and the differential mechanism allows for decoupling the motion of the two fingers. This characteristic, together with the modularity of the fingers and the flexibility of the joints, makes the gripper a deformable assembly, able to adjust its shape to the morphology of the object to grasp [19,21,37].

Figure 4. Underactuated gripper used to test the real application of the differential mechanism.

2.2. Kinesthetic Teaching

2.2.1. Design and Production of the Differential Test Rig

The working principle of a differential mechanism is much simpler to understand if one can see it in action, through an education test bench. The test rig developed for educational purposes was based on the principle of movable pulleys and enabled the high school students to understand how it works by tactile activities. The system is a tendon-driven device: a motor, controlled by an electronic board, allows the whole mechanism to move by means of linear guides and pulleys on which the tensioned tendon is fixed.

The test rig was built using components commercially available and self-made elements realized by 3D printing. The standard components were a servomotor with an actuation unit, linear guide bearings, plain steel parallel dowel pins, and ball bearings, as Figure 5 shows.

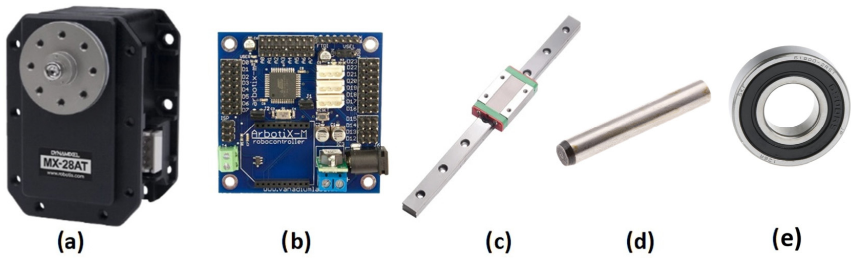

Figure 5. Standard components: (**a**) servomotor, (**b**) control board, (**c**) liner guide bearing, (**d**) pin, (**e**) ball bearing.

The servomotor was a Dynamixel MX28AT (Figure 5a), combined with the control board Arbotix-M (Robotis, Seoul, South Korea) (Figure 5b), and was used to actuate the differential movable pulley using a maximum torque of 3.1 Nm and a maximum angular speed of 684 deg/s. A movable pulley was translated on a linear guide bearing by the actuator and was connected to two other linear guide bearings through tendons.

Linear guide bearings were used to allow the translation of pulleys throughout a sliding ball bearing, ensuring low friction and resistance to loads on each direction. These systems are suitable for being used by unskilled students as they are very simple to mount and use and are provided with several holes to insert pins and screws, without further adjustments. The linear guide bearings used for this experiment were MGN12H with a length of 150 mm (Figure 5c), together with ball bearings (Figure 5e). The differential system was also provided with plain steel parallel pins (Figure 5d) and artificial tendons made by an inextensible wire.

The other components of the differential test rig were realized by additive manufacturing, using an Artillery Sidewinder X1 3D printer, represented in Figure 6, which allows for producing components and prototypes even in a nonindustrial environment as schools or offices.

Figure 6. FDM 3D printer.

The material chosen for all the components was ecoPLA (eco polylactic acid), a bio-based polymeric thermoplastic material suitable for a safe indoor use [38]. This PLA is simple to 3D-print and does not require specific skills to be handled or conditions (e.g., hot printing room and high temperatures).

The test rig components were modeled by using the 3D CAD (computer-aided design) software Solidworks (Dassault Systèmes®, Waltham, MA, USA), which allows a parametric 3D modelling. The 3D models were not realized by the students, but the parametric nature of the CAD software allowed for showing them how to change dimensions, configurations, and shapes in a fast and simple way, to realize different 3D-printed components without starting with a new drawing, but simply modifying an existing one.

The 3D-printed parts are represented in Figure 7:

- Ball bearing case to be fixed on the sliding bearing;
- Cylinder to couple the ball bearing and the steel pin;
- Movable pulley;
- Cylinder to fix the pulley;
- End of stroke of the sliding bearing;
- Support to cross the tendons

The ball bearing case (Figure 7a) is needed to mount the movable pulley on the sliding bearing. In the center of this case, there is the ball bearing seat with a diameter of 22 mm, and around the seat, there are four M3 holes to fix the case on the sliding bearing and another hole to mount a screw where the tendon is bound.

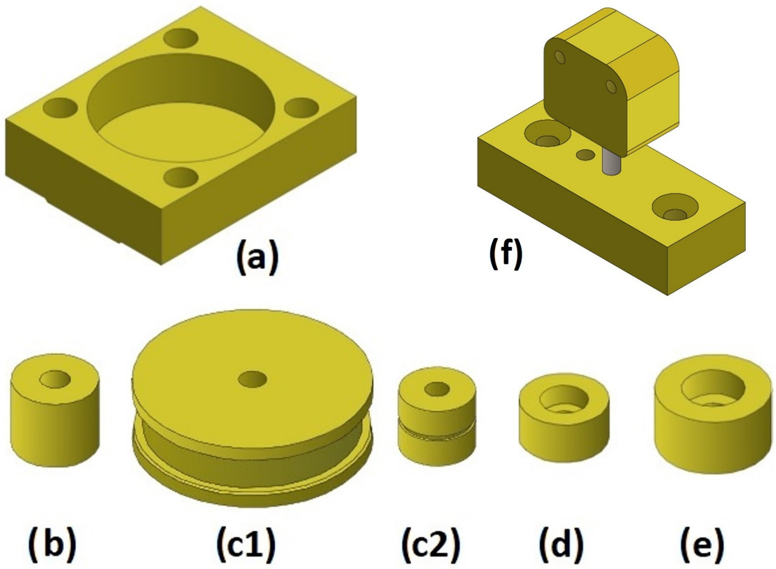

Figure 7. 3D-printed components: (**a**) ball bearing case to be fixed on the sliding bearing, (**b**) cylinder to couple the ball bearing and the steel pin, (**c1**) one kind of movable pulley, (**c2**) another kind of movable pulley, (**d**) fixing component for the pulley, (**e**) end of stroke for linear guide.

The cylinder to couple the ball bearing and the steel pin (Figure 7b) is mounted inside the inner hole of the ball bearing and has a central hole to place a plain steel parallel dowel pin.

On the movable pulley (Figure 7c1), which is the differential component, the tendon is coiled and then attached to other two sliding bearings. The pulley is located at a 6.5 mm distance from the ball bearing case and has a groove where the tendon can slide. Various types of movable pulley were manufactured to evaluate different behaviors of the differential mechanism.

The pulley is fixed by a cylinder (Figure 7d) mounted on the steel pin, which prevents the eventual extraction of the pulley, and another cylinder (Figure 7e) works as a limit for the stroke of the sliding bearings and can be mounted on the standard holes of the linear guide.

The CAD representation of the whole assembly of the movable pulley section is represented in Figure 8.

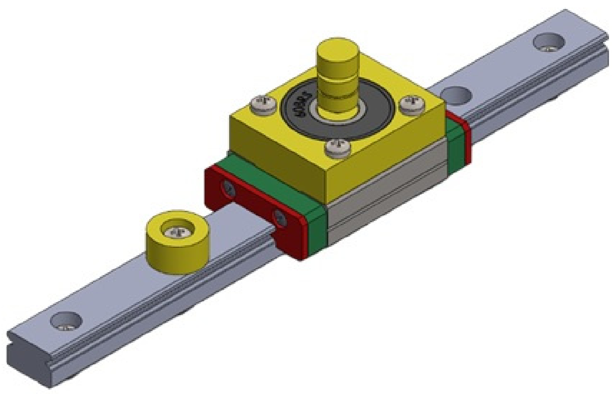

Figure 8. Assembly of the movable pulley section.

2.2.2. Assembly and Application of the Differential Test Rig with Students

The assembly of the differential test rig was performed by students with the help of the teachers according to the following steps:

I. The CAD drawing of the assembly (Figure 8) was used as guidance to mount the various components.
II. Three assemblies were mounted according to the drawings, one with all the components and the movable pulley and two without pulleys. The assembly with the pulley represents the differential mechanism, while the two assemblies without pulleys represent two independent fingers of a robotic gripper.
III. These three assemblies were connected to a plain wooden board using screws inside the standard holes of the linear guides, according to the configuration represented in Figures 9 and 10. The distances of the installed parts were established to allow a significant rotation of the pulley and a motion of the sliders.
IV. The servomotor was connected through a tendon to the sliding bearing, where the movable pulley was mounted.
V. Another tendon was coiled around the movable pulley, crossed through a 3D-printed tubular support (Figure 7f), and then attached by a screw to the other two sliding bearings, which represent two decoupled fingers. The tubular support works as a fairlead for the tendons and allows for increasing the lever arm of the actuator, and this makes the differential action more visible and recognizable. In fact, with this element, the tension on the tendon increases, and the efficiency of the test rig is improved.

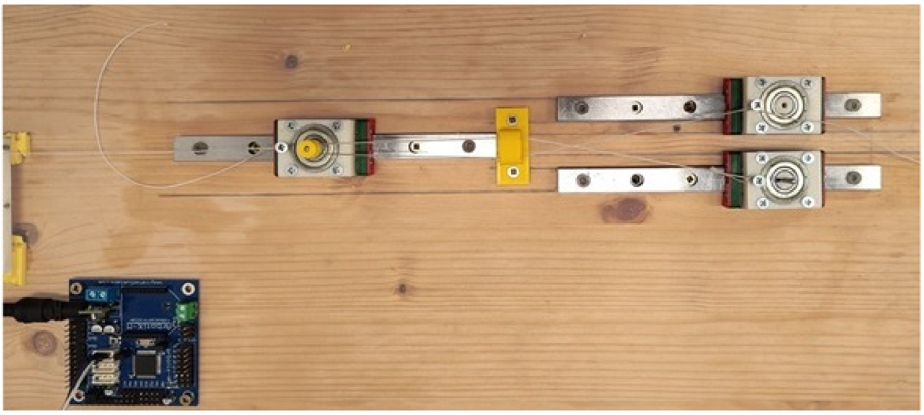

Figure 9. Test rig simulating the finger closure without an object to grasp.

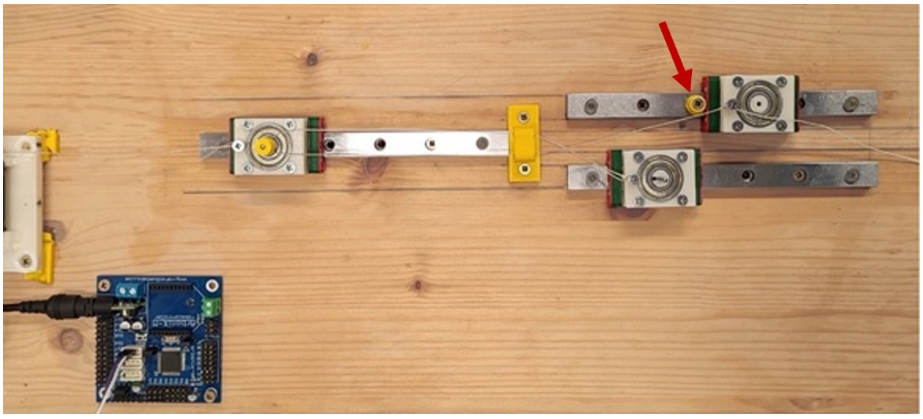

Figure 10. Test rig simulating the finger closure to grasp an object. The object is represented by the pin indicated by the red arrow.

Two kinds of experiments were carried out, while all the students could interact with the test rig: the first one simulated the finger closure without an object to grasp, as represented in Figure 9; the second one, represented in Figure 10, reproduced the presence of an object to grasp by inserting an end of stroke of the sliding bearing (Figure 7e) on one of the two guides representing the fingers.

2.2.3. Experimental Applications in Underactuated Grippers

After having performed some tests on the differential rig, the students had the opportunity to use a robotic underactuated gripper mounting a differential system to test how it works in a real application (Figure 4). Some different objects were grasped, and the decoupling of the fingers was evidenced, especially with free-form and deformable objects, as Figure 11 shows.

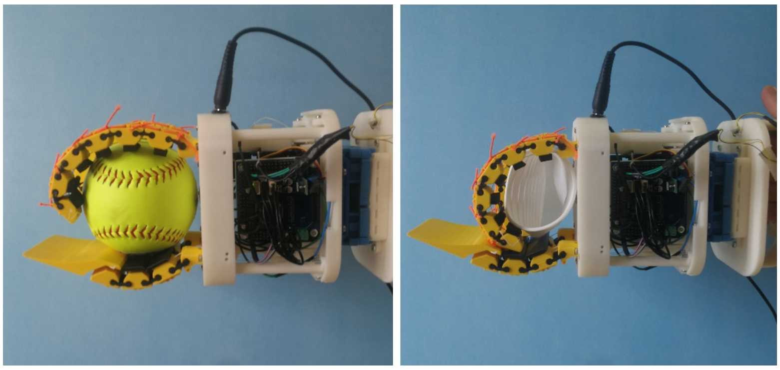

Figure 11. Grasping tests performed by the students with a real gripper and two different objects.

A technical issue discussed with the students was the miniaturization of the system realized with the test rig and the eventual installation on a real gripper. This activity surely needs the employment of SLA (stereolithography) 3D printers using resins to achieve a higher resolution and precision of details and could be an interesting matter for a future orientation seminar.

2.3. Evaluation of the Utility of the Kinesthetic Teaching

The survey given to the students comprised six questions to appreciate the learning results due to the oral, visual, and kinesthetic approaches. The students were asked to quantify their interest in the learning activities by giving four scores, as reported in Table 1.

Table 1. Survey for learning activities.

Visual and Oral Learning Phase					
Query		**Score** [1]			
1.	Visual and oral lectures were sufficient to deeply learn how the mechanism works.	0	1	2	3
2.	Kinesthetic lectures gave more insights to learn how the mechanism works.	0	1	2	3
3.	I preferred the oral and visual teaching.	0	1	2	3
4.	I preferred the kinesthetic teaching with the test rig and tactile activities.	0	1	2	3
5.	I was thrilled and felt interested in mechanisms for robotics after the visual and oral teaching.	0	1	2	3
6.	I was thrilled and felt interested in mechanisms for robotics after the kinesthetic teaching.	0	1	2	3

[1] 0 = not at all; 1 = little; 2 = quite; 3 = very.

3. Results and Discussion

Results are given in terms of data collected from the survey taken with the students, as reported in Table 2.

Table 2. Results.

Query	Total Score %	Score 0	Score 1	Score 2	Score 3
1	53	3	6	10	3
2	80	1	2	6	13
3	45	4	9	6	3
4	73	2	1	10	9
5	52	4	10	0	8
6	71	1	3	10	8

From these results, one can observe that 45.5% of the students were quite convinced that the visual and oral teaching were sufficient to understand how a differential mechanism works, and just 13.6% of them agreed that this kind of teaching was fully sufficient to them. On the contrary, 59% of the students were very persuaded that kinesthetic teaching gave them more insights to learn how the differential mechanism works, and just 13.6% of them had no more insights from the kinesthetic teaching. In fact, given a total score of 66 points, question 2 obtained 80% of this maximum score.

Only 13.6% of the students fully preferred the oral and visual teaching, while 41% of them fully preferred the kinesthetic activities. Of the attendees, 27.3% were quite interested in the visual and oral activities, while 45.5 of them were quite interested in the tactile learning.

Finally, investigating the enhanced interest of the students in mechanisms for robotics, questions 5 and 6 revealed that an equal percentage of the students (36.4%) were thrilled by both the visual/oral and kinesthetic activities. Although this could let one conclude that there is an equal contribution of the visual/oral and kinesthetic teachings to the enhancement of interest in robotics, by taking into consideration question 5, one can observe also that none said that the visual and oral teaching quite enhanced his or her interest in robotics, while 45.5% of the students gave a score of 2 to question 6. Thus, the final achievement demonstrates that 81.9% of the students developed a certain interest in mechanisms for underactuated robotics, thanks to the kinesthetic activities, and just 36.4% developed the same interest through oral and visual learning.

4. Conclusions and Perspectives

This paper presented the design, realization, and application of a differential test rig for educational purposes in the field of underactuated robotics. The developed test rig was used to explain to high-school-level students how different fingers of a robotic hand can be independently closed to grasp objects by using a single actuator. This concept was not so simple to understand by theoretical explanations, and the test rig provided a simple tool to understand and practice. The realization of the 3D-printed components and the assembly with the help of the students was a very interesting and fascinating activity. The possibility of using a real underactuated robotic gripper was the ingredient that allowed the students to touch with their hands the real application of the built system. Results demonstrated that the proposed approach facilitated the learning of a challenging subject related to robotics and mechanics without apprehension and helped even unskilled students to deal with technical issues, encouraging them towards robotic or mechatronic matters.

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References

1. Eguchi, A. Robotics as a learning tool for educational transformation. In Proceedings of the 4th International Workshop Teaching Robotics, Teaching with Robotics and 5Th International Conference Robotics in Education, Padova, Italy, 18 July 2014; pp. 27–34.
2. Bezerra, J.E.; De Lima, R.W.; Queiroz, P.G.G. A study of the publications of educational robotics: A systematic review of literature. *IEEE Lat. Am. Trans.* **2018**, *16*, 1193–1199. [CrossRef]
3. Tselegkaridis, S.; Sapounidis, T. Exploring the Features of Educational Robotics and STEM Research in Primary Education: A Systematic Literature Review. *Educ. Sci.* **2022**, *12*, 305. [CrossRef]
4. Roussou, E.; Rangoussi, M. On the use of robotics for the development of computational thinking in kindergarten: Educational intervention and evaluation. *Adv. Intell. Syst. Comput.* **2020**, *1023*, 31–44. [CrossRef]
5. Pozzi, M.; Prattichizzo, D.; Malvezzi, M. Accessible educational resources for teaching and learning robotics. *Robotics* **2021**, *10*, 38. [CrossRef]
6. Esposito, J.M. The State of Robotics Education: Proposed Goals for Positively Transforming Robotics Education at Postsecondary Institutions. *IEEE Robot. Autom. Mag.* **2017**, *24*, 157–164. [CrossRef]
7. Barradas, R.; Lencastre, J.A.; Soares, S.; Valente, A. Developing computational thinking in early ages: A review of the code.org platform. In Proceedings of the CSEDU 2020—Proceedings of the 12th International Conference on Computer Supported Education, Prague, Czech, 2–4 May 2020; pp. 157–168.
8. Penprase, B.E. The fourth industrial revolution and higher education. In *Higher Education in the Era of the Fourth Industrial Revolution*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 207–228. [CrossRef]
9. Barradas, R.; Lencastre, J.A.; Soares, S.; Valente, A. Usability evaluation of an educational robot for steM areas. In Proceedings of the CSEDU 2019—Proceedings of the 11th International Conference on Computer Supported Education, Heraklion, Greece, 2–4 May 2019; pp. 218–225. [CrossRef]
10. Tiboni, M.; Aggogeri, F.; Bussola, R.; Borboni, A.; Perani, C.A.; Pellegrini, N. Low-cost design solutions for educational robots. *J. Robot. Mechatron.* **2018**, *30*, 827–834. [CrossRef]
11. Birk, A.; Dineva, E.; Maurelli, F.; Nabor, A. A robotics course during covid-19: Lessons learned and best practices for online teaching beyond the pandemic. *Robotics* **2021**, *10*, 5. [CrossRef]
12. Ramirez, O.J.V.; Cruz, J.E.C.D.L.; Machaca, W.A.M. Educational robotics as a physical sciences teaching tool. In Proceedings of the 16th Latin American Conference on Learning Technologies, LACLO, Arequipa, Peru, 19–21 October 2021; pp. 404–407. [CrossRef]
13. Lemire, F.; Fowler, N. Linking education and practice: The outcomes of training project. *Can. Fam. Physician* **2018**, *64*, 866. [PubMed]
14. Fleming, N.D. VARK Visual, Aural/Auditory, read/write, Kinesthetic.; Bonwell Green Mountain Falls. Available online: https://vark-learn.com/v (accessed on 16 October 2022).
15. Fleming, N.; Baume, D. Learning Styles Again: VARKing up the right tree! *Educ. Dev.* **2006**, *7*, 4–7.
16. Gardner, H. *Intelligence Reframed: Multiple Intelligences for the 21st Century*; Basic Books: New York, NY, USA, 1999.
17. Verner, I.M.; Cuperman, D.; Reitman, M. Exploring robot connectivity and collaborative sensing in a high-school enrichment program. *Robotics* **2021**, *10*, 13. [CrossRef]
18. Verner, I.M.; Cuperman, D.; Gamer, S.; Polishuk, A. Exploring affordances of robot manipulators in an introductory engineering course. *Int. J. Eng. Educ.* **2020**, *36*, 1691.
19. Achilli, G.M.; Logozzo, S.; Valigi, M.C.; Salvietti, G.; Prattichizzo, D.; Malvezzi, M. Underactuated Soft Gripper for Helping Humans in Harmful Works. In *Mechanisms and Machine Science*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 264–272. [CrossRef]
20. Achilli, G.M.; Valigi, M.C.; Salvietti, G.; Malvezzi, M. Design of soft grippers with modular actuated embedded constraints. *Robotics* **2020**, *9*, 105. [CrossRef]
21. Achilli, G.M.; Logozzo, S.; Valigi, M.C.; Malvezzi, M. Preliminary study on multibody modeling and simulation of an underactuated gripper with differential transmission. In Proceedings of the ASME Design Engineering Technical Conference, Online, 17–19 August 2021; p. V009t009a005. [CrossRef]
22. Achilli, G.M.; Logozzo, S.; Valigi, M.C.; Dragusanu, M.; Malvezzi, M. Theoretical and Experimental Characterization of a New Robotic gripper's Joint. In *Mechanisms and Machine Science-Advances in Italian Mechanism Science*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 738–745. [CrossRef]
23. Pou, A.V.; Canaleta, X.; Fonseca, D. Computational Thinking and Educational Robotics Integrated into Project-Based Learning. *Sensors* **2022**, *22*, 3746. [CrossRef]
24. Kanamura, M.; Suzuki, K.; Suga, Y.; Ogata, T. Development of a basic educational kit for robotic system with deep neural networks. *Sensors* **2021**, *21*, 3804. [CrossRef] [PubMed]
25. Miller, A.T.; Allen, P.K. Graspit! A versatile simulator for robotic grasping. *IEEE Robot. Autom. Mag.* **2004**, *11*, 110–122. [CrossRef]

26. Koenig, A.; Rodriguez, Y.; Baena, F.; Secoli, R. Gesture-based teleoperated grasping for educational robotics. In Proceedings of the 2021 30th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), Vancouver, BC, Canada, 8–12 August 2021; pp. 222–228. [CrossRef]
27. Ribeiro, A.F.; Lopes, G. Learning Robotics: A Review. *Curr. Robot. Rep.* **2020**, *1*, 1–11. [CrossRef]
28. Manzoor, S.; Ul Islam, R.; Khalid, A.; Samad, A.; Iqbal, J. An open-source multi-DOF articulated robotic educational platform for autonomous object manipulation. *Robot. Comput. -Integr. Manuf.* **2014**, *30*, 351–362. [CrossRef]
29. Arif, A.H.; Waqas, M.; Rahman, U.U.; Anwar, S.; Malik, A.; Iqbal, J. A hybrid humanoid-wheeled mobile robotic educational platform - design and prototyping. *Indian J. Sci. Technol.* **2014**, *7*, 2140–2148. [CrossRef]
30. Zeng, C.; Zhou, H.; Ye, W.; Gu, X. iArm: Design an Educational Robotic Arm Kit for Inspiring Students' Computational Thinking. *Sensors* **2022**, *22*, 2957. [CrossRef]
31. Boegelsack, G.; Gierse, F.J.; Oravsky, V.; Prentis, J.M.; Rossi, A. Terminology for the Theory of Machines and Mechanisms. *Mech. Mach. Theory* **1983**, *18*, 379–408.
32. Birglen, L.; Gosselin, C.M. Force analysis of connected differential mechanisms: Application to grasping. *Int. J. Robot. Res.* **2006**, *25*, 1033–1046. [CrossRef]
33. Luo, M.; Mei, T.; Wang, X.; Yu, Y. Grasp characteristics of an underactuated robot hand. In Proceedings of the IEEE International Conference on Robotics and Automation, New Orleans, LA, USA, 26 April 2004–1 May 2004; pp. 2236–2241.
34. Massa, B.; Roccella, S.; Carrozza, M.C.; Dario, P. Design and development of an underactuated prosthetic hand. In Proceedings of the IEEE International Conference on Robotics and Automation, Washington, DC, USA, 11–15 May 2002; pp. 3374–3379.
35. Birglen, L.; Laliberté, T.; Gosselin, C. Grasping vs. manipulating. *Springer Tracts Adv. Robot.* **2008**, *40*, 7–31. [CrossRef]
36. Malvezzi, M.; Valigi, M.C.; Salvietti, G.; Iqbal, Z. Design criteria for wearable robotic extra–fingers with underactuated modular structure. In *Mechanisms and Machine Science*; Springer: Cham, Switzerland, 2019; Volume 68, pp. 509–517. [CrossRef]
37. Malvezzi, M.; Iqbal, Z.; Valigi, M.C.; Pozzi, M.; Prattichizzo, D.; Salvietti, G. Design of multiplewearable robotic extra fingers for human hand augmentation. *Robotics* **2019**, *8*, 102. [CrossRef]
38. Davis, A.Y.; Zhang, Q.; Wong, J.P.S.; Weber, R.J.; Black, M.S. Characterization of volatile organic compound emissions from consumer level material extrusion 3D printers. *Build. Environ.* **2019**, *160*, 106209. [CrossRef]