Brief Report

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Educational Robotics: Building and Applying an App-controlled Car to Study Newton's Laws

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Abstract: The use of technology – including mobile phones – in classrooms is a growing and promising trend, but it still needs research on ways to integrate it in classrooms and on its impacts. We propose a low cost educational product where students assemble an Arduino car remotely controlled through a mobile app and use it to study Newton's third law, of action-reaction forces. The teacher used an inquiry-based approach to prompt students to test towing capacity of the car. Students connected the car to different weights and used a structure of pulleys to investigate the behaviour of fixed and movable pulleys, as well as the forces involved. The goal of the activity is to motivate students to study physics and to facilitate learning. This article describes a pilot implementation of the educational product in a secondary school of Brazil. We used a qualitative approach to evaluate the implementation. Students answered a survey before and after the activities. They also delivered a report and answered questions about the physics involved. The teacher recorded his observations. The product and the strategy showed great potential: these students were more motivated and engaged in the classes and were able to learn the main concepts involved.

Keywords: Physics; STEM; experiment; hands-on; pulleys.

1 Introduction

The current generation of secondary students is much more familiar with and interested in technology (Persada, 2019; Turner, 2015). The use of mobile phones during classes, for

instance, is an increasingly present trend that generates controversy. Some arguments for its use include ease of access to information, interactivity and its use as a tool for motivation (Prensky, 2005; Grant, 2015; Nikolopoulou, 2020), while researchers and teachers are concerned with student distraction caused by mobile phone usage for non-class purposes (McCoy, 2016; O'Bannon, 2015; Flanigan, 2020). Robotics in education also emerges as a promising teaching and learning tool, but there are needs for research on the impact of learning outcomes and on new ways of integrating it in the curricula (Miller, 2016; Benitti, 2012; Zhong, 2020).

Many students think physics is too difficult and that classes focus on mathematics manipulations and lack real examples (DeWitt, 2019; Erinosh, 2013). Experiments are often used to illustrate and contextualize the concepts and motivate students (Anwar, 2019; Azar, 2011; Schwichow, 2016; Cardoso, 2019; Aris, 2019).

We propose a low cost educational product that unites robotics, mobile phones and pulley experiments to illustrate Newton's laws at secondary school level. This article describes a pilot study of the educational product implementation, whose goal is to motivate students to study physics and to facilitate learning.

2 Educational Product

We propose a low cost educational robotics product that combines a do-it-yourself remotely controlled car and structure of pulleys. Students may use different combinations of fixed and movable pulleys to subject the car to towing capacity tests. The car is built with Arduino – a programable open-source electronics platform – and a Bluetooth module. A custom mobile application was designed to control the car remotely.

The product was designed for students to get involved in its making. The teacher may determine the level of participation based on time availability and the previous knowledge of the students.

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Figure 1: Images of the educational product implementation: (a) students assembling car, (b) schematics of the electric connections and (c) car towing weight with the structure of pulleys.

2.1 Resources

The project uses low cost widely available materials. The main electronic parts of the car are an Arduino Uno board and compatible components, shown in Table 1. These components and toy wheels are attached to a wooden frame. A computer is required for a one-time upload of the software into the Arduino board. The pulley frame from Figure 1c was made of plastic pipes, long enough to fit the largest system to be used. We attached to it 2 pulleys and hook screws, we also used 3 movable pulleys.

The car is controlled remotely via Bluetooth by a mobile phone. The teacher built a mobile application with MIT App Inventor: an intuitive programming environment suitable for beginners, including children.

We have chosen low cost materials. The advantages of using Arduino are: it is user friendly and only requires basic electronics and programming knowledge; it is low-cost open-sourced with a large community of users and accessible knowledge; it is versatile, with many components and may be reused in several projects.

2.2 Assembly

The teacher may partially or fully assemble and program the cars before classes. Choice depends on students’

Table 1: Main components of the remotely controlled car.

Quantity	Component
1	Arduino Uno board
1	HC-6 Bluetooth module
4	Battery Operated DC gear motor 1:120 double shaft (3-6V)
1	Dual H-Bridge motor driver L298N
2	9V Batteries

profiles and time availability. But students may benefit from participating, being more engaged and achieving higher grades (Wilcox, 2016; Lee, 2018; Von Korff, 2016). Students also have the opportunity to develop technical skills, as well as soft skills such as communication, teamwork and problem solving.

In the implementation described here, the teacher performed the tasks that required the use of tools. He built the pulleys frame, drilled the car frames and attached the wheels and components to it. Students connected the electronic parts and built personalised cardboard fairings.

Although the teacher programmed the Arduino board and the remote control app, he involved the students in the process and instigated discussions about the key ideas. The control used has 4 direction buttons. *Forward* tells Arduino to start all motors while *backward* reverses their direction. *Left* arrow starts only both right motors and *right* starts only left motors. There is also a stop button.

3 Didactic Implementation

The activities described here were implemented in a 1st year class of a secondary state school in southern Brazil. Twenty 14 to 16 year-old (male and female) students participated in 15 class hours distributed in 6 sessions. Total hours may vary according to depth of discussions and the familiarity of teacher and students with the technology involved.

3.1 Learning Goals

The experiments illustrate concepts and applications of Newton’s Laws, but the focus is on the action-reaction law. At the end, students should have experimented with fixed and movable pulleys. They were expected to understand the advantages of using pulleys and their basic working principles, to represent the main force vectors involved

and to understand Newton’s third law: for every action, there is an equal and opposite reaction (Halliday, 2018).

3.2 Resources

All sessions took place in the school science lab, but could have been done outside. Students used the items described in the educational product section and mobile phones to remotely control the cars. Sand filled plastic bottles represented weights from 100 to 800 g. Students also used a digital hanging scale.

3.3 Proposed Activities

The teacher used an inquiry-based approach (Coffman, 2017; Deignan, 2009) to share the main goals and kick off the activities: build a remotely controlled car and determine its towing capacity. The teacher posed the question and the main structure, while students actively defined questions and strategies to answer them. The teacher acted as a facilitator and guided the process, as students discussed and reflected on their findings. Table 2 shows the schedule. Students were divided into 5 teams of 4. Vygotsky (1978) argued that knowledge results from social interactions and that it is better to assess mental development when students work in groups.

Each team received an assembly guide and a chassis, with electric and electronic components attached. In the 1st session, students created and personalized a paperboard fairing. Students connected electric and electronic components, including batteries, and installed the mobile application for remote control.

Students started the 3rd session with tests and then troubleshooted, aided by the assembly guide and group discussions, all mediated by the teacher. Once a car was working, the students connected it to a fixed digital hook scale and assessed its towing capacity.

During the 3 final sessions, the students subjected the cars to towing tests with different loads. They used fixed and movable pulleys. Figure 2a shows the schematic with fixed pulleys only, that alter force direction but towing capacity remains the same. The addition of a movable pulley, shown in Figure 2b, maintained direction but doubled towing capacity, as the weight of the load is evenly distributed in both sides of the rope. In the final session students were encouraged to include more movable pulleys. Figure 2c shows two, quadrupling towing capacity.

The students represented simplified 2-D models of the systems with the force vectors involved. They assumed

Table 2: Schedule of Activities.

Session	Class hours	Activity
1 st	2	Introduction and problem proposal. Fairing assembly and personalisation.
2 nd	3	Electric and electronics connections.
3 rd	2	Tests and adjustments. Towing capacity experiments.
4 th	3	Fixed pulleys experiments.
5 th	2	Movable pulleys experiments.
6 th	3	Associations of pulleys.

ideal pulleys and ropes. Friction and air resistance were neglected. In each session, the teacher stimulated discussions with questions and each team delivered a report with measurements and answers to the questions proposed. Discussions included potential implications of simplifying the model. Teams were encouraged to create demonstration and explanatory videos.

4 Evaluation

Two questions guided the evaluation of the didactic activities described in this article:

Was there an impact on students’ perception of physics classes?

Did the activities facilitate learning?

We adopted a qualitative approach to address these questions (Cohen, 1999). The students answered two surveys to share their opinions on physics before and after the activities. They were also asked about the methodology used after the implementation, with closed and open questions.

During sessions, the teacher frequently asked questions and encouraged discussion. Students also answered written form of questions about the physics involved. The goal was to evaluate their understanding of physics concepts and interpretation of the phenomena observed. Students debated, delivered team reports and recorded demonstration and explanatory videos. Only reports were graded. The teacher prepared model answers, with key concepts and ideas students should include in their answers and used it to grade written answers by each team. Each answer was graded from 0 to 10 and expressed as percentage.

Figure 2: Schematics of the experiments to investigate the behaviour of (a) fixed pulleys, (b) a movable pulley and (c) compound pulleys.

All sessions were recorded. The teacher also wrote down his perceptions on challenges faced by the students during the activities, their questions and their verbal explanations and conclusions about the physics they were experimenting with. These notes were qualitative, without any systematisation.

5 Results and Discussion

We have compared student survey responses from before and after the didactic implementation. All 20 students responded. Four questions raised interesting points. When asked to rate their motivation and interest in physics, students rated both items evenly before and after the implementation. However, 19 of 20 students agree they would feel more motivated if classes would continue with experiments like these. Figure 3 shows the proportions. Researchers have shown improvement in students' attitudes with experiments and discussion (Marušić, 2012), with robotics (Khanlari, 2013) and inquiry-based learning (Wongwatkit, 2017; Fernandez, 2017), all of them combined in this implementation.

When asked if they liked to study physics the way it's being taught, 19 of them agreed after the experimental sessions; the number was 11 before. Figure 4 illustrates the differences in the proportions.

An open question asked students for their opinions about these sessions. Here are some excerpts from their responses: "I loved getting out of routine, replacing copying with practical activities, I learn better this way"; "I am passionate about robotics and it was wonderful to find out I can use it to study, this is what I would like to do"; "I had never felt so much like going to class!"; "we were able to create and learn, sometimes make mistakes and work together to fix them". Most students reported to have enjoyed doing practical activities. Some students complained about the difficulties they had doing electrical connections. Because they were able to accomplish the

Figure 3: Students' opinions about the methodology used after implementation.

Figure 4: Students' opinions about physics classes before and after the implementation.

goal, we believe such challenge was beneficial to their learning (Warshawer, 2014).

Students' lab reports and answers to the questions about physics suggest they were able to learn the main concepts. Figure 5 shows the questions and the boxplot of the scores obtained by the teams. The mean is indicated by the dashed line. Each datum point corresponds to a lab report score obtained by a team each time they were asked one of these questions. The first 4 questions were asked at the end of each experiment: 3rd, 4th, 5th and 6th sessions, while the last question was only asked in the 5th session. After each added pulley, students were asked what its purpose was.

Figure 5: Team scores on each physics question of the lab reports.

Students properly linked real life examples with the experiments. They cited clothesline, civil construction, weight training machines, cranes, window shutters, lifts, etc. Most of them were also able to identify and explain correctly the effects of using each pulley, movable and fixed. In most cases, they applied correctly this knowledge to explain how to increase towing capacity of the system. In fact, by the end of the activities they were able to successfully design pulley systems for the car to be able to tow specific given weights – the final task given by the teacher.

Although students were able to apply correctly the main concepts, most of them were not able to represent correctly all the vector forces of the systems in a simplified 2-D model. Secondary students often find it difficult to represent vector forces (Poluakan, 2018; Mongam, 2020), the class would revisit this item on future classes.

We were not able to conclude from their answers that students learned more than with traditional lectures, but the teacher observed that these students were much more engaged in the activities and were more active in class discussions than usual. These aspects are closely linked to meaningful learning (Ausubel, 1978; Fink, 2013). Although we need stronger evidence to conclude students were more engaged, previous research has shown students may feel more engaged when they are able to make connections to the real world (Geller, 2018) and when they participate in the process, even achieving higher grades (Wilcox, 2016; Lee, 2018; Von Korff, 2016).

The inquiry-based approach gave students freedom to explore and define their own learning goals, according to their interests. Besides the learning goals we had in mind, students got competitive and were curious about capacity differences among cars. They noticed friction played an important role and repeated the experiments with extra weight added to the car and on top of alternative surfaces. Their queries initiated group discussions about friction. Inquiry-based learning has been shown to induce students to feel more responsible for their learning and engaged with the activities (Barron, 2010; Deignan, 2009; Fernandez, 2017), which is what we believe happened to this group.

We have not assessed soft skills, but some of the references we presented previously show that the methodology and similar conditions may foster development of critical thinking, communication, teamwork and problem solving (Khanlari, 2013; Schwichow, 2016; Coffman, 2017; Lee, 2018; Nikolopoulou, 2020; Zhong, 2020).

This is a preliminary study. More consistent results require a larger sample and implementation in different classes, by different teachers and within schools. The evaluation instruments must also be expanded, improved, validated and applied to control groups.

6 Conclusion

The educational product proposed here was successfully used in a secondary school physics class. In this pilot implementation, the teacher did most of the preparation and all the programming, but we recommend involving the students in the programming. The students successfully assembled the car and executed the experiments. The product and the inquiry-based strategy showed great potential, according to our preliminary results. The teacher and the students believe they were more motivated and engaged in the physics classes. They were also able to learn the main concepts, and even discussed and learn concepts outside the learning goals.

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References

- Ahlfeldt*, S., Mehta, S., & Sellnow, T. (2005). Measurement and analysis of student engagement in university classes where varying levels of PBL methods of instruction are in use. *Higher Education Research & Development*, 24(1), 5-20.
- Arduino Uno (2020). Retrieved from <https://www.arduino.cc/en/Guide/ArduinoUno>
- Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A Systematic Review of Studies on Educational Robotics. *Journal of Pre-College Engineering Education Research (J-PEER)*, 9(2), Article 2. doi:10.7771/2157-9288.1223
- Arís, N.; Orcos, L. (2019). Educational Robotics in the Stage of Secondary Education: Empirical Study on Motivation and STEM Skills. *Education Sciences*, 9(2), 73. doi:10.3390/educsci9020073
- Ausubel, D., Novak, J. & Hanesian, H. (1978). *Educational Psychology: A Cognitive View*, 2nd ed. New York: Holt, Rinehart & Winston.
- Azar, A. & Şengülec, Ö. A. (2011). Computer-Assisted and Laboratory-Assisted Teaching Methods in Physics Teaching: The Effect on Student Physics Achievement and Attitude towards Physics. *International Journal of Physics & Chemistry Education*, 3(SI), 43-50.
- Barron, B. & Darling-Hammond, L. (2010). Prospects and challenges for inquiry-based approaches to learning. In H. Dumont, D. Istance & F. Benavides (Eds.), *The Nature of Learning: Using Research to Inspire Practice*, 199-225.
- Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, 58(3), 978-988. doi: 10.1016/j.compedu.2011.10.006
- Cardoso, J. M. & Zannin, M. (2019). Proposta experimental para análise das variáveis de estado dos gases com Arduino. *Revista Brasileira de Ensino de Física*, 41(4), e20190028. doi: 10.1590/1806-9126-rbef-2019-0028
- Coffman, T. (2017). Inquiry-based learning: Designing instruction to promote higher level thinking. Rowman & Littlefield, 3 ed.
- Cohen, L., Manion, L. & Morrison, K. (2011). *Research Methods in Education*. Routledge, New York, 7 ed.
- Deignan, T. (2009). Enquiry-based learning: perspectives on practice. *Teaching in Higher Education*, 14(1):13-28.
- DeWitt, J., Archer, L. & Moote, J. (2019). 15/16-Year-Old Students' Reasons for Choosing and Not Choosing Physics at a Level. *International Journal of Science and Math Education*, 17, 1071-1087. doi: 10.1007/s10763-018-9900-4
- Erinosh, S. (2013). How Do Students Perceive the Difficulty of Physics in Secondary School? An Exploratory Study in Nigeria. *International Journal for Cross-Disciplinary Subjects in Education*. 3. 1510-1515. doi: 10.20533/ijcdse.2042.6364.2013.0212.
- Fink, L. D. (2013). Creating significant learning experiences: An integrated approach to designing college courses. John Wiley & Sons.
- Flanigan, A. E. & Babchuk, W. A. (2020). Digital distraction in the classroom: exploring instructor perceptions and reactions, *Teaching in Higher Education*, doi: 10.1080/13562517.2020.1724937
- Fernandez, F. (2017). Action research in the physics classroom: the impact of authentic, inquiry based learning or instruction on the learning of thermal physics, *Asia-Pacific Science Education*, 3(1), 1-20. doi: <https://doi.org/10.1186/s41029-017-0014-z>
- Geller, B. D., Turpen, C., & Crouch, C. H. (2018). Sources of student engagement in Introductory Physics for Life Sciences. *Physical Review Physics Education Research*, 14(1), 010118.
- Grant, M. M., Tamim, S., Brown, D. B., Sweeney, J. P., Ferguson, F. K. & Jones, L. B. (2015). Teaching and Learning with Mobile Computing Devices: Case Study in K-12 Classrooms. *Tech Trends*, 59, 32-45. doi: 10.1007/s11528-015-0869-3
- Halliday, D., Resnick, R. & Walker, J. (2018). *Fundamentals of physics*. 11th ed. New York: Wiley.
- Khanlari, A. (2013). Effects of educational robots on learning STEM and on students' attitude toward STEM. In *2013 IEEE 5th Conference on Engineering Education (ICEED)*, 62-66.
- Lee, M. C., & Sulaiman, F. (2018). The Effectiveness of Practical Work in Physics to Improve Students' Academic Performances. *PEOPLE: International Journal of Social Sciences*, 3(3). Retrieved from <https://grdspublishing.org/index.php/people/article/view/1062>
- Marušić, M., & Sliško, J. (2012). Many high-school students don't want to study physics: active learning experiences can change this negative attitude!. *Revista Brasileira de Ensino de Física*, 34(3), 1-11. <https://doi.org/10.1590/S1806-11172012000300013>
- McCoy, B. R. (2016). Digital Distractions in the Classroom Phase II: Student Classroom Use of Digital Devices for Non-Class Related Purposes. *Journal of Media Education* 7(1), 5-32.
- Miller, D. P. & Nourbakhsh, I. (2016). Robotics for Education. In: Siciliano B., Khatib O. (eds) *Springer Handbook of Robotics*. Springer Handbooks. Springer, Cham.

- Mongan, S. W., Mondolang, A. H., & Poluakan, C. (2020). Misconception of weights, normal forces and Newton third law. In *Journal of Physics: Conference Series* 1572(1), 012046).
- Nikolopoulou, K. (2020). Secondary education teachers' perceptions of mobile phone and tablet use in classrooms: benefits, constraints and concerns. *Journal of Computers in Education*, 7, 257–275. doi: 10.1007/s40692-020-00156-7
- O'Bannon, B. W. & Thomas, K. M. (2015). Mobile phones in the classroom: Preservice teachers answer the call. *Computers & Education*, 85, 110-122. doi: 10.1016/j.compedu.2015.02.010
- Persada, S., Miraja, B., & Nadlifatin, R. (2019). Understanding the Generation Z Behavior on D-Learning: A Unified Theory of Acceptance and Use of Technology (UTAUT) Approach. *International Journal Of Emerging Technologies In Learning (IJET)*, 14(05), 20-33. doi:http://dx.doi.org/10.3991/ijet.v14i05.9993
- Poluakan, C., & Runtuwene, J. (2018). Students' difficulties regarding vector representations in freebody system.
- Prensky, M. (2005). What Can You Learn from a Cell Phone? Almost Anything!. *Innovate: Journal of Online Education*, 1(5).
- Schwichow, M., Zimmerman, C., Croker, S. & Härtig, H. (2016). What students learn from hands-on activities. *Journal of Research in Science Teaching*, 53(7): 980-1002. doi:10.1002/tea.21320
- Turner, A. (2015). Generation Z: Technology and Social Interest. *The Journal of Individual Psychology*, 71(2), 103-113. doi: 10.1353/jip.2015.0021
- Von Korff, J., Archibeque, B., Gomez, K. A., Heckendorf, T., McKagan, S. B., Sayre, E. C., Schenk, E. W., Shepherd, C. & Sorell, L. (2016). Secondary analysis of teaching methods in introductory physics: A 50 k-student study. *korff*, 84(12), 969-974. doi:10.1119/1.4964354
- Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*. London: Harvard University Press.
- Wongwatkit, C., Panjaburee, P., & Srisawasdi, N. (2017). A proposal to develop a guided-inquiry mobile learning with a mastery learning mechanism for improving students' learning performance and attitudes in Physics. *International Journal of Mobile Learning and Organisation*, 11(1), 63-86.
- Wilcox, B. R. & Lewandowski, H. J. (2016). Open-ended versus guided laboratory activities: Impact on students' beliefs about experimental physics. *Phys. Rev. Physics Education Research* 12(2), 020132. doi: 10.1103/PhysRevPhysEducRes.12.020132
- Zhong, B. & Xia, L. (2020). A Systematic Review on Exploring the Potential of Educational Robotics in Mathematics Education. *Int J of Science and Math Education* 18, 79–10. doi: 10.1007/s10763-018-09939-y