Spike Up Prime Interest in Physics

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Abstract. The popularity of using robotics sets in schools is likely to continue the rising trend even two decades after the outbreak started by the introduction of LEGO MINDSTORMS sets. Yet, their use outside the usual scenario of constructionist robotics hands-on activities is still very limited and rare. We are concerned with using the sets in interdisciplinary scenarios, in particular to learn about and teach physics in elementary and secondary schools. We have designed a set of ten publicly available physics experiments that can be performed with the newly released LEGO Education Spike Prime to demonstrate physics principles and phenomena in playful sessions. We describe the experiments and their preliminary testing.

Keywords: Teaching materials · Physics · Spike prime

1 Introduction

For more than 20 years, versatile construction robotics sets from LEGO Education have attracted strong attention of progressive schools and individual teachers who aim to offer the best learning experience to their pupils. Typical use-cases include hands-on activities with the goal to learn about robotics, sensors, automated control, and programming. These activities implicitly contribute to enhancing the learners' potential to catch on in the subjects of mathematics, physics and others. By creating their own representations of the observed phenomena, learners develop a substrate for making associations to real-world from the theoretical material learned in those subjects. There have also been a few explicit instances of using robotics sets in interdisciplinary scenarios *to teach physics, mathematics, or other subjects* [11–13]. Yet, this potential has not been uncovered to a satisfactory extent and its merit has not been fully recognized and understood. The presence of the robotics sets in schools is popular. Their capabilities in demonstrating scientific principles and phenomena in a creative and constructionist way remain to be discovered, constituting a relevant field of study. The motivational factor of LEGO improves the learning rate. Pupils experience immersion and flow. Carefully designed experiments allow students to gain more insight into doing science [10]. Among the reasons for slow adoption of the robotics sets in interdisciplinary scenarios are inflexible curricula and schedules in schools, insufficient hours for the respective subjects, lack of teaching materials and ideas, lack of teachers' interest, in some cases the high cost of specialized hardware, and insufficient attention of the research community to this topic.

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Treating the topic properly is a challenge. It requires a strong and active experience with the robotics sets, deep insight into subjects like physics or mathematics, the pedagogical experience, and extensive creativity. This potential is understood by LEGO Education. For instance, in their latest contribution to the robotics sets family released earlier this year, the LEGO Spike Prime, they have included a force sensor measuring forces in Newton units. In this article, we present a compact series of publicly available physics experiments that are possible and built around the Spike Prime. Each experiment contains the task description, detailed building instructions, and software to perform the experiment, but they are open-ended with the aim of further experimentation. We provide pictures and videos from our realization of the experiments as well. Teachers and students are welcome to modify them and explore further. Our ideas originate from previous studies [1, 14], where we were involved, several tasks that we have designed for the Robot League competition [15], the long-term cooperation with the Department of Didactics in Mathematics, Physics and Informatics at our faculty, the textbooks on Physics for primary and secondary schools in Slovakia [2, 3], and our own ideas. In this article, we also show some examples of these inspirations. In the following sections, we will make a short overview of recognized hardware/software kits for making scientific physics experiments in schools, mention the related work on using robotics sets for teaching physics, introduce our set of experiments, provide feedback from our tests with pupils, and conclude with remarks for future developments.

2 Hardware Solutions for Teaching Physics

Preparing a comprehensive set of hardware tools for physics experiments usually leads to a long run project. It takes great efforts to find and develop reliable and durable good quality parts and equipment and to prepare a mature software environment with the ground educational principles of low floor and high ceiling. Several of such systems are used in schools. Only small set of schools can afford them and thus there are some interesting alternatives for those that can't [5]. The increased availability of smartphones opens to further promising applications [6]. These systems typically contain set of sensors, an external unified interface unit that connects to a computer and a software for collecting, visualizing and reporting the results, often including some advanced experiment automation and control including scripting. Some of them have also designed interfaces for connecting with LEGO Education sets. An obvious obstacle is that the commercial systems (including LEGO Education) tend to be more or less closed systems, prohibiting easier integration and interoperability of the equipment. The lack of being open is still an issue, while the developers seem to at least have overcome the platform compatibility and portability partially (Windows, Mac, Android).

2.1 IP-Coach (CMA)

Originally developed at the University of Amsterdam in the 80s, CMA Coach is still in development, reaching version 7, claiming to be "the most versatile and complete software for STEM Education" providing interfaces suitable from primary to college level. Available in various scale – including some that are recommended for student work at home. The system is student-centered and designed with the true scientific spirit. Among the features are storing sensor calibration, using video camera in experimentation, modelling and comparing the model prediction with the measured data, interactive animations.

2.2 LogIT

DCP Microdevelopments, a UK based company provides science education sensor equipment: tens of different sensors, several types of data loggers, and software for data logging branded under the LogIT name. For our case, it is important that there is a logIT LEGO Mindstorms adapter bringing the two worlds together. Furthermore, LogIT website comes with tens of experiments in Physics that can be realized with the equipment (or otherwise) at primary and secondary levels [7, 8]. This is a useful resource for everyone operating in our field.

2.3 Pasco

Probably the major overseas competitor for the CMA Coach is Pasco. Schools in Slovakia usually do not have the options to purchase Pasco equipment, except of some individual projects. Some talented teachers show examples of inspiring projects [9]. Pasco set and products include teacher guides.

2.4 Vernier

Another strong player with a full selection of sensors, interfaces, loggers, software, scientific lab equipment offering educator trainings is Vernier. In our context worth mentioning is the LEGO Mindstorms interface that makes the tens of various sensor accessible in the projects using the popular robotics sets.

3 Related Work

Barbara Bratzel is known for her series of books on teaching physics using LEGO Mindstorms [11, 13]. Several experiments are described also in a short paper [12]. LEGO Education has been running its LEGO Education Academy training programs for teachers. The specialized LEGO sets with the focus on Physics, namely Simple & Powered Machines (9686), Pneumatics Set (9641), Renewable Energy (9688), Simple Machines (9689), Early Simple Machines (9656) are all accompanied with building instructions for several exploratory projects. These sets are very specialized and significantly smaller number of schools or households are the proud owners of those as compared to the general robotics sets, which gain larger popularity. We still see an advantage in harnessing their potential. Even though they are a wonderful example how LEGO can be used to demonstrate physics principles using hands-on activities, they contain only limited options for experiment automation, control, and scripting.

4 LEGO Education Spike Prime

As contrasted to the renowned EV3 sets, the new universal construction set is designed to be easy to use and simple yet strong and powerful. It contains a programmable module (LEGO® Technic™ Large Hub for SPIKE™ Prime) with 6 input/output ports using LEGO Power Functions 2.0 type connectors, same as those used in WEDO 2.0, BOOST, and LEGO Trains. It has a built-in Bluetooth, Gyro, and simple square matrix LED display, three push buttons and micro-USB connector for program download and charging – again an improvement over EV3. A surprising limitation is the inability to collect measured data and transfer them to a computer for further processing and visualization. The only exception being lists, but in the current version of the software, it is not possible to export the lists. As we will show, we have overcome this constraint. Yet, their maximum length is somewhat limited.

5 Physics Experiments with Spike Prime

We will introduce all 10 experiments in selected topics of physics we have designed. For each, we describe its inspiration or motivation, the concept, the activity in the experiment, and ideas for further experimentation and modifications. Some are shown in full detail, however, the details of all of them including Studio models, rendered images, pictures, videos, complete building instructions to download or to view, programs to download or to view, all is available at the project website [4], which serves as the resource for teachers and students.

5.1 Measuring Speed

The task is to build a device for detecting crossing a speed limit through measuring with ultrasonic sensor. An object (for instance a car) is moving towards the device and the device uses its ultrasonic sensor to measure the time needed by the vehicle to cross a certain distance. Several measurements are averaged and can be compared to the speed limit value. The measuring device indicates the result to the driver. A similar task occurred in the Robot League [15] two years ago, see Fig. 1 for an example solution.

In this exercise, the pupils first build the vehicle and sensor module according to the instructions, then experiment – the times, calculated speeds, and an average of the velocities – which is an estimate of the average speed, not so proper one, as they learn in the second exercise (Figs. 2, 3, 4 and 5). Speed is shown on the screen, see Fig. 6. The suggested modifications and exploration include measuring the actual maximum speed instead of averaging several measurements, exploring different positions of mounting the sensor wrt. measurable distances and modifying the vehicle by attaching motors to make it move on its own.

Students work in pairs or small groups. Measuring speed is not that simple as it looks like, as it depends on many different conditions – the way the vehicle is started, in which direction, shape of the robot, or the wall, and the results will not always show the expected values. The students perform the experiments and discuss in their groups, record videos or take pictures. Finally, they make a short presentation to others.

Fig. 1. Measuring speed with ultrasonic sensor, from Robot League 8/2018, team Šachisti.

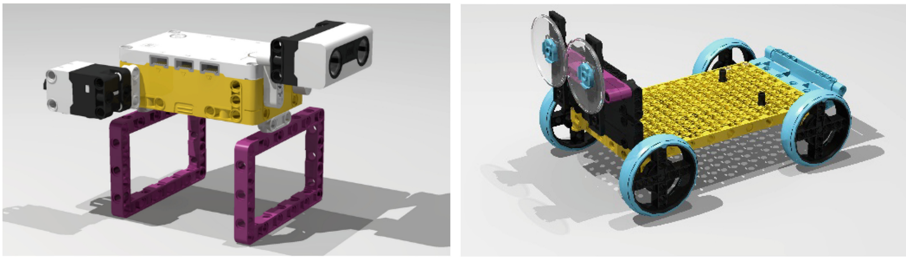

Fig. 2. 3D models prepared in Stud.io 2.0 of both parts.

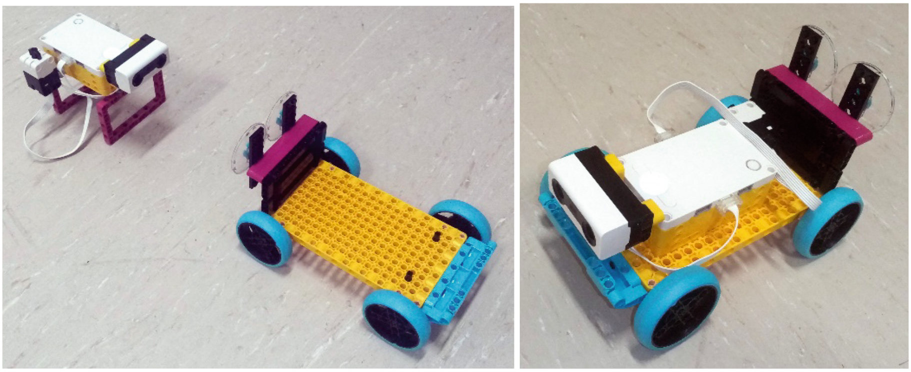

Fig. 3. Models built of Spike Prime, vehicle moving towards sensor module (left), vehicle with sensor module on-board moving towards a wall (right).

5.2 Average Speed

As the pupils learn in this exercise, the average velocity is not the average of the velocities – even when the travelled distances are the same. The task is inspired by an experiment suggested by a teacher from the elementary school of our robot club who has originally prepared it with NXT robots [1] (Fig. 7).

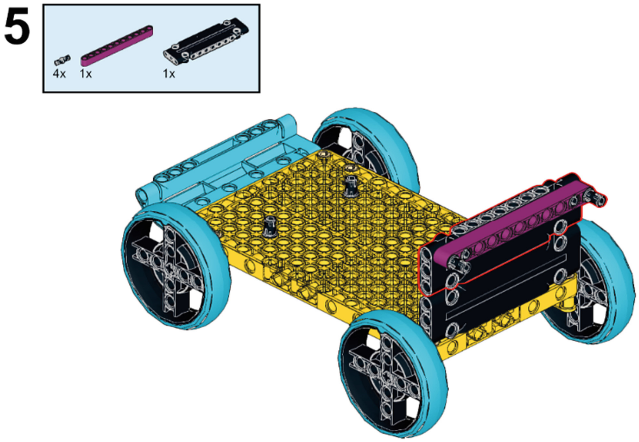

Fig. 4. One example step from building instructions.

In our experiment, a motor-powered vehicle is moving forward with a constant velocity 30% between cities A and B and continues with a constant velocity 70% from B to C, where it stops. Then it calculates velocities for both segments based on the known distances (100 cm each) and the measured times. Finally, it displays the average of the two velocities as well as the proper average velocity of the complete trip. Pupils can modify the program to use different velocities or change it so that it will calculate the velocity even when the segments have a different length, measuring it with rotation sensor (Fig. 8).

5.3 Rotational Inertia

This is an exercise, where pupils will discover that the time a free rotation of an object lasts does not depend only on its weight. The model is capable of setting an object into rotation with a low friction, and it uses a color sensor for measuring the time until the rotation stops. By using objects of the same weight, but with a different rotational inertia momentum, the students notice and observe the influence of the mass distribution in the rotating object on the kinetic energy it can absorb.

5.4 Center of Gravity

In this more practical hands-on exercise, there is no need for programming, but pupils will learn about the concept of center of gravity that is required for successfully completing modifications in the next exercise. Pupils are encouraged to try attaching also different objects so that the center of gravity will change. Try to estimate its position by guessing first, then verify the guess by a measurement. The center position is estimated as an intersection of two vertical lines passing through different points, Fig. 9.

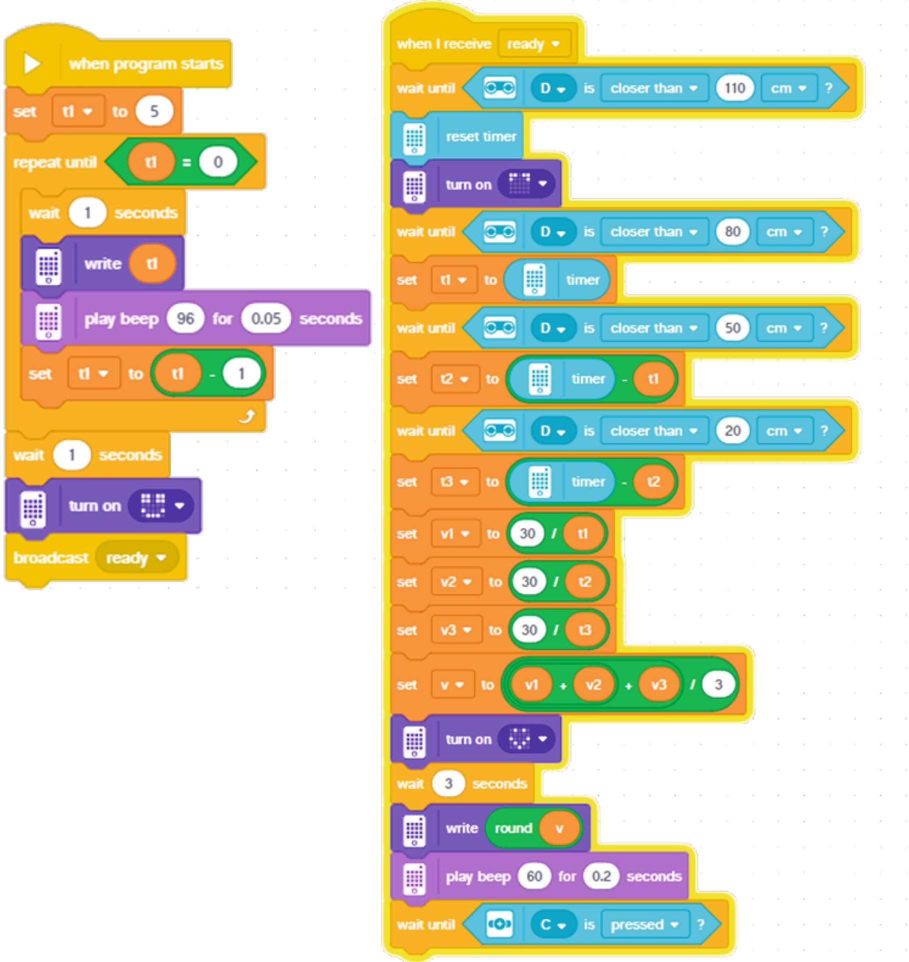

Fig. 5. Program for performing measurements that the students download to the hub.

5.5 Scales

This exercise is inspired by a task in Robot League, which itself was inspired by a beautiful model of scales in FLL 2014 (Fig. 10).

In this exercise, pupils build a model of scales for measuring the weight. The object will be hung at the end of the scale's arm, and the gravity will compete with the gravity of the hub and the arm. Both competing parts try to pull the arm their way, but since the centers of gravity and the fixed point of center of rotation are not on the same line, for each given weight, there is a unique equilibrium location, when the forces are in balance. By reading the hub's gyro sensor the hub can backwards-calculate the mass of the object at the tip of the arm. After estimating the center of gravity using the method from the previous exercise, we were able to tune a precision of about 2 g (comparable to those of a typical electronic kitchen scales).

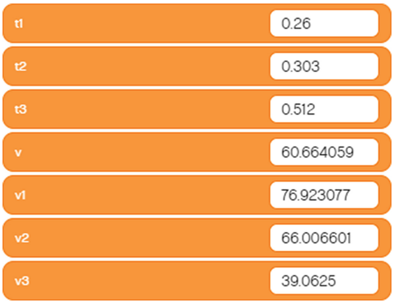

Fig. 6. Example of measured result.

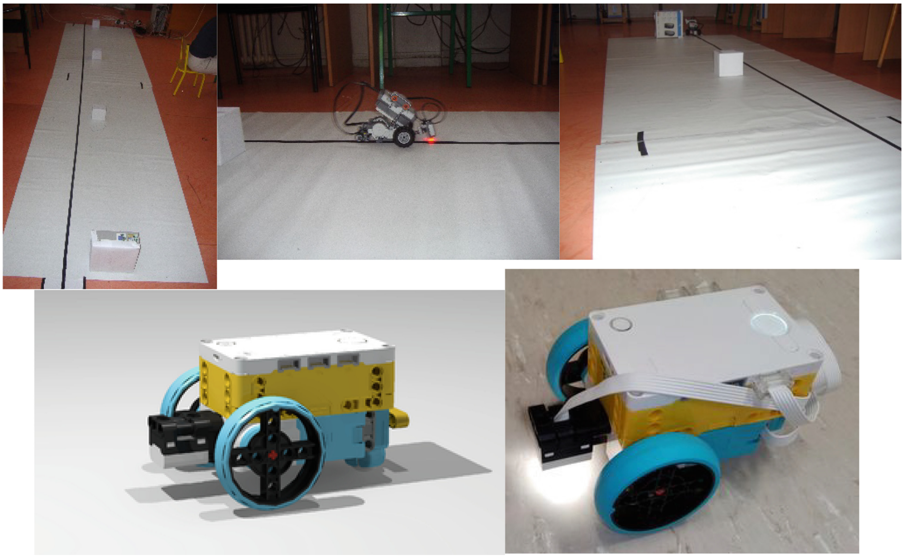

Fig. 7. Measuring average speed on trajectory with several segments with varying speed, top: original idea [7], bottom: our Spike Prime version – easy to build and measure.

5.6 Mechanical Lever

Pupils will discover how the simplest mechanism for amplifying or diminishing force works and how the force can be amplified or diminished. The model contains a force sensor, that will measure the force applied to it. In the experiment, pupils attach objects of different weight at the end of the free long arm of the mechanical lever, and observe the force reported by the sensor. Pupils are encouraged to notice what makes the lever strong and stable so that it can hold even some heavy objects and how the force is transmitted from the lever to the sensor (Figs. 11 and 12).

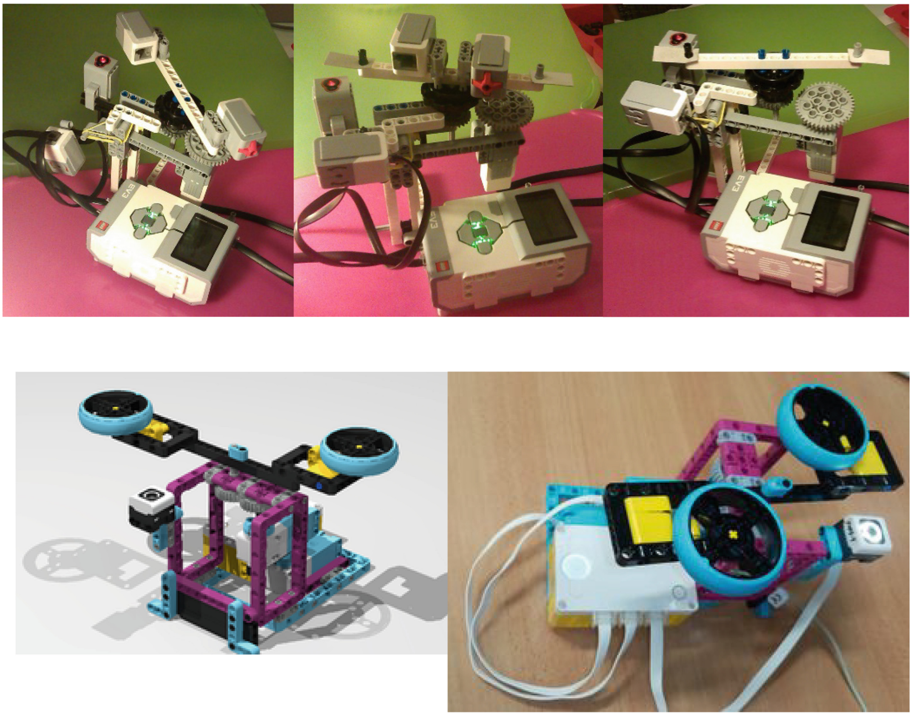

Fig. 8. Measuring momentum of inertia for three different weight distributions, top: our original version from [9], our Spike Prime version, which is improved.

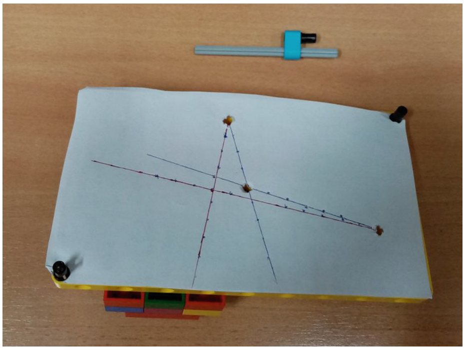

Fig. 9. Finding the center of gravity of an object with modifiable mass distribution.

5.7 Pulleys for Lifting Weights

In this project, the students discover a very useful pulleys mechanisms that allows lifting objects that are too heavy. Here, we use the possibility to control not only the motor speed but also its raw power. In this way with the help of the rotation sensor, we slowly

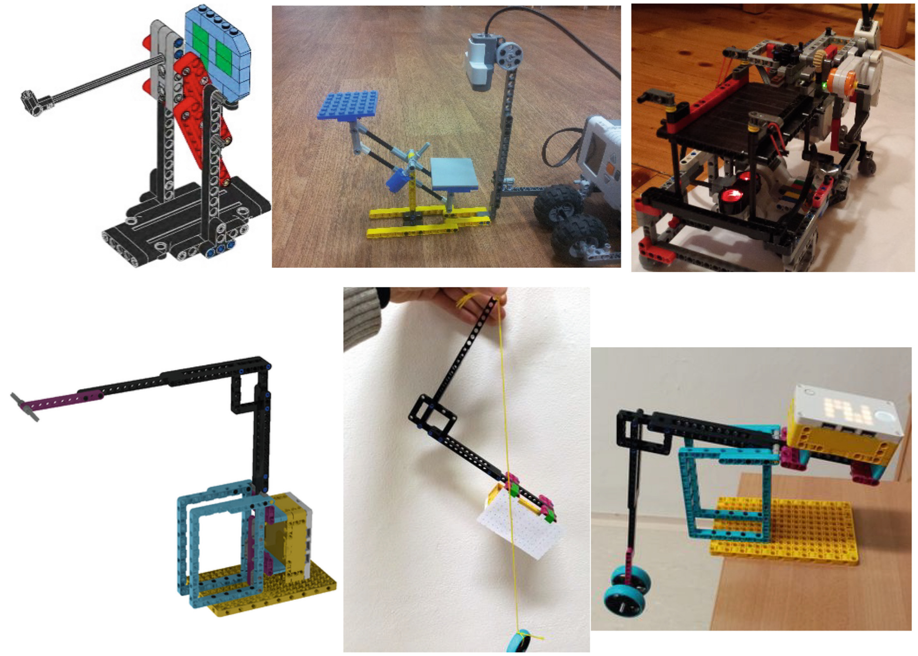

Fig. 10. Mechanical scales from FLL 2014, and two solutions of scales from Robot League 3/2015 (top), and our scales design for Spike Prime.

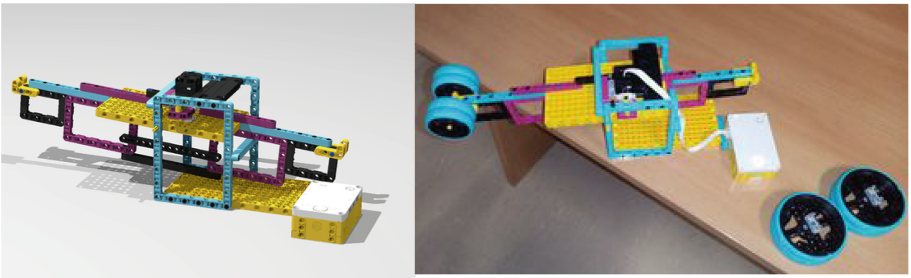

Fig. 11. Mechanical lever model, virtual and real. The reinforcements help to avoid bending of the lever even for more heavy objects.

accelerate the motor until the power is sufficient to lift the object of varying weight. This power is reported on the hub display.

5.8 Mathematical Pendulum

In this exercise, the pupils discover by experimentation the relation between the various parameters of the pendulum and the resulting behavior (Fig. 13).

Namely, they modify the weight, the length, and the starting position of the pendulum and observe the amplitude and the period of the oscillations. We have designed a tool

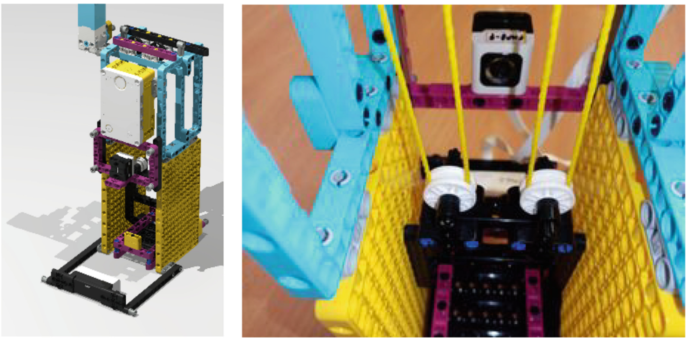

Fig. 12. A pulley mechanism with three alternate pulley configurations.

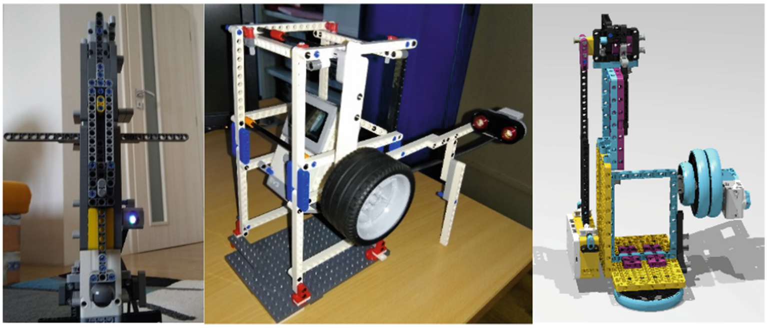

Fig. 13. Mathematical pendulum as constructed by teams BoscoBoti (left) and Jakubovskí Roboti (center), Robot League 3/2019 and our Spike Prime pendulum (right).

that allows exporting the data from the Spike Prime project (the measured gyro angle) and importing them into Excel for visualizing the data in the chart. In our realization of the experiment, the chart shows the expected behavior beautifully – the resulting period depends only on the arm length, see Fig. 14.

5.9 Static Wave Generator

When using a rope (string) that is tight to a flexible end, it is possible to tune the base frequency or higher harmonic frequencies, measure the speed of the wave travel in the rope and tune the frequencies for different number of nodes in a static wave. The pulses to the rope are generated by an oscillating mechanism (Figs. 15 and 16).

5.10 Centrifugal Force

A moving body would continue in a straight motion unless we apply a force. If it is bound by a string, or some other way it will move along a circular trajectory, but it will pull the string with a centrifugal force. How large is this force? Pupils measure the force using the force sensor in this exercise and visualize the results in chart again (Fig. 17).

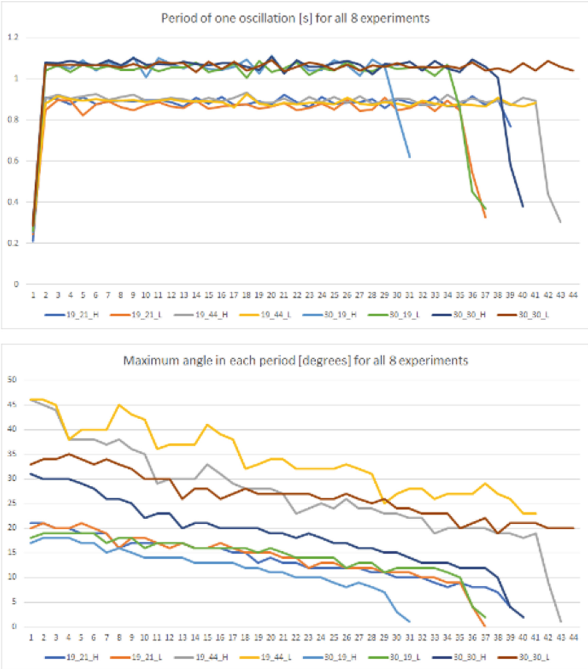

Fig. 14. Visualization of the oscillations: period depends only on the pendulum length (top) and remains constant while the pendulum moves; max amplitude decreases over time (bottom).

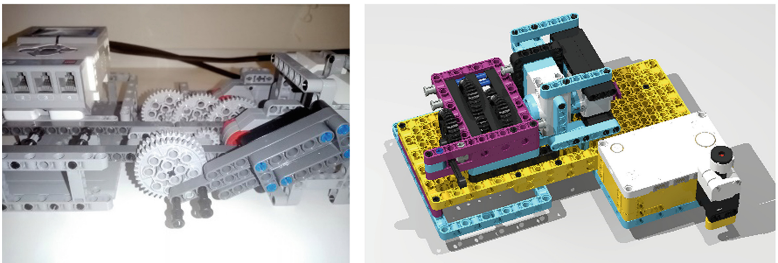

Fig. 15. Static wave generator, team Šachisti, RL 1/2020 (left), Spike Prime model (right).

6 Preliminary Testing

We have tested some of the experiments in the elementary school robot club. We have found that the children felt very comfortable using the building instructions, and had fun building the models. They were also confidently downloading and running the programs for the experiments. In the case of the scales experiment, we have discovered a small discrepancy in the scales model resulting in different measured values, but we have corrected the model based on this experience. We have shared the materials with the teachers who follow the LEGO Education resources in our country and we are currently

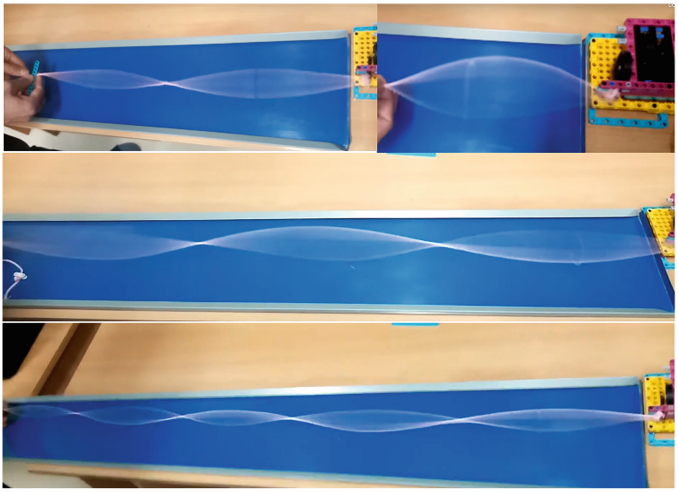

Fig. 16. Static wave generator, examples of produced static undulation.

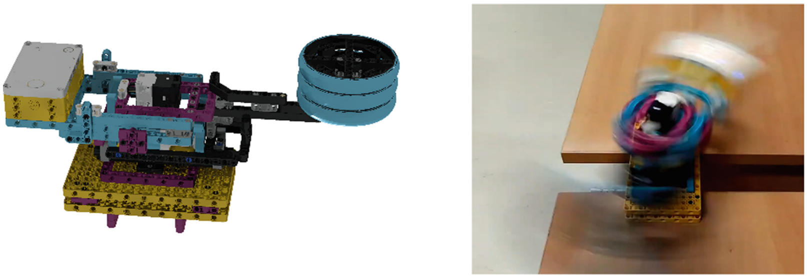

Fig. 17. Centrifugal force model and its operation.

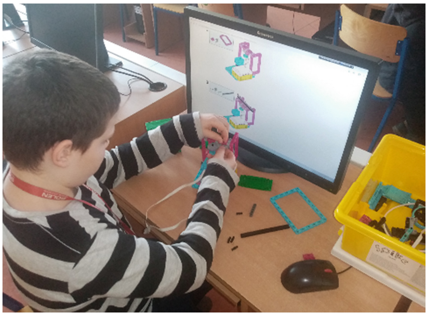

Fig. 18. Evaluation in the robot club.

performing further testing and evaluation including the Spike Prime on-line community (Fig. 18).

7 Conclusions and Future Work

In this paper, we present an approach to teaching and learning Physics that is based on the constructionist principles, aiming to result in faster learning curve due to robotics sets working as a catalyst for children motivation and by giving them real-world experiences that they can connect with the theoretical knowledge covered in their school Physics subject. We propose to achieve this by providing a set of 10 open-ended experiments with complete building instructions for the models, programs for performing the experiments, as well as media supplementary material – such as pictures and videos of our realizations. All projects contain ideas for further experimentation, modifications, measurements. Instead of providing the answers, they are rising questions. Pupils work in groups and present their results to the group to discuss the challenges and obstacles they resolved. We believe this to be an example of constructionist learning. The primary target and purpose of the LEGO robotics sets as educational tools. Our plans are to further validate our approach with more experiments in the classroom and if successful, extend the set of activities further by a degree of magnitude. To make the Spike Prime set compatible with our goals, we have designed special scripts that allow extracting the measured data from the project for the purpose of further processing and visualization. These scripts can be useful for the community. All media and files are available online as public domain at [4].

References

1. Lehocká, D.: Didaktické materiály k téme robotické stavebnice a Imagine Logo. Final report of DVÚI. Štátny pedagogický ústav Bratislava (2010)
2. Demkanin, P., et al.: Fyzika pre 2. ročník gymnázia a 6. ročník gymnázia s osemročným štúdiom. Združenie Educo (2010)
3. Demkanin, P., Horváthová, M.: Fyzika pre 3. ročník gymnázia a 7. ročník gymnázia s osemročným štúdiom. Združenie Educo (2012)
4. Petrovic, P.: Spike up Prime Interest in Physics – portal with instructions for students and teachers. robotika.sk/spike/
5. Kodejška, Č., De Nunzio, G., Kubínek, R., Říha, J.: Low cost alternatives to commercial lab kits for physics experiments. Phys. Educ. 50(5), 597 (2015)
6. González, M.A., et al.: Doing physics experiments and learning with smartphones. In: Proceedings of the 3rd International Conference on Technological Ecosystems for Enhancing Multiculturality, Porto (2015)
7. LogIT World: Secondary Teaching Resources. www.logitworld.com/index.php/secondary-higher/teaching-resources
8. LogIT World: Primary Teaching Resources. www.logitworld.com/index.php/primary-junior/primary-teaching-resources
9. Krejčová, J.: Dovnútra automobilu. Tvorivý učiteľ fyziky VIII, Smolenice (2015)
10. Round, J., Lom, B.: In situ teaching: fusing labs & lectures in undergraduate science courses to enhance immersion in scientific research. J Undergrad Neurosci Educ. Summer 13(3), A206–A214 (2015)
11. Bratzel, B., Rogers, C.: STEM by Design: Teaching with LEGO Mindstorms EV3. College House Enterprises, LLC (2016)

12. Church, W., Ford, T., Perova, N., Rogers, C.: Physics with robotics using LEGO® MINDSTORMS® in high school education. In: AAAI Spring Symposium: Educational Robotics and Beyond (2010)
13. Bratzel, B.: Physics by Design with NXT Mindstorms. College House Enterprises (2009)
14. Petrovic, P.: Robotický manuál. Deliverable of stage KA01 in EU-funded project "Od studenta k vědci" (CZ.1.07/1.1.16/02.0111) Jihomoravské centrum pro mezinárodní mobilitu. Brno (2015)
15. Balogh, R., Petrovič, P.: Robot League – A Unique On-Line Robotics Competition. In: Merdan, M., Lepuschitz, W., Koppensteiner, G., Balogh, R., Obdržálek, D. (eds.) RiE 2019. AISC, vol. 1023, pp. 344–355. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-26945-6_31