Omnidirectional Robot Construction at the Math Class

Kristóf Fenyvesi (*)
Dept. of Music, Art and Culture Studies
University of Jyväskylä
Experience Workshop Math-Art Movement
fenyvesi.kristof@gmail.com

Ákos Vecsei
REBOT, Hungary
Experience Workshop Math-Art Movement
avecsei65@gmail.com

Diego Lieban
IFRS - Campus Bento Gonçalves, Brazil
diegolieban@yahoo.es

Zsolt Lavicza
STEM Center
Johannes Kepler University, Linz
Experience Workshop Math-Art Movement
lavicza@googlemail.com

Hogul Park
4Dframe Inc., Korea
parkhogul2@gmail.com

Gábor Vecsei
REBOT, Hungary & Budapest University of Technology and Economics

Abstract

The goal for this workshop is to expose participants to an example of the Experience Workshop Math-Art Movement's implementation of robot-design and construction in the mathematics classroom. While participants experiment with solving the problem of how to build an omnidirectional robot—a vehicle capable of driving in any direction in a 2D plane—several physical phenomena and properties can be discovered through geometrical measurements and mathematical calculations. After the mechanical problems have been resolved, the participating students can develop individual character to their robots by improving the aesthetics of their design, while also considering practical and technological questions. The workshop combines hands-on learning with digital modeling, an approach based on combining a Hungarian ReBOT Kit with the Korean 4Dframe as well as GeoGebra dynamic geometry software. The workshop is suitable for students above the age of 12 years. Students work in teams to develop their collaborative problem solving skills.

Introduction: Omnidirectional Robots in Real Life and in Education

Implementing robotics in education is a fast growing field, which is among the prioritized areas of STEM and STEAM movement. Several studies suggest that robots increases motivation, engagement and attitude towards learning, just as designing, constructing and programming robots can develop creative thinking, and can improve problem-solving skills. [1] Physics and mathematics plays the major role in these projects and many of these subjects' topics can be explored through robotics. [2] Experience Workshop Math-Art Movement [3] offers a great variety of robotics workshops for several age groups from early childhood education to programs for university students. The Arduino-based, Hungarian ReBOT Kit—available to make robots from simple, recycled cardboard materials, such as milk boxes—, the Korean 4Dframe, BBC micro:bit as well as the GeoGebra dynamic geometry software are often used in our events. We present a combination of ReBOT with 4Dframe and GeoGebra in this paper, focusing on the topic of omnidirectional robots.

Omnidirectional robots can maneuver in environments containing various obstacles or narrow corridors. Such environments are commonly found in factories, warehouses, office-buildings, hospitals, etc. Due to their unique mobility, omnidirectional robots are mainly utilized in various fields for the purposes of transportation, surveillance, and inspection tasks. Another emerging market for this type of devices is as mobile entertainment robots. [4] Although omnidirectional robots mostly come into the fore in the context of "robot soccer" [5], omnidirectional robot design in education can also be completed with additional aesthetic considerations. Working on aesthetical aspects can further develop creative problem-solving skills and support students' authorship through the experience, that they are "doing their own" applied mathematics and science.

Conducting the Workshop

Phase 1: Initial discussion. In the beginning of the workshop, a building containing corridors the width of one unit is first visualized. A robot—also one unit wide—has to be capable of moving through this building's corridors. In this particular case, the robot would not be able to turn using the usual mechanism: another method has to be found. Through discussion, workshop participants are to realize that the robot must be able to move forward, backward, right, or left without turning its body. For this to be possible, wheels must be designed to produce sufficient thrust in a direction parallel as well as perpendicular to the robot's longitudinal axis.

The workshop follows with a discussion concerning the mathematical concepts describing wheels in motion. Throughout this discussion, participants are to consider the properties inherent to real, physical objects, the ways in which abstract mathematical concepts can be mapped before being used to perform mathematical operations, the achieved results and how the outcome can be once more understood in relation to real, physical properties.

Based on this information, the discussion will focus on unit visualization (e.g. what is one unit wide?), then on how—from a mathematical perspective—the wheel is a circle, the center of which represents the axle while the radius shows how high the car's axle is in relation to the road. The circle's arc, on the other hand, corresponds to the wheel's rim. Once this has been established, it is time to examine how certain properties of a circle affect the vehicle's motion.

Phase 2: Modelling and Experimenting with GeoGeobra. The vehicle, for example, moves forward when its wheels revolve around their axles, meaning that a different point on the wheels' rims will hit the road's surface throughout moments in time. In other words, this type of motion can be interpreted as movement around a circle's circumference. Due to the fact that a circle is mathematically defined as a set of points equidistant from the center, while the wheels turn their axles constantly remain at the same distance from the road. Since this also represents the circle's arc, the vehicle will not jolt as it moves forward along a flat road (Figure 1).

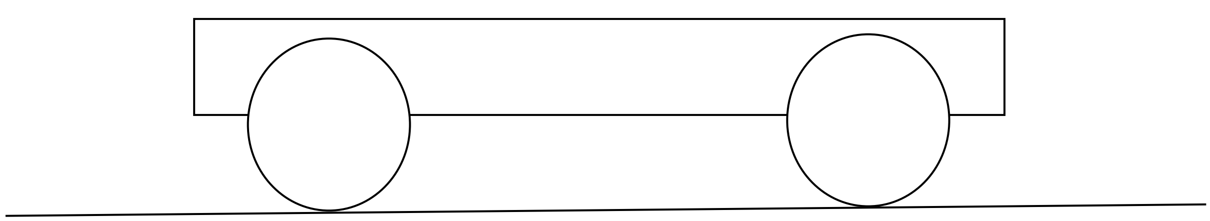


Figure 1: *The wheels of the vehicle on a flat road.*

Next, it must be examined how the wheels—possessing certain properties inherent to the circle—affect the vehicle's motion. At this point, concepts related to physics have to be introduced, such as (s) the distance covered, i.e., the distance completed by the vehicle. The vehicle's speed (v) represents the distance covered during a unit of time, while (n) symbolizes the revolutions completed by a wheel, i.e., the number of turns completed within a unit of time.

Connections can be made between these given concepts and examined by animations and interactive applications in GeoGebra. GeoGebra, as one of the most popular dynamic mathematics learning technology, support a model-centered approach in mathematics education, which can be greatly employed at this workshop. Sense making and the enrichment of the discussion among the participants. [6]

During one unit of time (t) the vehicle completes (s) distance; its speed can therefore be shown as v=s/t. The distance (s) covered by the vehicle can be defined once it has been calculated according to how many times the wheels revolve within a given time (t), multiplied by the wheel's circumference (C): s=n*C, in which the circumference is known based on the circle's arc (r), i.e., C= 2*r*Pi. The final formula for the distance completed by the vehicle within a given amount of time is therefore the following: s=n*2*r*Pi.

By analyzing this formula we can reach certain conclusions concerning the vehicle's motion. If the number of revolutions performed by the wheel is constant, then a vehicle possessing larger wheels (i.e., a circle with bigger radii) will complete a greater distance within a unit of time, due to the fact that the completed distance is proportionately equal to the number of revolutions. Given that the same wheel size is used, the completed distance will be proportionately equal to the number of revolutions. In either case the vehicle's speed will increase in equal proportion to the completed distance. If we would like the vehicle to go faster, then either larger wheels or wheels that revolve faster will be necessary. These concepts borrowed from both mathematics and physics can be demonstrated using GeoGebra.

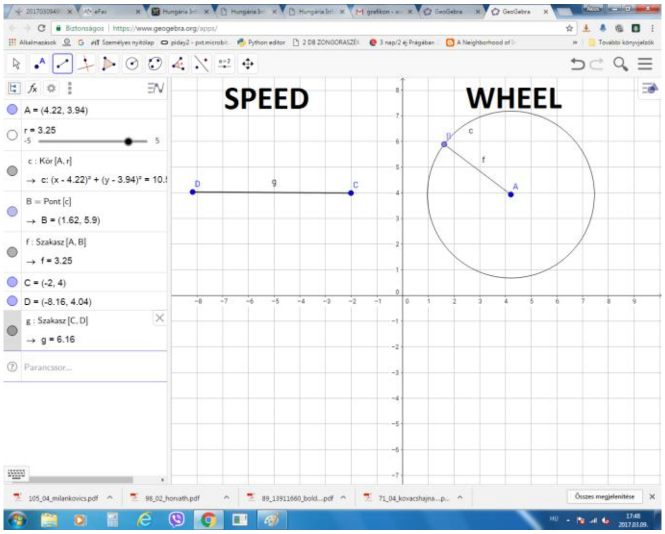


Figure 2: *The relationship between the vehicle's wheel and its motion in GeoGebra.*

After an analysis of the relationship between a vehicle's wheel and its motion has been made, workshop participants are to be familiarized with the concept of force as well as its representation in physics, the vector. Since the force acting on the vehicle possesses not only magnitude, but also direction, this is shown using the vector. A vector is a line the direction of which indicates the direction of the force acting on the vehicle, while its length represents the force's magnitude. These relationships can then be shown and tried in GeoGebra (Figure 2).

It must not be forgotten, however, that a vehicle has four wheels, not just one. This means that the vehicle's motion results from the sum total of the thrust acting on all the wheels. At this point it is necessary to introduce the concept of adding all the vectors for each involved force, a process that can be initially demonstrated through the following experiment: multiple cords are tied to a cuboid, then pulled apart at different angles while observing which direction the cuboid moves. These observations can be first be observed on a physical model, then participants can study the concept of adding vectors in GeoGebra (Figure 3).

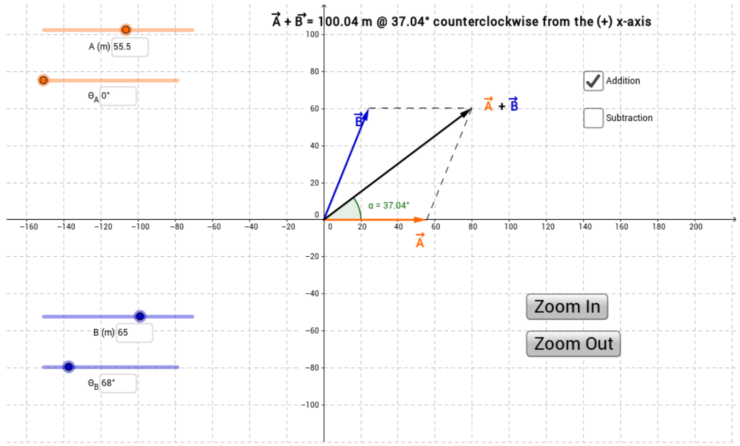


Figure 3: *Modeling vectors in GeoGebra.*

By using this principle, we raise the possibility that each force acting on a body can be broken down into components of various forces, the sum of which adds up to the resultant force acting on the given body. A special case of this separation is when two forces perpendicular to one another are broken down into the thrust acting on the wheel currently under discussion (Figure 4).

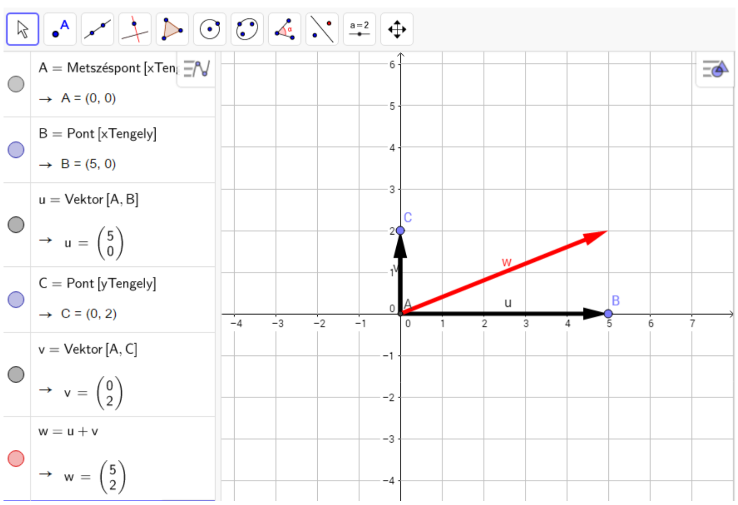


Figure 4: *A special case.*

Following experimentation, participants will come to understand that the resultant force created by the thrust acting on all four wheels is what allows the vehicle to move at a speed equal to the force's magnitude and in the direction indicated by the vector representing the original force.

In traditional vehicles the wheels are placed parallel to one another; this is why the direction of thrust for the sum total of their produced thrust is also parallel to the wheels. In other words, the vehicle can only move in a direction parallel to its wheels.

If, however, we would like the vehicle to move in every direction, then the wheels must be placed so as to allow for thrust that can be produced with components that are both parallel and perpendicular to the vehicle's direction (Figure 5).

By utilizing GeoGebra to demonstrate various means of altering the direction for the wheels to turn, participants can discuss what resultant force will act upon the vehicle and how this influences the direction in which the vehicle will move (Figure 6).

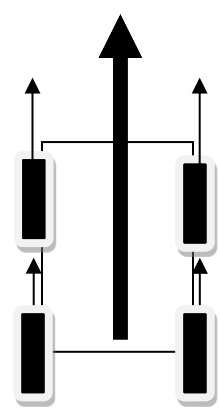
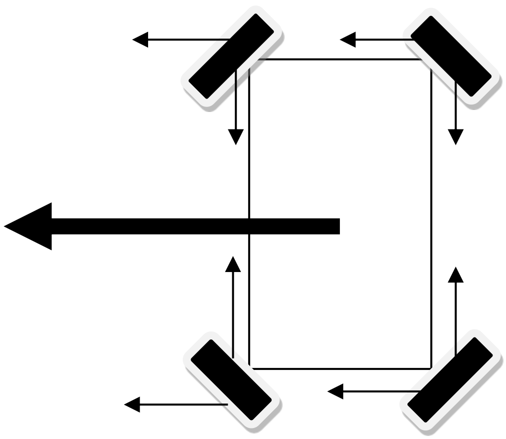


Figure 5: *Normal direction of wheels.*

GeoGebra can also be applied to analyze similar cases in which participants can experience how changing the speed of the wheels' revolution or the direction of the turn will affect the magnitude and direction of the resultant force acting upon the vehicle.



Phase 4: Let's Roll! At this point the time has arrived to put our theoretical hypotheses to practice! Now the 4DFrame and the REBOT building kit can be brought out. Participants are divided into 4-members small groups. Depending on their level of interest, the small groups can be further divided into two parts, with one or two students preparing a vehicle using the 4DFrame building kit, while the other becomes acquainted with using the mobile application found in the REBOT kit.

Figure 6: *Positioning the wheel for our omnidirectional vehicle.*

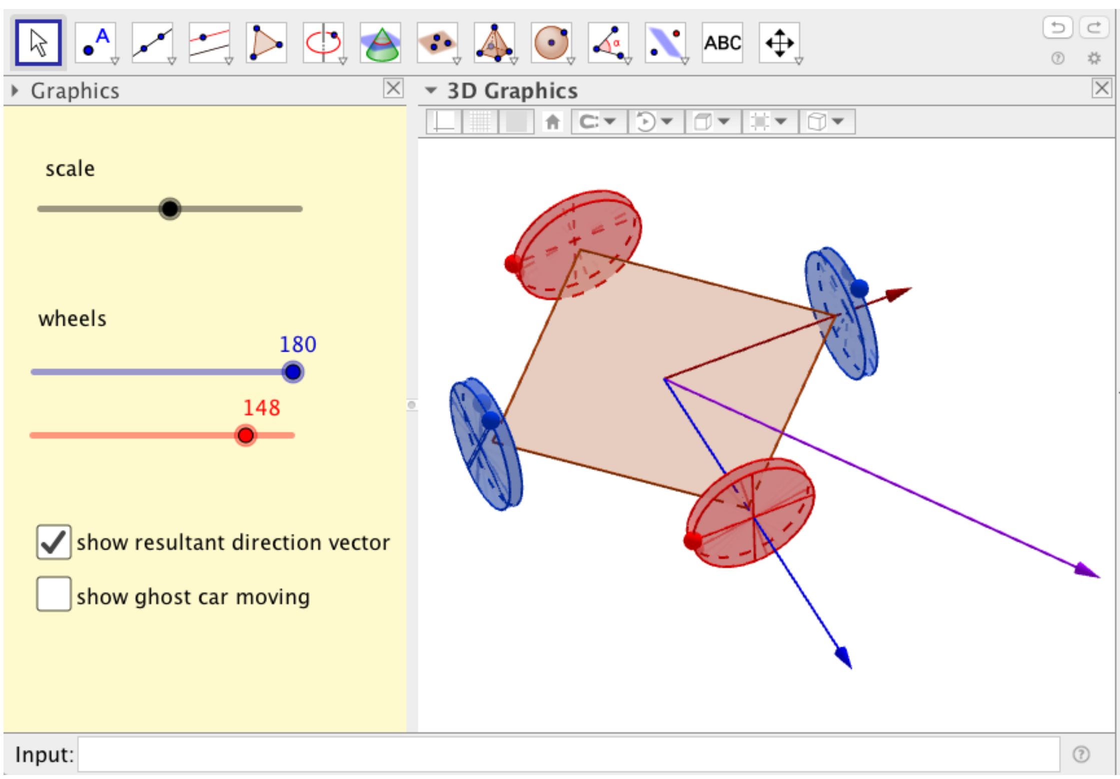


Figure 7: *Screenshot from the GeoGebra omniwheel simulation application. Available at: https://www.geogebra.org/m/bAxksK2t*

Construction of the vehicle can be done in two stages (Figure 8). First of all, the vehicle's rectangular body needs to be completed. Secondly, the four wheels can be constructed according to a special design reflecting their function. Since these wheels can move not only parallel to their plane, but also at an arbitrary angle, rollers will be placed at their rims to allow the wheels to turn perpendicularly to their plane. This type of wheel is called a simple, universal wheel, or an omniwheel [2].

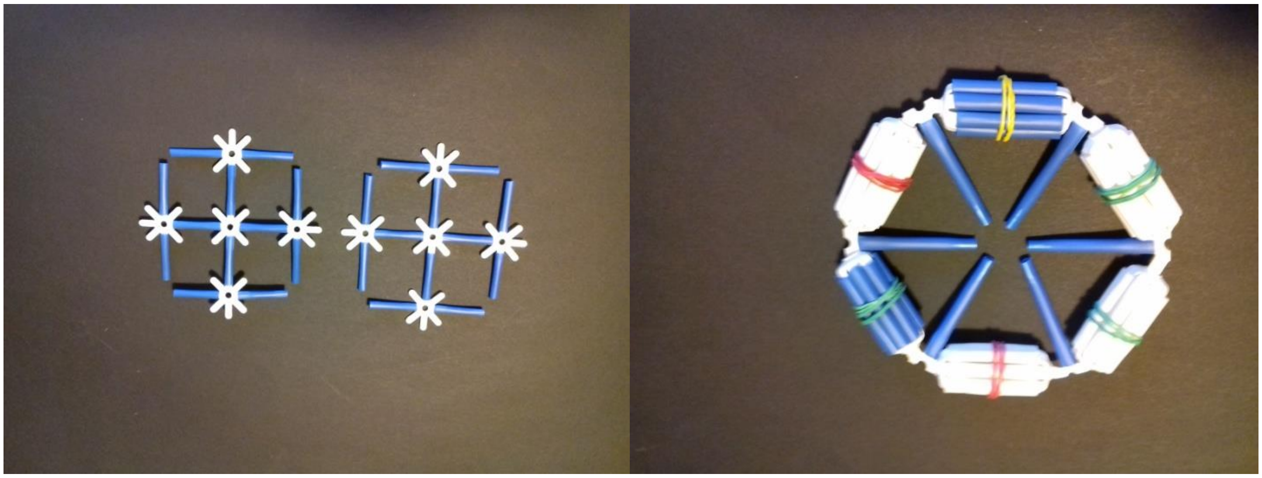


Figure 8: *Construction of the vehicle in two easy steps.*

After the vehicle's parts have been assembled, the controller found in the REBOT kit must be placed on its body, along with the battery used to provide a power source. The motors contained in the REBOT kit are to be attached to the wheels' axles, thereby propelling the vehicle in the given direction (Figure 9).

Figure 9: *Completing the construction.*

While the first group completes construction, the second can practice using the mobile application needed to direct the vehicle and included in the REBOTKit. This application allows workshop participants to use a mobile phone in order to control the vehicle's wheels via a cordless, bluetooth connection. With this application, participants can configure the speed for the motors turning each wheel as well as adjust their direction. This setting can then be altered using the direction buttons seen on the screen.

After the settings for every direction have been established, the fun can begin as the participants test how the vehicle they constructed and programmed can move in all four directions.

Phase 5: Aesthetics Design. The fusion of 4Dframe and REBOT Kit gives an opportunity for the designers to the combination of the geometric structure with different modules. The aesthetic design of the 4Dframe basis can be extended with a simple sheet of paper, or with a cardboard body and a little flag to follow the tweenbot "tradition", or with recycled materials according to the REBOT system. The modules made of paper, cardboard or recycled materials, such as the milk, candy or yoghurt box can be further decorated during the process. The variability of the structure supports the development of the creative, artistic skills by coloring, cutting, gluing the recycled modules. Based on the many advantages of 4Dframe, the functioning omniwheel can be done simply, in a short time and then the participants have time to think and work on the aesthetic design to give a unique character to their robots (Figure 10).

Figure 10: *Designing an individual character to the omnibot.*

Phase 6: Further Directions. If more than one omnidirectional robot is created during the workshop, students can extend the artistic problem solving part of their project by e.g. choreographing a dance performance for the robots they have created by coordinating their movements by coding, remote controlling them or adding path following features to their constructions. To enrich further the workshop program's mathematical connections, a choreography for a robot-dance can be based on a system of lines, which forms a geometrical pattern on a plane.

Conclusion

The above described program from Phase 1 to Phase 5 can be realized in 2 consecutive mathematics classes of 45 minutes. As an introduction, participants can freely experiment with 4Dframe and familiarize with the ReBOT kit and GeoGebra. Introducing with GeoGebra the theoretical basis and differences between moving on wheels and moving on omniwheels can take about 20 minutes. Problem-solving based construction of the omniwheels and robot design and construction can take about 40 minutes. Setting the control functions with the ReBOT mobile app and testing and studying the robot's properties can take 20 minutes and closing discussion 10 minutes. [8] Phase 6 can be added in 1 or 2 further classes, depending on the group's interest.

According to Experience Workshop's programs, robot-related activities in general and especially in complex topics, like the construction omnidirectional robot can hold a great potential to re-frame mathematics learning in a transdisciplinary STEAM context. Skills related to geometric measurements and mathematical calculations can be effectively developed in the workshop program. Aesthetic design of the robot can call the attention to several hidden aspects of applied mathematics and applied science in general. The design, build and code-approach opens further areas for learning and exploration both from the scientific and the artistic / creative aspects and development of various problem-solving skills, which a traditional or a more formal mathematics class hardly can include.

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