Technical school students design and develop robotic gear-based constructions for the transmission of motion

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Abstract

This paper describes how students of a Technical and Vocational School in Greece (age 16-20) learnt important mathematical and scientific ideas through their own design and programming activities using the Technological Inventions LEGO Mindstorms Package. Most of those students have been of poor performance in traditional maths and science activities but they have strong design and mechanical skills. They were invited to design, develop and program a robotic construction using gears, sensors and Lego bricks in order to explore the relationship between the technical characteristics of the gears, the frequency and the properties of rotation as well as the transmission of motion.

Keywords

Lego Mindstorms, Technical and Vocational School, robotics, gear-aided transmission of motion, cooperative learning

1. Introduction

Nowadays robotics is not included in the official curriculum of Greek school education. Initiated by our belief that robotics education offers a rich opportunity for students, especially those attending technical and vocational schools, to become engaged in problem solving and cooperative learning, we are planning to develop an innovative robotics project that will be implemented in the technical and vocational Greek education in the areas of science and technology.

This paper presents our experience from a first attempt with a pilot group of students who were engaged in a hands-on, student-centred project to study the relationship between the technical characteristics of gears, frequency of rotation as well as the transmission of motion. The students were actively engaged in the project designing, building, programming and testing of robots using the Lego Mindstorms construction kit.

2. Theoretical background and educational objectives

Various specific learning expectations and objectives can be integrated in a robotics project. Working with robotics materials, students have the opportunity to gain authentic experiences with science and technology concepts and to develop a meaningful understanding of how a technological device works. A robotics project can take multiple forms and can focus on a variety of outcomes depending on time, teachers' and students' interests and preferences, as well their previous robotics experience.

Our project is inspired from:

- the constructivist theories of Jean Piaget (e.g. Piaget, 1972) arguing that human learning is an active process of knowledge construction based on experiences gained from the real world
- the educational philosophy of constructionism (Papert, 1993) adding that the construction of new knowledge is more effective when the learners are engaged in constructing products that are personally meaningful to them

In this pilot project the student group was asked to design, build, and program a robotic device that would allow them to study the gear-aided transmission of motion. More specifically, the main cognitive objective was the idea that, if you use a small gear to drive a large one in terms of the number of gear cogs, the large one will turn slower and vice versa. Finally, students were expected to discover through team-work the so called gearing down (and up) ratio, that is the ratio of rotation speed equal to the reverse ratio of gear cogs.

The gear-aided transmission of motion is a fundamental subject in technology education with many applications in real life (biking is a good example of a gearing up system) and plays a very important role in the specific students' curriculum. The understanding of the transmission of motion is thought to be a difficult subject for students to grasp, as well as for adults (Papert 1980).

In addition to the pre-mentioned cognitive objective, we wanted to familiarise students with tools that enable them to work with concepts in mechanics (such as the gearing down and up ratio) in a concrete way, visualising and concretising them, to promote active exploration and discovering, to provide them with opportunities to test their own models, detect and correct any inconsistencies and finally to encourage students to work collaboratively and to share their ideas with their mates.

Educational experience has shown that merely presenting the correct information about science and technology concepts, either orally or in written form is seldom effective in helping students overcome their difficulties (McDermott 1984).

The research in science and technology education has made possible the development of learning strategies and materials that attempt to meet students' needs and address their specific difficulties, such as computer-based learning environments intended to help students learn how to relate motion to its graphical representation (Trowbridge 1989), microcomputer-based laboratory (MBL) tools that allow students to collect real time data in graphical form used to enhance and evaluate students' learning motion concepts (Thornton 1992).

Nowadays, increasing attention is paid to computer-based modelling activities in science and technology education. In a general sense, modelling is the most fundamental activity in science and in science education (Niedderer et al. 2003). Computer–aided modelling in learning is considered to be a useful mind tool and a valuable learning tool that contributes to the enhancement of learning and the development of student thinking (Jonassen 2000).

Taking into consideration that students have a better understanding when they express themselves through invention and creation (Piaget 1974), we selected for the purposes of our project to provide students with the opportunity to design, build and program robotic models. Programming as a general model-building and toolmaking learning environment has been shown to support constructionist learning across the curriculum (e.g. Papert, 1980).

Lego Mindstorms has been used world-wide in both elementary and secondary education as well as in higher education, and provides a flexible medium for constructionist learning, offering opportunities for design and construction with limited time and small funds

(Portsmore, 1999). The system is comprised of building materials (regular blocks, gears, pulleys and axels) and programming software built upon the graphical programming language of LabVIEW. By programming the Remote Command System (RCX box) to react to input from the sensors, students can create behaviours for their inventions. The programmable bricks make possible new types of science experiments, in which children investigate everyday phenomena in their lives (both in and out of the classroom) (Resnick et al. 1996).

3. Methodology

The project was implemented at a Technical and Vocational School in Patras - Greece (3rd T.E.E. of Patras). The pilot group of students involved in the project were aged between 16 and 20 and were in the first year of their three years course of study. The group consisted of six students, two of which were female. Three of the students follow the field of electricity technicians and the rest the field of machinery technicians. The performance of almost all of those students in traditional maths and science activities has been poor, but they have strong design and mechanical skills.

The students worked with their teacher in a weekly basis (three hours meetings) for a period of six weeks. The project was scheduled on an authentic learning basis in order to help the students carry out experiments with the Lego Mindstorms parts such as Lego RCX, Lego gears, Lego bricks.

3.1. Educational activities

The project consisted of three basic educational activities:

- *Familiarization with LEGO mindstorms.*

  The first activity lasted over a span of two three-hours meetings. The teacher presented the hardware of the LEGO Mindstorms package such as the bricks, the gears, the Lego RCX, the sensors, the electrical motors, etc. and the ROBOLAB software as well.

  First the students explored the pilot Lego programmes offered with the ROBOLAB. Following that, a worksheet was given to them asking them to design, construct and program a car using two motors. The car had to drive forward and backward for a certain amount of time.

- *Designing a device for the motor rotating speed measurement.*

  The second activity took one three-hour meeting. It was based on a worksheet aiming to design, construct and test a scientific instrument that is able to measure the rotations of an electrical motor. Students would then be able to use this instrument to measure the rotations of the Lego motors at different rotation levels (there were 5 levels with a gradually increasing rotation speed). According to the instructions the students had to use a motor, a light sensor, and any other part they might need in order to complete the device.

- *Designing a device for understanding the gear-aided transmission of motion.*

  The last and main activity took a period of three meetings. In this activity students were asked to design, construct and program a device using gears, sensors and Lego bricks in order to explore the relationship between the technical characteristics of the gears (number of teeth) and the rotational speeds (input and output) of a transmission system of motion. At the beginning a questionnaire was given to diagnose the students' knowledge of concepts such as rotational speed, frequency and transmission gear systems.

3.2. Monitoring methodology

During the six work meetings with the group of students three monitoring methods were used:

- Teacher observation
- Video capturing
- Student interviews

The teacher was present in all meetings and observed the students' brainstorming, discussions, working activities and reactions. He kept notes and intervened whenever students needed help, mainly with science and programming concepts. The role of the teacher was more that of an experienced advisor and his instruction was context-driven to supply what was required. The activities were video captured so as researchers could analyse the students' 'how to'-ideas and the way they express them, their activities, reactions and reflections. The teacher conducted student interviews at the end of each work meeting. The interviews were semi-constructed and concerned the problems raised each time and the solutions given by the group.

4. Description of student work

During the meetings the interest and the motivation of the students to work on the LEGO Mindstorms package increased continually as the project evolved. They became involved in discussions, arguments, agreements and disagreements in order to complete their activities.

4.1. Familiarisation with LEGO Mindstorms.

During the first session, the teacher presented the content of the LEGO Mindstorms Technological Inventions package and showed how someone can build a construction. He also presented the ROBOLAB software and photos of Lego Robotic constructions as examples. The students had the opportunity to try the pilot programming examples using the icon graphical programming environment and used the different kind of sensors, electrical motors and lamps in order to become familiar with their function and their control procedure.

The first worksheet was given to the group asking them to design and construct a car with two electrical motors. The students had a meeting and decided on the design of their car. The construction was unexpectedly built very quickly and they started programming the RCX element using the inventor mode of the software.

Figure 4. Students' car from two different views

The students decided to program the car in order to drive forward for two seconds with the front white lamps turned on. Afterwards the car had to drive backwards for two seconds with the red rear lamp turned on. The first attempt was not successful but after some trials and discussions among them the students discovered that the motors had to be programmed with reverse rotational direction. Every time a trial was unsuccessful disappointment was expressed but every time a trial was successful the glee and encouragement were obvious. The final version of the program is shown in the following picture.

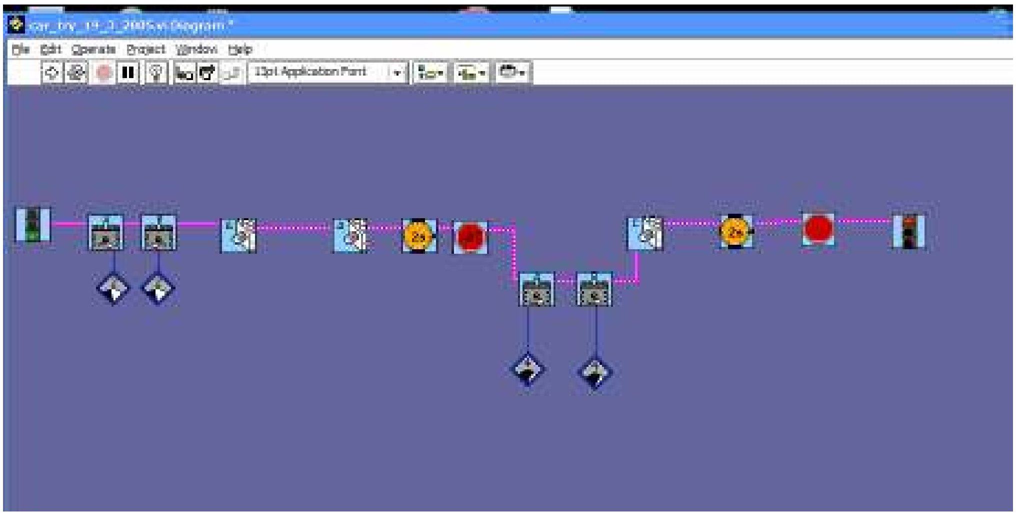

Figure 5. The Robolab screen with students' program driving the car

During the activity two subgroups of students seemed to appear; one would have the responsibility of programming the constructions and the other one of constructing the models. The subgroups were formulated according to the personal interests of each student as they were raised during the first meetings.

4.2. Designing a device for the motor rotation speed measurement.

The students worked based on the second worksheet in order to design and develop a measurement device for the motor rotation speed. After a long discussion among them, they decided to use a light sensor, a piece of a notebook cover white-out, and a black marker to make a paper wheel for their rotation measurement device. They then put an axle through the centre of the paper, secured it with bushings and connected it directly to an electrical motor. They also decided to use a lamp in order to observe the changes of the light levels that the sensor had to measure and feel more confident for the functionality of their device. The construction is shown in the following figure.

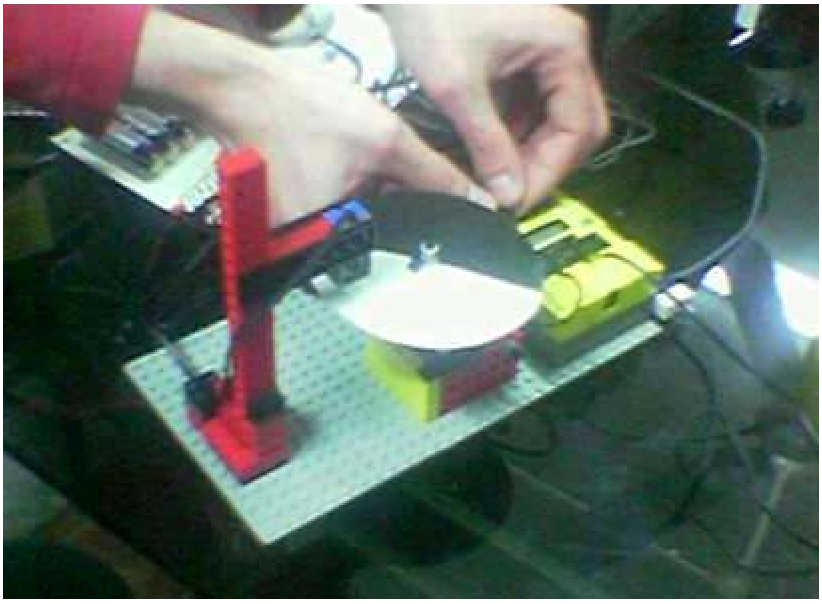

Figure 6. Students' construction to measure the rotation speed of the motor

The students started the programming of their device at the ROBOLAB environment as soon as they completed their device. They carried out a lot of testing and debugging. The final version of the code is shown below.

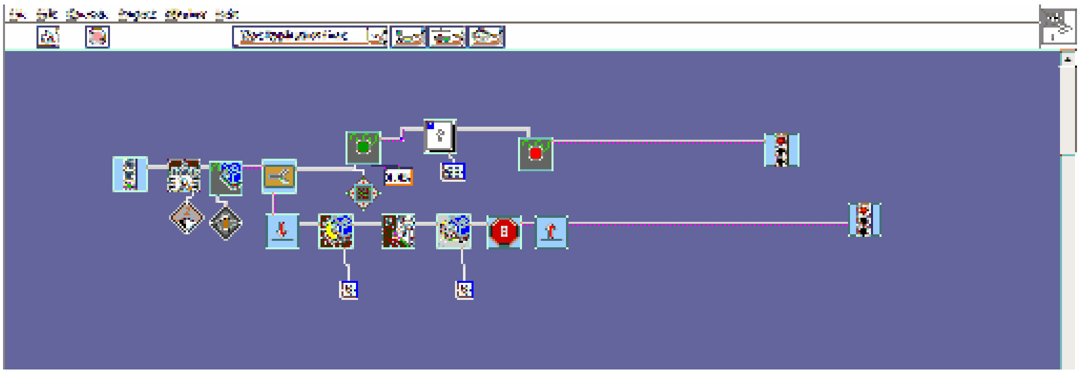

Figure 7. Students' program for data acquisition

We have to mention that the students calibrated the light sensor every time they started a new experiment with the help of the RCX Lego brick. They collected 200 experimental data points with a data acquisition rate of 0.05sec per experiment. They tried to use data acquisition rates of 0.1, 0.01, 0.05 sec and they observed that the best results were obtained with the 0.05sec sampling rate. The students carried out the experiments for all the 5 different rotation levels of the Lego motor. Unfortunately they had efficient results only with the 1st and the 2nd rotation levels of the motor. A typical diagram of the data collected for the 1st rotation level of the motor is shown below. When they used the motor rotating at the 3rd, 4th and 5th level, the rotation speed was very fast and the light sensor could not acquire efficient experimental data for its estimation.

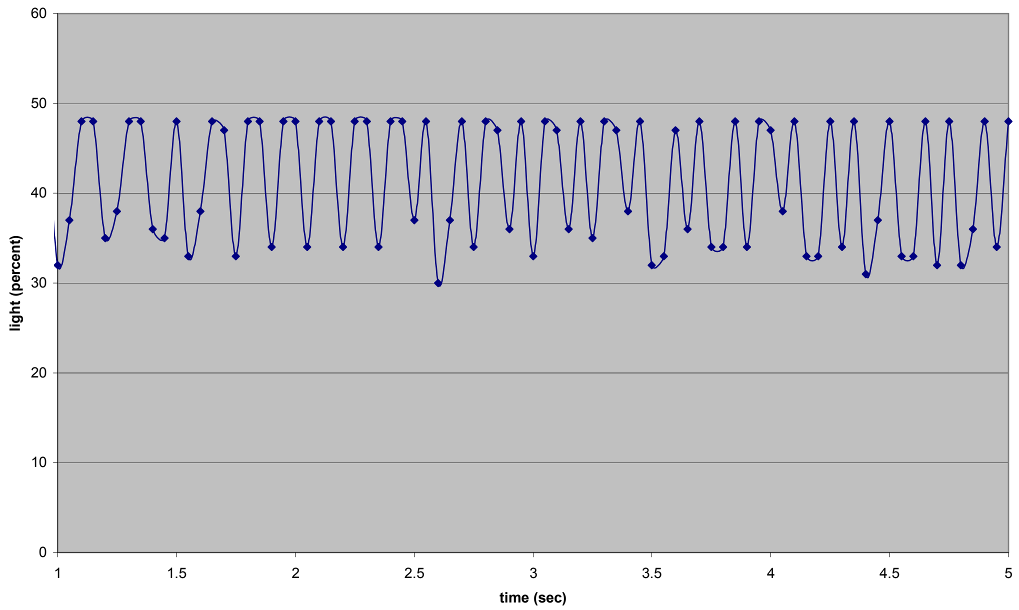

Figure 8. A typical diagram for the first operating level of the motor

Using the diagram the students counted the changes of the light levels measured by the light sensor for a certain time. Thus they could calculate the motor rotation speed in RPS (Rotations Per Seconds).

4.3. Designing a device for understanding the gear-aided transmission of motion.

During the last activity the students had to expand their measuring device according to the third worksheet. They used different pairs of gears as the main element of a transmission system to transmit the rotation from the motor to the rotating carton. The idea was to use different pairs of gears to reduce or increase the revolutions of the rotating 'black and white' disc. They tried to reduce the rotation speed of the 3rd, 4th and 5th level of the motor in order to overcome the pre-mentioned measurement problem. The device students constructed is shown below.

The students used pair combinations of three different gears: one with 12 cogs, one with 16 cogs and one with 24 cogs. They carried out many experiments using the different pairs of gears for all the operating levels of the motor. Students' experiments using gear-pairs in order to reduce the output speed for the first two rotation levels of the motor were successful because students watched the resulting effect (the reduced output rotation speed), acquired their experimental data and calculated the rotation speeds they were looking for. The teacher prompted them to compare the ratio of the gear cogs, in each case, with the ratio of the input and output rotation speeds. This led them to the expected equation that is shown below:

$$\frac{f_1}{f_2} = \frac{n_2}{n_1}$$

where f denotes the rotating speed in RPS and n denotes the number of gear-cogs.

The students' experiments using gear-pairs in order to increase the output speed for the first two rotation levels of the motor were not fully successful. They watched the resulting effect (the increased phenomenon speed) but they could not collect efficient experimental data to estimate the output rotation speed because of the light sensor limitations. When they used a transmission system to reduce the output rotational speed, for the 3rd, 4th and 5th level of the motor they could also observe the resulting effect but they could not compare the input and output rotation speeds because of the non efficient data acquired again due to the light sensor limitations.

Some experiments that led the students to find the expected relationship are shown in the following table.

Table 3. Typical data from the students' experiments

Experiement	Motor Level	f_1(RPS)	f_2(RPS)	n_1	n_2	f_1/f_2	n_2/n_1
1	2	5.6	4.3	16	24	1.30	1.50
2	1	5.8	2.8	12	24	2.07	2.00

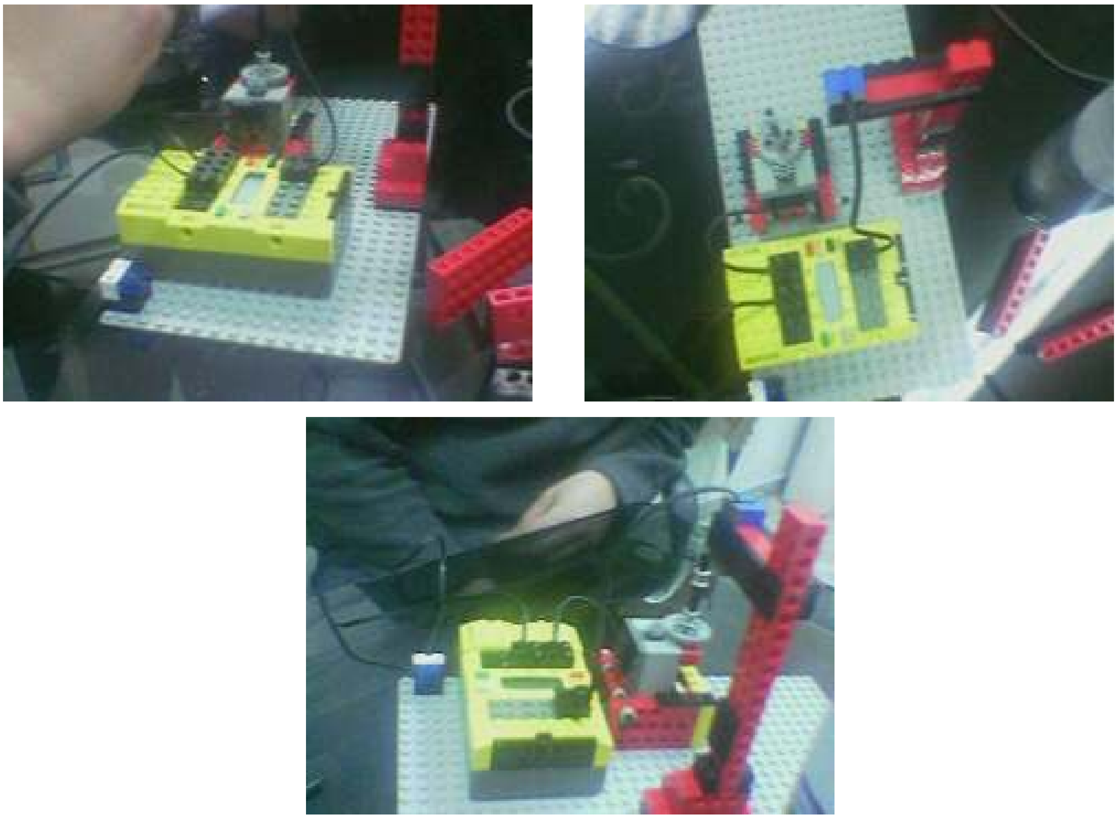

Figure 9. The final students' construction from three different views

The program code used for this activity was the one the students made for their second activity. Some sample data extracted from various experiments in the current activity are presented in the following diagrams.

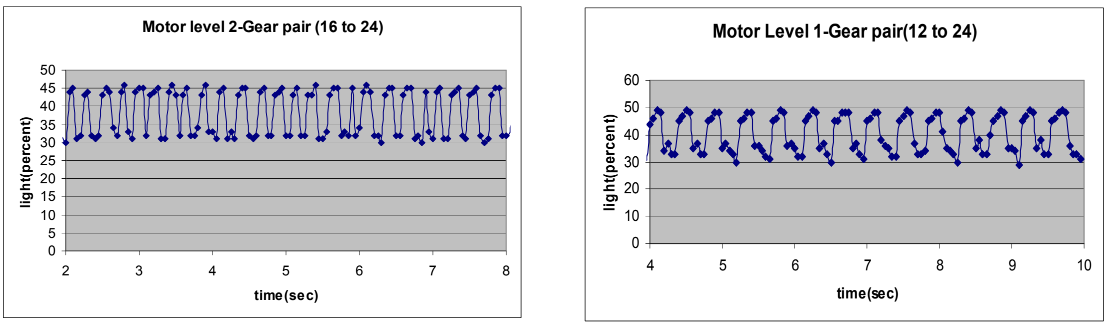

Figure 10. Some sample data extracted from students' experiments

5. Results and discussion

At situ observation of the students' work during the implementation of the activities and the video recordings indicated a continuously increasing interest in the project and a dedication to their work.

It is common knowledge in Greece that students that attend Technical and Vocational Schools are mainly those who have been unsuccessful in traditional math and science activities. However, these students have usually strong design and technical skills, but many of them have been frustrated by the analysis-centred approach of traditional math and science classes. Almost always these students viewed by their teachers, but also by themselves, as poor learners.

All of the students involved in the project had been taught about rotation speed, frequency and transmission gear systems but almost none of them could give a definition of these concepts at the beginning of the project. Their responses to the diagnostic questionnaire were extremely poor and confused. During the first discussions with their teacher they complained that they didn't like Physics, they didn't want to use the laws of Physics and equations or to work on Physics. During the project their attitudes changed, their interest increased and their willingness to continue working on the project became stronger and stronger. At the end of the project they could not only give a description, although not very precise, about rotation speed, frequency and transmission gear systems but they were also able to argue about them. They learned to measure the rotation speed of the motor and were able to decide if a measurement was satisfactory or not and why. From the video recording as well as from the interviews we had with them at the end of each meeting, their understanding of what they were working on gradually became deeper.

It is important that during the project the students tried to understand how their devices worked and what they had to do to make the devices work properly. Working on each activity students had the opportunity to use their experience as a guide and take advantage of their mistakes. In this way, they had the opportunity to understand their own thinking process during problem solving or understanding and explaining a situation. They were provided with the necessary skills to plan a technical project logically and carry it through to completion. At the same time they collaborated with others and had a sense of a common sharing of ideas, designs and constructions and discussing them. In this way they developed collaboration and teamwork skills. One girl seemed to have developed leadership skills as she stood out as the coordinator in most of the activities. That's very interesting, given that science and technology are usually considered to be "male" subjects. The students' communication skills as well as their ability and fluency to express their ideas and argue about them were also gradually improved.

After the LEGO Mindstorms activities the students acquired a better opinion of themselves as capable learners and their self-confidence was obviously enhanced. This was demonstrated by their celebrating expressions after a successful activity as well as by their enthusiastic responses to the teacher like 'Sir, we have succeeded', 'look at it! It is working! Do you like it?', 'We are good, aren't we?', 'What else do you want us to construct?'…

Many times they were willing to show their work to their friends and explain to them how they had made and programmed their constructions.

The role of the teacher was different than the usual one. His role was more like an experienced advisor and his instruction was context-driven to supply what was needed. It was something new for him and offered him a new approach to work with his students. He had the opportunity to discover his students' learning difficulties, to understand how his students like to work, how they may think, what they don't dare to do, how they feel and consequently how to design future educational activities for them.

6. Conclusions and Implications

The current project was just a first attempt to explore the potential of how LEGO Mindstorms robotic constructions can be effectively used in Technical and Vocational Schools in Greece. It was a first time not only for the 3rd Technical Vocational School (TEE) of Patras, but also for Technical and Vocational education in Greece in general to experience LEGO Mindstorms, and the results of this pilot work could prove useful for the learning community of vocational and technical education.

The project seems to have been a useful learning experience for the students who were actively involved in it, it contributed to significant learning gains and helped them to associate the world of theories and models with the world of objects and events. The 'learning-by-doing' concept was realized effectively in the Lego Mindstorms environment. Designing a construction to achieve even a simple task can place extensive demands on students' individual creativity and problem-solving abilities.

Finally, this pilot project has provided very promising indications that robotic activities developed by students themselves could be utilized in the teaching process as a subservient tool in the understanding of the concepts and phenomena of Mechanics. The design of similar educational projects calls for the development of creative educational techniques in a student-centered learning context.

ACKNOWLEDGMENT

The Project described in this paper was funded by the National Educational Program 'Daidalos'. The authors would also like to thank the students participating in the project for all of their diligent work and the Headmaster of 3rd Technical and Vocational School of Patras (Greece) MR. Kostas Rallis for his cooperation in the frame of this project.

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