# National Mechatronics and Robotics Elective Course for Upper Secondary School Level

Heilo Altin
Institute of Technology, University of Tartu, Tartu, Estonia
Heilo.Altin@ut.ee

***Abstract*—Recent studies show that pupils are very enthusiastic when using robotic systems and robots in schools. However, in Estonia, these are mainly used only in extracurricular activities to learn about the robots, take part in various contests or for research purposes. Robotics increases the level of problem solving skills and enhances pupils' better understanding of various aspects of math and physics. Robots could be used for that but the work done so far in schools in Estonia has been at interest level. To make teaching robotics more systematic, a facultative course of mechatronics and robotics was developed to be available for all high school pupils (aged 16-18). This paper describes the developed course, its structure and methods of teaching.**

***Index Terms*—Educational robotics; Mindstorms; Homelab; facultative course**

## I. Introduction

Integrating various subjects has been a downside in the Estonian school system for years. In addition, several subjects in the upper secondary school curriculum are very abstract, such as laws of Physics, regulations for Math calculus or the construction of a cell in Biology. ICT has been seen as a helpful tool for integrating subjects, however, it can only reach its goals through methods of active learning, projects in school and on international level. These methods can be used very easily at upper secondary school level. The purpose for developing this course was to use robotics more systematically in Estonia to gain more.

Robotics is a tool for integration on its most simple level [1]. When teaching robotics, it is crucial and unavoidable to use methods of active learning [2]. Robotics enables to connect all the subjects of natural and exact sciences as well as technology. Courses in comprehensive schools in Estonia are 35 school hours long. For the existing 35-lesson timetable, each topic is connected to Physics or Math or Information Technology. As pupils will encounter a lot of new notions, the terminology of robotics and the particular topic involved will be provided in English. It will provide useful when the pupils wish to do further research on their own or, for example, use some sources in English when writing a summary. In principle, robotics enables to relate many other subjects, from Music to Physical Education. During the 35-lesson-course, authors would like to see that the pupils become more interested in robotics and STEM subjects. Authors wish pupils could feel enthusiasm and success over the fact that they can control the robots and by doing so, better understand the mechanisms of natural world. The schools can choose which platform (MINDSTORMS NXT [3], Homelab [4]) will be used to conduct the course. The particular facultative course aims at combining manual work with abstract understanding, integrating several subjects through the practical work done within a group and offering some joy of learning that seems to be lacking in schools.

## II. Course Methods

The course of mechatronics and robotics is conducted in pair lessons for one lesson is too short to introduce the theory and then conduct a practical task. Should there be a pause in between the theory and practical work; the course would not be as beneficial. Furthermore, setting up and taking down the hardware of a robotics class is time-consuming.

During the course, marking is based on practical tasks, which have been chosen to revise the theoretical knowledge of the previous classes and give the pupils a chance to use these in creating their own solutions. Practical tasks are conducted as collaborative work in pairs. This study form has already proven to be the most effective robot-user ratio in Estonia. In addition, the course includes some more challenging practical tasks that require teamwork. Practical tasks have been compiled keeping in mind that they are interesting to pupils and so that they would create the wish to try out new ideas and improve the solutions created. At the same time, the plan and phases of creating a solution will be followed and the activities will be documented. All tasks are presented as problems for which pupils need to find solutions in project based work.

The practical tasks and the project of robotics will be conducted with the given hardware solution – the study sets of robotics. It is recommended to use the sets supported by the University of Tartu and the Tallinn Technical University – LEGO MINDSTORMS NXT / NXT-G or NXC and the Robotics Homelab. Some other suitable solutions, such as Arduino, TI Development Toolchain, etc, could also be used. Course material is divided into two levels for the aspect of simplicity. For pupils, it is possible to finish the course with generic understanding of how robots act and work, but if they are already at that level, they could find more detailed information on the second level. The theoretical part of each chapter ends with revision questions and an online test which purpose is to check if pupils understand the theory. Otherwise, they would face more problems during the practical work. The online test and questions are not compulsory and it is teacher's decision whether to let the pupils take them or not. This is a possibility for teachers to evaluate pupils' work. As this course takes advantage of e-learning methods, teachers have a possibility to change tests as needed. Teachers are not obligated to require pupils to have working solutions after the practical lesson is over. In many cases, the purpose is not to finalize a working robotic system but to see what pupils learn during the design process and how they apply this knowledge. The purpose of examples and tasks is not to gain new knowledge, rather to systemize skills and knowledge and create links and better abstract view of the topic. To gain all this, pupils should have the opportunity to think about the subject independently to generate links and conclusions. General suggestion to teachers would be to have lots of discussion after independent work to eliminate false conclusions pupils might come up with. The most important part of evaluating pupils is the final project of the course. Other than the developed system, also team work, documentation, presentation and software are under assessment.

## III. Course structure

The course is made up of 35 lessons which are divided into pair school lessons. The course is made up of six topics:

- Main principles of robotics – 4 lessons
- Actuators – 4 lessons
- Sensors – 8 lessons
- Robot motion and positioning – 2 lessons
- Data processing – 8 lessons
- Project – 9 lessons

1) *Main principles of robotics:* 4 lessons

*a) Lesson 1-2 (Introduction/lecture):* Robotics' history, everyday use, sample platforms and safety. Learning outcomes: pupils should know what a robot, robotics, a manipulator, mechatronics, a sensor, an actuator and a controller is. In addition, pupils can determine whether a robot belongs to the first, second or third generation and can explain robot-human interaction through I. Asimov laws.

*b) Lesson 3-4 (Robotics system/lecture and practical work):* Robotics system as a sensor-brain-actuator system, microcontrollers, programming, debugging and compiling. Learning outcomes: pupils know what a mechatronic's system, its parts and structure are.

2) *Actuators: 4 lessons*

*a) Lesson 5-6 (Displays/lecture and practical work):* Various types of displays. Learning outcomes: pupils can name visual information transmitting devices and can select the most appropriate device for a robot to transmit information.

*b) Lesson 7-8 (Motors/lecture and practical work):* Various motors, electrical, DC, servo and stepper motors. An overview of alternative actuators such as a linear motor, a solenoid, an artificial muscle is given. Learning outcomes: pupils know which motors to select for the robot, H-bridge and control mechanisms for servo and stepper motor.

3) *Sensors: 8 lessons*

*a) Lesson 9-12 (Analog Sensors/lecture and practical work):* Analog sensors with various examples, A/D converter. Learning outcomes: pupils know how analog sensors and a A/D converter works. They also know what A/D converter resolution is and how to find it.

*b) Lesson 13-16 (Digital Sensors/lecture and practical work):* Different digital sensors and examples. Learning outcomes: pupils can name different digital sensors, know how these sensors work and the structure of a digital signal.

4) *Robot motion and positioning: 2 lessons*

*a) Lesson 17-18 (Robot Motion and Positioning/lecture and practical work):* Various ways of robot motion (wheels, omni wheels, treads, legs) and positioning (GPS, sensor). Learning outcomes: pupils know how to select the most suitable motion device for the robot. Pupils also know how the simplest positioning algorithm works and how to use it.

5) *Data processing: 8 lessons*

*a) Lesson 19-22 (Data Communication/lecture and practical work):* Various ways of data communication between robots (bluetooth, cable). Learning outcomes: pupils understand digital data communication, can name the positive and negative aspects of various data communication.

*b) Lesson 23-26 (Data Collection and Manipulation/lecture and practical work):* Various ways of data collection, reasons, principles are explained. Learning outcomes: pupils can name robots that collect and process data, can give reasons for using robots for collecting data, know how data is stored.

6) *Project: 9 lessons*

*a) Lesson 27-35 (Project/practical work):* Practical assignment that applies all knowledge learned before. The work includes project management, research, teamwork, wireless data communication, documenting, reporting, presenting.

The course has five various books which are also printable in paper format. The first book is theoretical textbook which includes all the theoretical information about all the six topics, see "Fig. 1". The theoretical part is not platform dependent, so pupils can read it whether they use MINDSTORMS or Homelab. It is also possible to give the course without a platform, but it is considered to be a downside and should be discussed carefully as probably the course would not fulfill its purpose to give pupils practical skills in mechanical and robotics system engineering.

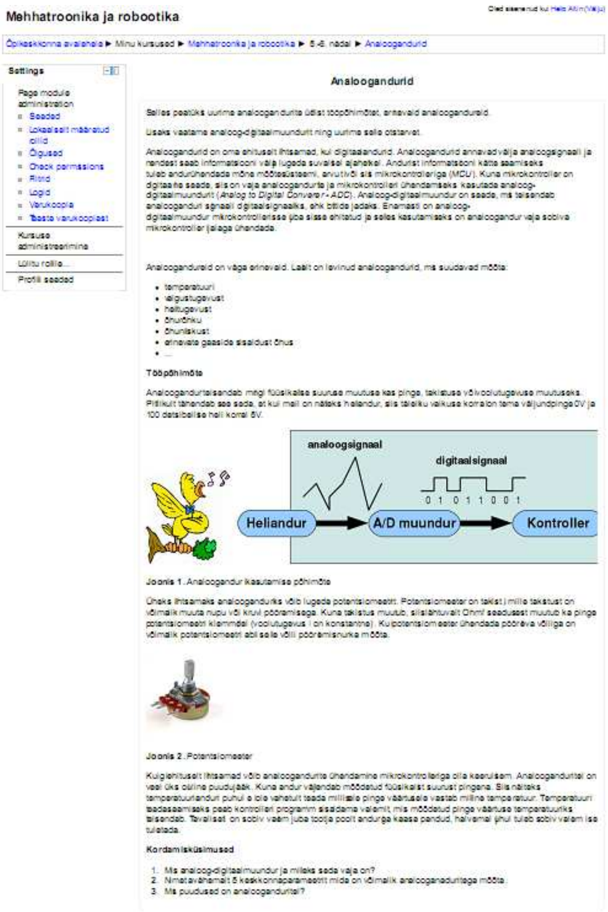


Figure 1. Chapter "Analog sensors" of theoretical workbook which explains the idea of changing an analog signal to digital form.

The textbook also includes support for the teacher in form of teacher textbook which includes more notes, links and hints to have the discussion going in the classroom. First, pupils read the theoretical part, then continue with practical work. Two platforms are supported and so there are two various workbooks, see "Fig. 2". Each lesson has up to four assignments which in most cases are not all to be solved during the lesson. The teacher can make a choice of the assignments. For each workbook, there is also support for the teacher in form of teacher's workbook. This includes all solutions for the assignments and ideas for new assignments. There is also a glossary of the new concepts. It is linked to the theoretical textbook. As mentioned, theoretical part is divided into two levels for reading.

First level is easier as it explains all the important aspects in one topic but does not go into details. Second level explains the same aspects but in more detail. This division leaves to teachers and pupils a choice whether they want to know more if they could understand a technical text. This kind of differentiated textbook was developed because some schools in Estonia are not as advanced as others, but the authors wanted the target group to be as wide as possible.


Figure 2. Example of one assignmenet in Mindstorms workbook where pupils have to build a robot that could climb over LEGO box.

## IV. Course Piloting

The course was piloted in four schools as a part of the standard curriculum, but the lessons were carried out as the last lessons during one school day. This was also recommended in the teachers handbook as pupils frequently find themselves wanting to do more or to finish practical activities even when the time is up. Each week included two school lessons, eighteen weeks altogether. Two schools used Homelab and others MINDSTORMS platform. Twenty pupils from grades ten (aged 16) and eleven pupils from grade eleven (aged 17) used MINDSTORMS platform. Eleven pupils from grade eleven and twelve pupils from grade eleven used Homelab platform. The course was set up in Moodle environment. At the beginning, this seemed to be an obstacle because schools were not able to set up our course in their Moodle environment without problems. This led the authors to setting up a central course in a central server that all the schools were able to access. Teachers were added to Moodle environment according to their role and they were able to add pupils. Feedback was collected via forms in Moodle environment from pupils and teachers. For that, various questions were used. Among other questions, teachers had to evaluate how the course supported upper secondary schools to fulfill requirements of the general competence of the national curriculum. Pupils had to assess the theoretical part of each chapter in Likert scale (1-5) by:

- clearness (1 – material was not clear at all, 5 – material was completely clear)
- novelty (1 – all material was new, 5 – there was no new information)
- level of interest (1 – material wasn't interesting, 5 – material was very interesting).

Besides piloting in schools, another method was used during the development of the course. An eight-day-long teacher training was applied. First four days were set up on MINDSTORMS platform, the last four days on Homelab. During the training teachers were able to give feedback as they worked through the topics. Thirty teachers took part in this training.

## V. RESULTS

Feedback from schools revealed that the course has a substantial amount of material, so pupils were not able to finish the project in the end. That was partly based on a teacher's decision. Another reason for that which was also mentioned by the teachers was that they were teaching this course for the first time which led them to setbacks. These problems are not connected to the course but to their level of experience. In the coming years, teachers know what to change in their methods in order to finish in time. The system of having a central server with Moodle running was approved by the teachers. That did not pressure them or the school staff with technical problems. Piloting with Homelab showed that Homelab needs a high level of previous knowledge about electronics and programming in C. That led to great time consumption when solving the textbook for Homelab. Other problems raised were connected to the sets used for practical assignments. One school mentioned that they did not have a sufficient number of MINDSTORMS sets to have these only for the pupils of the particular course. As the sets had to be used by other pupils as well, it was difficult to maintain the built solutions over the weeks. Most of the pupils (more than 37 %) always assessed the clearness of the material as very clear. In some topics, pupils also answered that the material was not clear to them at all. When it comes to the novelty of the topics, most pupils found some new information for them. Again, in some cases, pupils did not get any new information. That might be due to the teacher's decision of the pupils piloting the course. Pupils' knowledge before taking the course was not measured, but teachers selected pupils they had been working with before during extracurricular activities in robotics. The interest level of the topics varied, but most of the pupils found the material to be suitable or interesting. In teachers' feedback, it was mentioned that the theoretical workbook is complete and motivating for pupils to read it.

One reason for developing this course was the promotion of STEM subjects. When pupils are about to graduate high school and make their choice for the future during the last upper secondary school year, this course would guide them towards engineering in university. From the feedback, it turned out that starting this activity in upper secondary school level is too late. The age group for using robots for the mentioned reason should be as low as lower secondary or elementary school. This course is not to be used on the elementary school level, but teachers gave positive feedback about the possibility of using it in lower secondary schools with the first level of the theoretical part. All in all, some changes were conducted to the course according to piloting in schools. The most positive effect rose from teacher training. It was not expected to collect that amount of feedback that authors got from the training. Another unexpected positive effect took place in Estonia due to the course. This course will be leased as a national facultative course for mechatronics and robotics at the beginning of 2013 and a large amount of schools joined the educational robotics school network. The reason for joining was the will to be able to teach this course from the beginning of 2013. The competition between schools is mentionable as the course became a key point for some schools to gain more pupils on upper secondary school level.

## VI. CONCLUSION

The decision of using Homelab as a technical platform for the course must be analyzed carefully by teachers and the school staff. As MINDSTORMS is intuitive and easy to use, it did not encounter so many problems as Homelab. Homelab could be the next level for the same pupils after passing the course with MINDSTORMS. Ministry of Education and Science in Estonia is aware that schools might get held up with setting up Moodle courses. This can also cause problems while teaching pupils. The decision of whether there should be a central course has not been made. A positive side of this could be that fact that technology changes on a daily basis and the theoretical book expires quickly; a central place for the course will allow authors to make changes if needed and these will reflect immediately in all schools. Server requirements for this course were not substantial. The course will go through the process of book reviewing and language check before it is released to the schools. Some teachers are planning to use the course also in lower levels in school because they find some classes being able to do that. In the end, this course has a systematic approach into robotics and mechatronics which also reflects in all of the learning materials. Schools can continue with robotics from extracurricular level to the curricular level. The next step is using robots as natural part of physics [5], math, informatics and chemistry.

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