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Development of a multi-grade curriculum: project "READY"

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***Abstract*— The use of robotics in education can be found in many initiatives in order to motivate students for technology and engineering. Hands-on experiments are often used as an instrument. In this paper we present a multi-grade, consistent and gender neutral curriculum starting in primary school until the end of high school in the areas robotics, computer science and measurement and control. Additionally we describe the implementation of a certificate for middle school.**

Keywords—Robotics in Education, Curriculum, STEM

I. Introduction

Many initiatives have chosen robotics in education to motivate children for technology and science. Therefore several robot competitions like the First Lego League [1], BotBall [2], Roberta or RoboCupJunior have been developed and expanded in the last two decades in order to increase confidence for pupils in using technology [3], to enlarge their knowledge in physics, programming, mechanical engineering, electronics and science and to enhance skills of communication, teamwork and personal development [4].

The department of Computer Science at the University of Applied Sciences Technikum Wien hosts a regional center of the initiative RoboCupJunior in Vienna since 2007. Being part of the research oriented RoboCup, the competition RoboCupJunior aims to provide a framework that enhances young students learning in the field of robotics. RoboCupJunior offers three disciplines to compete in: rescue, soccer and dance – the tasks are very similar every year in order to show the progress of the solutions and to enlarge the knowledge. Additionally the regional center supports young students and their mentors to participate at the competition with robot kits, introductory courses and further education courses for teachers or arenas for the students to test their robots in a tournament environment, to name a few [5].

However, those supporting actions always depend on motivated teachers who mostly work with the students in their spare time. Therefore it is important to install a curriculum in schools which fosters the technical aspects in education to strengthen the competitiveness. This paper presents the project "READY – Robotics and Engineering AcaDemY" to develop a multi-grade, consistent and gender neutral curriculum for kids and students from primary school until the end of high school in the field of robotics, computer science, measurement and control. Moreover, a certification "OCG Certified Junior Robotics Engineer" for middle schools (students of the age of 10 to 14 years) was developed. The goals were mainly to give the students a first insight in the field of robotics, because it is a topic that is till now not present in the Austrian school system. Moreover it serves to promote interest students for programming as early as possible by using hands-on methods, as well as prepare them for a future academic career. As a result, an engineer-related thinking and development process should be trained.

This project was promoted by "The Austrian Research Promotion Agency (FFG)"[1] and conducted by the "Austrian Computer Society"[2] in cooperation with the University of Applied Sciences Technikum Wien.

The remainder of the paper is structured as followed: Chapter II delivers background information of curricula in the field of robotics. Chapter III explains the development of the curriculum in our project READY, followed by the development of the certification "OCG Certified Junior Robotics Engineer" for middle school. Moreover the next chapter evaluation describes the implementation of the project. Chapter VI discusses future work.

II. Background

The public education system and their contents remained constant over the last years, even though the world is changing rapidly. That's why it is important to transport the innovational progresses in technology also to the school's curricula in order to prepare the students for the future. [6] Many movements in education use robotics to integrate STEM learning in primary and secondary education in order to increase the number of students pursuing careers in Science, Technology, Engineering or Mathematics [7], [8].

[1] https://www.ffg.at/en
[2] www.ocg.at

The Carnegie Mellon University founded a Robotics Academy [3] focusing on tasks for middle and high school. Their mission is to use the motivational effects about robotics to encourage students about science and technology. Therefore they provide curricula for teachers to integrate robotics in their classes [9]. According to the "Partnership for 21st Century Skills"[4] teachers need to include four "Cs" in the lessons additionally to the core subjects like mathematics or science: Critical Thinking, Creativity, Communications and Collaboration.

Another example for integrative curricula in the field of robotics is "WaterBotics"[5] for middle and high school developed by the Stevens Center for Innovation in Engineering and Science Education at Stevens Institute of Technology. Students work in teams on the design, construction, testing and retesting underwater robots with LEGO MINDSTORMS NXT kits. They report a positive impact of their curriculum on learning in science concepts and programming. [7], [10]

III. Development of the Curriculum

The guiding idea of developing the curriculum of our project was to create a broad knowledge of the basics and theory behind robotics followed by practical applications to solidify the understanding. Fig. 1 shows the developed curriculum.

A. *Developing the main topics*

Due to its importance in robotics, measurement and control was selected as a major pillar in the first phase of the development. Concerning measurement, the goal was to familiarize students with an array of commonly used sensors. In accordance with the guiding idea, that includes both why and how exactly a specific sensor works as well as its potential uses and how to best utilize them.

Control should contain the usage of information gained by sensors to affect the operations of the robot, specifically how to react to expected as well as unexpected measurements and how to detect and deal with potential errors.

The second main pillar, in accordance with our guiding idea was physics. This theoretic information was important to understand the function of the used sensors. The areas selected first were mechanical science, kinematics, energy, electricity and waves.

Lastly, in order to utilize the gained knowledge the two pillars robotics and computer science were added. Computer science contained mostly basic introductions to the different programming languages used. This also included an introduction to commonly used algorithms and advanced data structures.

In robotics, the aim was to give a broad overview over the field including both history and current developments. Additionally, this included advanced algorithms especially for the use with robots.

[3] http://www.education.rec.ri.cmu.edu/index.htm
[4] http://www.p21.org/
[5] http://waterbotics.org

B. *Implementation*

The final goal of the project was to create three certifications to be completed by students over the course of 12 years. In order to be able to convey the content most effectively 5 different course concepts were created. The first four were designed to be held approximately every 2 years. The 5th course was meant to be held after completion of all prerequisite courses and concludes with a final certification at the end of high school.

The basic layout of the courses is very similar. Each one has a different module for the five different main topics such as Introduction, Mechanics/Electronics, Computer Science, Sensors/Actuators and Group Projects.

1) *Introduction*

The Introduction modules are designed to give students a first insight into robotics. The first two modules focus mostly on the representation of robots in popular media and compares it to actual models in today's operation. This helps to create a more realistic image of robots and their capabilities. Later modules focus more on how different types of robots are commonly used and how those robots are created while the last course discusses the ethics of robots, specifically their use in warfare.

All introduction modules also include the history of robotics in varying detail as well as an overview of commonly used robots today. Furthermore they show the most recent experimental models and provide a future outlook.

The goal of these modules is to give a very broad overview of different robots. The purpose here should not be to make students learn dates or names but to awaken their interest and make them think about the influence of robotics in our lives.

2) *Mechanics/Electronics*

The Mechanics/Electronics modules are much more differentiated than the Introduction modules. They mostly cover theory starting with a very simple overview of robot construction and the basic function of an electric motor.

Later modules introduce more advanced construction methods and have an increasing focus on the physics behind different sensors and other robot parts.

Important to note is that since those modules consist mostly of theoretic knowledge it is recommended that they are interspersed with the outer modules. Specifically the physics of sensors are most effective when the students are able to see how the different sensors work and can try out different applications for the sensors themselves.

3) *Computer Science*

As with the Mechanics/Electronics modules, the Computer Science is most effective when used in conjunction with practical exercises where students can immediately see the effects of their programs.

The first module is designed to be appropriate even for students who are not yet proficient in writing, math or general use of computers. Therefore a robot that does not require a separate input via a computer should be used here to allow a focus on the logic behind a program and minimize the time spent on teaching basics outside of the scope of this course.

The 2nd and 3rd module concentrate on programming with a graphical user interface. Similar to the first module this is meant to ensure an easy introduction into programming and focuses on the use of different commands. The 3rd module also introduces data storage flow control structures.

The 4th module introduces text based, imperative programming and concentrates mostly on establishing a solid basis for the last course, which applies that knowledge in programming a microcontroller.

More than any other topic, Computer Science modules are very much dependent on their prerequisites. They may be adapted to suit students with less preexisting knowledge, but only at a significant time cost since the modules are designed to rely upon a specific level of knowledge. Conversely however, students with a more advanced knowledge of computer science may need an adapted module to sufficiently challenge them or may even visit a later course.

4) Sensors/Actuators

These modules focus mostly on introducing the sensors used in the respective course as well as the commands used in the respective programming language. From the 3rd module onward, it also includes information how to interpret data from more advanced sensors as well as how to detect incorrect results and how to deal with them.

5) Group Project

The Group Project modules are inspired by the tasks of the RoboCupJunior. The 1st module is a collaboration task and should contain at least 2 robots working together or at least simultaneously in the same area. It can and should be adapted to suit the specific capabilities of the respective group of students in order to sufficiently challenge them but also be achievable for weaker students. The goal in the first course should not to be make a student into a programmer but to cultivate their interest into robotics and computer science.

The 2nd module is adapted from the Dance discipline of the RoboCupJunior[6]. Similar to the 1st module it allows an easy adaptation to different groups of students in order to give an appropriately motivating challenge. The task should also be further specified to an interesting area to the students so that the time spent finding and trying out ideas is minimized. If necessary, a teacher can also give some predefined options to choose from in order to concentrate of honing their programming skills rather than extending the creative process.

The 4th module is based on the Soccer discipline. It is worth noting that although it may be possible to modify the task so that no arena is needed, may be very difficult without significantly changing the intended purpose of the task. Also, of all the tasks, this is one of the most open and can very easily lead to some groups concentrating too much on specific features and as a result not being able to complete the basic functions like finding the ball or the goal. Therefore close supervision by the teacher is required in order to guide the students and ensure equal competition. In some cases it may even be beneficial to provide a premade solution for those basic functions so that the students can focus on extending their other features.

The 3rd module uses the very popular RescueA discipline as a template. As with the previous modules, it is recommended to restrict or extend the task as needed. The task can also be modified so that it does not need the arena specified in the RescueA rules.

Lastly, the 5th module is modelled after the RescueB discipline which has a robot navigating a maze and finding heat sources on the wall. Be advised that this task requires a significant effort both in procuring appropriate sensors for heat detection as well as constructing an arena and outfitting it with heat sources. Since microcontroller programming allows for easily more severe errors to occur, it also requires significant oversight by a teacher in order to minimize potential damage to the robots. As with the previous module a basic solution for some problems may be provided in order to speed up development of other features.

All of the Group Project modules are meant to give the students a specific goal to attain with the completion of a course that has a more personal meaning to them than a certification. Therefore the projects are structured to be solved in groups of 3 to 4 people and the module concludes with a competition where the teams either compete directly against each other or are scored by a jury. Furthermore, the students should work mostly on their own with only guiding interference by a teacher. Optimally this module is even started with a short introduction to possible methods of working in a group.

Lastly, while there is an exam for the certification in certain courses the aim of this particular module is not just to teach working as a group but also, like the introduction, to nurture the students interest in robotics and computer science. As such, it is of the utmost importance that all students are continuously encouraged and motivated by the teacher.

After developing the curriculum matrix course description of each module were written down to ensure the right implementation of teachers. They describe scope, duration, prior knowledge, literature recommendations, necessary material, content of teaching and forms of teaching and learning.

IV. Certification

Based on the experience of the Austrian Computer Society in developing certifications, like the “European Computer Driving Licence”[7], one part of the project was to offer students the possibility to take a certification exam after participating in the courses.

The project’s long-term objective was to create three certifications throughout the curriculum. The first one should be available after the first two courses at the end of primary school. The second certification should be settled after finishing middle school and the last one after high school.

[6] The rules for the RoboCupJunior Dance, RescueA, RescueB and Soccer leagues can be found at: http://robocupjunior.org

[7] http://www.ocg.at/en/node/158

	Level of education	Introduction	Mechanics/Electronics	Computer Science	Sensors/Actuators	Group Project
Primary school	1+2	**Robotics in Society** Media vs. Reality Types of Robots Current Robots	**Propulsion & Construction 1** Simple Engines Basic Construction	**Find the Way 1** Basic Navigation Tasks Basic Planning Simple Commands	**Move the Robot** Basic Sensors (sound) Basic Motions Time & Speed	Collaboration Task
	3+4	**Robotics in Society** Media vs. Reality Types of Robots Current Robots	**Propulsion & Construction 2** Gear Transmission Engines Construction	**Find the Way 2** Graphic Programming Driving simple shapes Feedback with Display & Sound	**Sensors 1** Ultrasonic Sensor Touch Sensor Light Sensor	Creative Task
Middle school	5+6	**Robotics in Society** Engineering Design Process Types of Robots Current Robots	**Basic Physics** Physics Mathematics Construction	**Programming 1** Advanced Graphic Programming Loops & Switches Conditions & Events Variables & Data Storage	**Sensors 2** Advanced Sensors Sensor Precision Data Interpretation Basic Error Handling	Rescue Task
	7+8	**Robotics in Society** Engineering Design Process Types of Robots Current Robots	**Advanced Physics** Waves & Frequency Force & Energy Bluetooth & W-LAN Advanced Construction	**Programming 2** Imperative Programming (text-based) Basic Algorithms Basic Data Structures	**Sensors 3** Infrared Sensor Advanced Error Handling Data Filters Infrared Sensor Compass Sensor	Robot Soccer
High school	9-12	**Robot Ethics** Engineering Design Process Robotics in Warfare Current Robots	**Advanced** Kinematics Electricity, Voltage & Resistance Trigonometry Advanced Construction	**Microcontroller Programming** Synchronization Advanced Algorithms	**Measurement & Control** PID-Controller Passive Infrared Sensor Advanced Sensors	Pathfinding Task

Fig. 1. Developed Curiculum Matrix of the project READY

However, as a pilot in this project only a certification for middle school (10 to 14 year-olds) was developed. Based on the developed curriculum for middle school, educational goals were formulated. This learning goal oriented didactic gives the possibility to fixate the learning success. Therefore the lessons are structured in order to meet those learning goals. The transparent specification of the pursued goals allows an improvement of the teaching activities.

In detail the process of defining the learning goals was a deduction process from the main topics and area of knowledge. Fig. 2 shows an extract of the learning goal catalogue.

Category	Knowledge area	Number	Learning goal - After the teaching unit the students are able to…	Amount of teaching units
1 Introduction	1.1 types of robots – current robots	1.1.1	define a robot with their own words	1 TU
		1.1.2	explain the differences between various robots	
	1.2 Engineering design process	1.2.1	apply a basic engineering thought process	
	1.3 Robotics in society	1.3.1	give an overview of the development of robotics (status quo and future development)	
2 Physics	2.1 Waves and frequency	2.1.1	differentiate various kinds of waves and their usage	2 TU
		2.1.2	handle and manage an ultrasonic sensor	

Fig. 2. Learning goal catalogue of project READY

Based on the learning goal catalogue, the questions for the exam were defined. This method was used to ensure that the students are able to pass their exams. The assembly of questions was chosen for every student differently according to the random principle, based on the rule to take from each category at least one question. Mode of examination was the single choice principle (one answer is correct out of four possible).

This gives the possibility to evaluate the exams fast, even though they were carried out on paper. Nevertheless, on a future's perspective it is planned to create a database with more questions and to examine the exam on the computer.

In this project one class of middle school of the partner schools got the opportunity to make the certification. The certification took place two weeks after the last teaching unit, so that the students had the information fresh in their memory. Additionally the students got a script to prepare for the exam so as to repeat the contents taught in class.

Fig. 3. Presentation of the certification through the headmaster of the school © OCG

Eighteen out of twenty students passed the exam and therefore got the "OCG Certified Junior Robotics Engineer". Fig. 3 shows the presentation of the certification through the headmaster of the school. An example of the certificate is shown in Fig. 4.

Fig. 4. Example of a certificate “OCG CERTIFIED JUNIOR ROBOTICS ENGINEER”

V. IMPLEMENTATION

The project was implemented in five different schools: three primary schools, one middle school and one high school. Each of the five developed courses were implemented in at least two classes.

The implementation of the curriculum was workshop based and adjusted to the timetables of the classes. Therefore the workshops were organized differently. In primary school the workshops took place on two sequential days, in middle school the workshops were held weekly over a period of three months (à three hours) and in high school one-week block courses were defined. Teachers of different subjects (mathematics, computer science, handicrafts, etc.) made their lessons available in order to have the possibility to implement the curriculum in the student’s timetable.

Regarding the design of a consistent curriculum, in this pilot the first lessons were used to teach the necessary contents from previous courses in order to have the required basis to be able to implement the topics of the curriculum. In the future the workshops can be implemented according to the curriculum.

The workshops were designed for the students to work on the tasks in teams of two using hands-on robotics technology due to its motivational effect. Therefore each class was equipped with different robot kits. In primary school and middle school Lego Mindstorms NXT kits were used, whereas in high school acrob-robot kits developed by Slovak University of Technology in Bratislava [11] were applied. Those kits are now property of the school, so that sustainability can be ensured. It should further be noted that the curriculum was developed independently of any specific robot technology. Consequently, if a school is in possession of any other appropriate kit, it can be used as well.

Moreover, the curriculum was developed in the context of gender studies in order to address girls and boys equally, based on the experience in developing workshop contents of the University of Applied Sciences Technikum Wien. Since typical classes consist of mixed gender we specifically wanted to appeal to all students equally. Short introductions in the form of videos, pictures, stories were used to inspire curiosity and motivation. Working with the robots facilitates the understanding of the topics and leads to enthusiasm among the students.

The teachers who were students of the University of Applied Sciences Technikum Wien have been trained according to the curriculum, the module descriptions and the learning goals. Those students already had a lot of experience in teaching kids and young students. But the courses are meant to be taught by anyone with general education in programming and sufficient interest in robotics.

Additionally to the courses two companies also supervised those selected classes. Those “Buddys” gave an age-based insight in their daily business work and showed the innovative implementation of robotics in business context.

Fig. 5. Workshop in primary school using LEGO MINDSTORMS NXT © OCG

Fig. 6. Workshop in middle school
© OCG

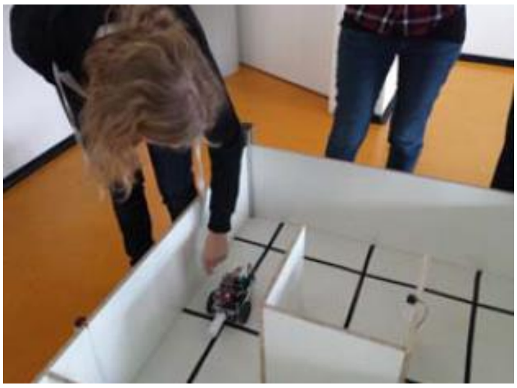

Fig. 7. Workshop in high school, testing in the RescueB Arena © OCG

VI. Future Work

Robotics is used to foster STEM education in many initiatives. Hands-on experiments have shown to be an appropriate instrument for the implementation of those projects.

In this paper we presented a multi-grade, consistent and gender neutral curriculum for kids and students from primary school until the end of high school in the field of robotics, computer science, measurement and control.
The implementation was a pilot scheme. In the future we want to include the experiences of the first implementation to improve the curriculum. Additionally a scientific evaluation is intended in order to measure the impact of the programme. We would also like to hold further courses in the participating classes after the intended time has passed in order to evaluate knowledge retention and adapt the curriculum as necessary. After our first evaluation stage is completed we are also planning to provide specifically tailored curricula to support school types with varying focus on programming and technical skills in general and to achieve recognition by other universities and technical companies.

Based on the experiences in developing the curriculum for the project READY, the University of Applied Sciences Technikum Wien is currently working on a module of a curriculum for highly gifted students of on behalf of the "Talentehaus"[8], a subsidiary of the "Landesakademie Niederösterreich". Their goal is to promote highly gifted students additionally to their regular school education in the STEM field. Therefore they introduced a robotic curriculum, which consists of two modules: robot programming and robot construction. Whereas the first module is already developed and implemented, the development of the second module just started.

[8] http://www.talentehaus.at/talentehaus/

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