RїE 2015

Proceedings

6ᵗʰ International Conference on Robotics in Education

Yverdon-les-Bains, Switzerland, 20 - 23 May 2015

Jean-Daniel Dessimoz, Richard Balogh, David Obdržálek, Editors, May 2016

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Roboptics Edition

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Dear RiE 2015 Participant,

Welcome to RiE 2015 Conference.

RiE international conferences on Robotics in Education aim at providing an insight to state-of-the-art educational robotics to participants from both academic and school education. They allow to report on latest results in the fields of research and development as well as new applications, the latest products, systems and components for using robotics in schools, in universities and in informal education.

RiE international conferences have a history of previous successful editions, which witness the continuously growing interest in educational robotics in Europe and world-wide. They had counted so far 5 editions; in Bratislava (2010), Vienna (2011), Prague (2012), Lodz (2013), and Padua (2014). And Yverdon-les-Bains, this year, in 2015, brings an additional contribution.

For the Conference, as expected, scientific exchanges between specialists are the goal. The 6th International RiE Conference, RiE 2015, however happens in a broader context both thematically and geographically. The final round of Eurobot robotics competition is organized this year at Yverdon-les-Bains, as well as the Swiss Robotics Cup and a Robotics competition between local, primary and secondary schools, along with the « Robots:15» festival and Yverdon-les-Bains "Year of Robot" events. Indeed, many activities relating to robots in the realms of art, science, technology, and education are organized these days in Yverdon-les-Bains. Welcome to this festival as well. This is also well in line with "Robot-Int", the Robotics-International initiative to promote robotics for the benefit of mankind, which should make a new step of development during these events.

Now let us see the program. The RiE 2015 Conference features two keynote lectures, relating to real-time robot simulation and space context. Mostly though, the presentations address more specific, scientific issues. The RiE 2015 Robotics in Education Conference mainly consists in six technical sessions where are discussed Methods and Best Practices, Education and Mechatronic Platforms, Curriculum Aspects, Competition-related Aspects, Conceptual Aspects and Cognition, and some other selected topics.

Beside RiE 2015 Conference and discussions, we hope that you, participants, will take advantage of the workshop opportunities, competitions and demos, that you will benefit from the wide offering of other events relating to robots, also in arts and education, and that maybe you will even go out and explore the beautiful region of Yverdon-les-Bains, with its lake and neighbouring mountains.

    Jean-Daniel Dessimoz, Richard Balogh and David Obdržálek Co-Chairmen of RiE 2015

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1. Methods and Best Practices

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Proposal of a low cost educational mobile robotics experiment: an approach based on hardware and simulation

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Abstract—In this paper it is presented an educational mobile robotics experiment based on a low cost mobile robot prototype and its simulation. The chosen educational robot challenge is a classical introductory experiment, that consists in following a line with a mobile robot based on the differential kinematics. The presented experiment has as goal to introduce students to the challenges of mobile robotics, initially programming a simulated robot, building a real robot and finally testing the developed code in a real robot. The robot was simulated using SimTwo, which is a realistic simulation software that can support several types of robots. Having as base the proposed challenge, a mobile robot competition was conducted as a part of the evaluation of the curricular unit of "Systems Based on Micro-Controllers" of the "Electrotechnical and Computer Engineering" course of the Faculty of Engineering of the University of Porto.

Fig. 1. SimTwo 3D View.

I. INTRODUCTION

In this paper it is presented an educational mobile robotics experiment based on a low cost mobile robot prototype and its simulation. The mobile robot, consists in a 3D printed small prototype, that uses inexpensive hardware, such as servo motors, an Arduino Uno platform and an infra-red detector array. For the proposed robot, continuous rotation is necessary, so the servo motors must be modified. This modification consists in disconnecting the position potentiometer from the gear train, setting the potentiometer to a fixed position, and removing the angle stops from the motor shaft. The robot is also equipped with the Zumo reflectance sensor, providing an easy way to add line sensing or edge detection. The chosen challenge is a classical introductory mobile robotics experiment, that consists in following a line with a mobile robot based on the differential kinematics [2] [3] [7] [14]. The presented experiment has as goal to introduce students to the world of mobile robotics, initially programming a simulated robot and finally testing the developed code in a real robot. The robot was simulated using SimTwo, shown in Figure 1, which is a realistic simulation software that can support several types of robots. Its main purpose is the simulation of mobile robots that can have wheels or legs, although industrial robots, conveyor belts and lighter-than-air vehicles can also be defined. Basically any type of terrestrial robot definable with rotative joints and/or wheels can be simulated in this software [1] [8] [13] [15].
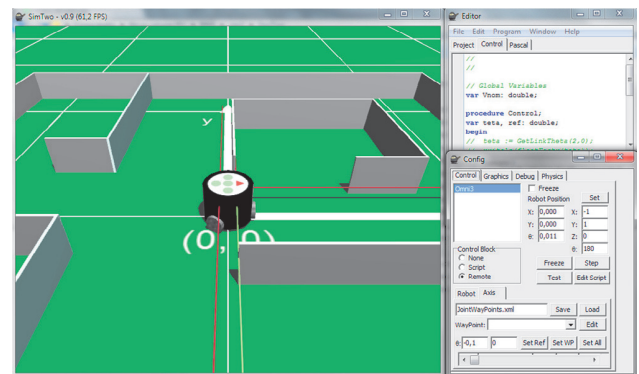
Having as base the proposed challenge, a mobile robot competition was conducted as a part of the evaluation of the curricular unit of "Systems Based on Micro-Controllers" of the "Electrotechnical and Computer Engineering" course of the Faculty of Engineering of the University of Porto. It was received feedback from the students, concerning the success of the mobile robotics experiment, based on that feedback some reflections were made. The students that participated in the referred robot competition are shown in Figure 2.

Fig. 2. Students at the mobile robot competition.

The paper is organized as follows: After a brief introduction

it is described the robot prototype and its model, then the mobile robotics experiment is introduced and finally some conclusions and future work are presented.

II. ROBOT PROTOTYPE DESCRIPTION

The prototyped mobile robot consists in a 3D printed small prototype, being presented in Figure 3, that uses inexpensive hardware, such as servo motors, an Arduino Uno platform and an infra-red detector array. The 3D printer models that were developed, in order to prototype the robot, are presented in Figure 4, where it can be seen the 3D models for the robot chassis and wheels 3D models. In the next subsections it will be introduced the prototype sensors and actuators description and their modeling.
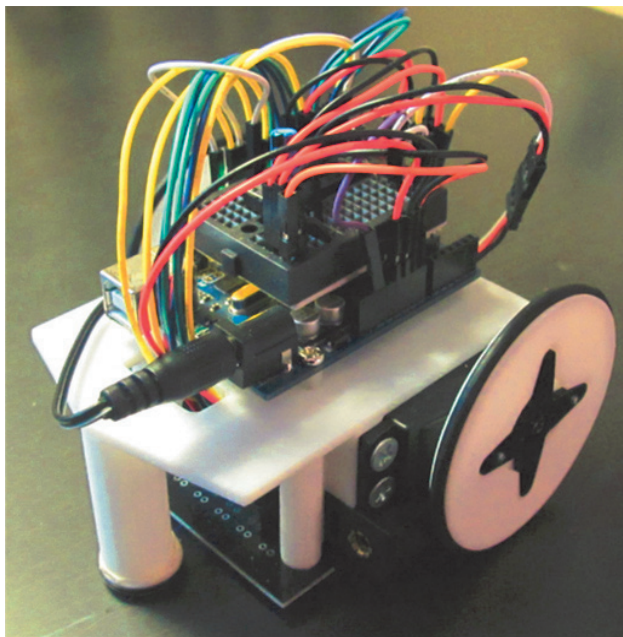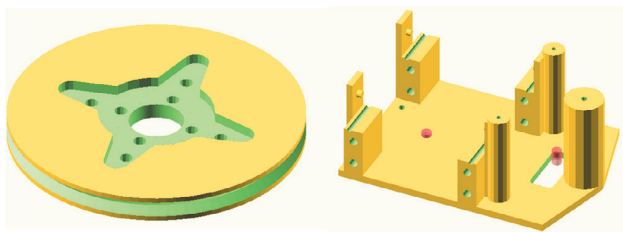

Fig. 3.   Robot prototype.

Fig. 4.   Robot prototype 3D printer models.

A. Sensors

The robot is equipped with the Zumo [4] reflectance sensor, providing an easy way to add line sensing or edge detection. It features six separate reflectance sensors, each consisting of an IR emitter coupled with a phototransistor that responds based on how much emitter light is reflected back to it. The purpose of using the referred sensor is to sense and follow a line. A Zumo reflectance sensor array with labeled sensors and dimensions is shown in Figure 5. More information about this

sensor can be found in [4]. The simulated model of the sensor returns binary information, it is assumed that if the sensor is above a black line it returns 1 and if not 0.
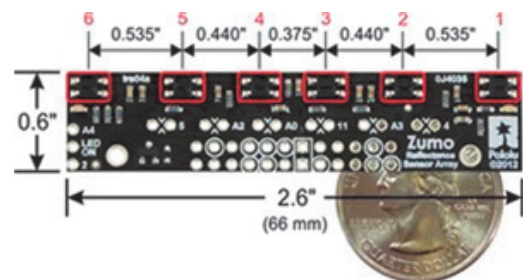

Fig. 5.   Zumo reflectance sensor [4].

B. Actuators

The robot actuator is the Futaba S3003 Servo. A servo motor is a complete assembly made of a small high RPM motor, gear reduction, H-Bridge and position control circuitry. If the servo is not modified it is used to produce a rotational position based on a Pulse Width Modulated (PWM) signal. The Futaba S3003 servo motor has three inputs: PWM (white), power (red), and ground (black). Based on the PWM signal the servo will turn its shaft to a position within a range of approximately 200 degrees. When a PWM command is given to the circuitry an error signal is produced. This error signal turns the motor in the appropriate direction. The motor gearing turns a position potentiometer, which gives a feedback signal to the position control circuitry. When the correct position is indicated by the potentiometer, the error signal becomes small enough, so the motor stops turning. For the proposed robot, continuous rotation is necessary, so the servo motors must be modified. This modification consists in disconnecting the position potentiometer from the gear train, setting the potentiometer for a known PWM signal and removing the angle stops from the motor shaft. Some offset developed by software is necessary to get the two motors to turn at the same speed. More detailed information of the Futaba S3003 servo motor and its modification can be found in [5].

In order to obtain the actuator model it was necessary to know for each control signal the output velocity of each modified servo-motor, incremental encoders were used for that purpose. The use of incremental encoders, as shown in Figure 6, is only necessary to obtain the actuator model. The used incremental encoders are an expensive piece of hardware that would increase considerably the cost of the robot prototype. A tachometer was used in order to convert the measured transitions per sample time to Rad/s. In order to measure the motor angular velocity with the tachometer, a printed black and white pattern with transitions was attached to a robot wheel.

The control signal is the same as for a standard servo, only this time the length of the on time pulse will affect the speed and directions. For a certain pulse width the servo will stop. Values above or below will make the servo rotate faster in either direction. The signal (d), depicted in Figure 7, is the difference for the stopping pulse width. This value must be divided by 40000, in order to obtain the time in seconds. As there is a gearbox with an high ratio, the dynamic response
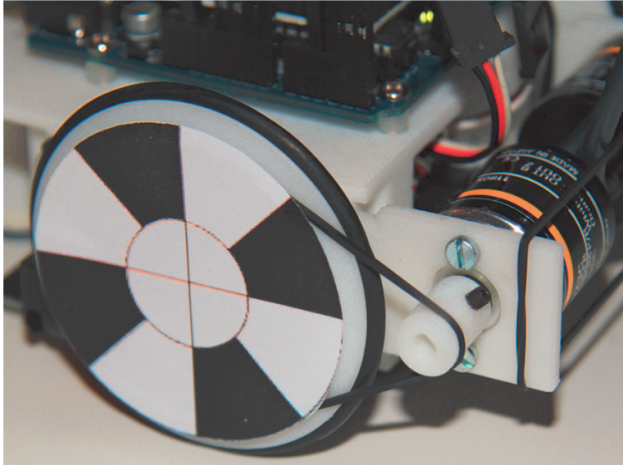
Fig. 6.   Robot with encoders.

is very fast. The most important aspect of the model is the non linearity introduced by the modified controller. This non linearity can be seen in Figure 7 where the steady state speed for a certain pulse width has a small dead zone and a non linear behavior as it approaches the maximum speed. In order to model these non linearities, equation 1, saturated for values inferior to zero, was estimated. Using the experimental speed measures the best fit was found by optimizing the values of $a_2..a_0$, $b_2..b_0$. The total error, being the sum of the absolute differences, was used as the target function [6]. The estimated values can be seen in Table I.

$$\omega(d) = \frac{a_2.d^2 + a_1.d + a_0}{b_2.d^2 + b_1.d + b_0} \qquad (1)$$

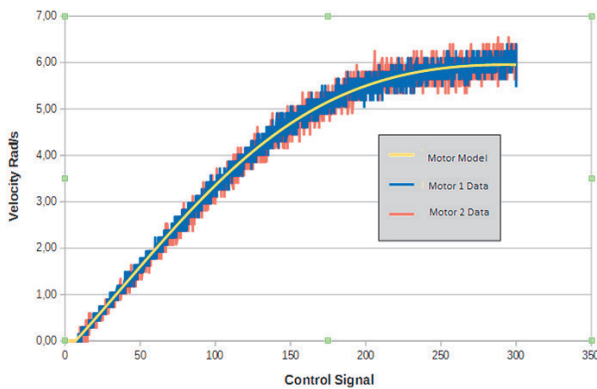| Parameters	Value
a_1	-34.760E-6
a_2	-69.581E-3
a_3	488.777E-3
b_1	-29.663E-6
b_2	2.278E-3
b_3	-1.964

TABLE I.   ESTIMATED PARAMETERS.

Fig. 7.   Futaba S3003 Model.

In order to invert equation 1, equation 2 can be obtained.

The solution for equation 2, corresponds to equation 3, resulting in a function with its domain from 0 to 5.955 Rad/s, that has as input a velocity and as output the servo control signal.

$$(\omega b_2 - a_2)d^2 + (\omega b_1 - a_1)d + \omega b_0 - a_0 = 0 \qquad (2)$$

$$d = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad (3)$$

where:

- $a = \omega b_2 - a_2 <$
- $b = \omega b_1 - a_1$
- $c = \omega b_0 - a_0$

For an input inside the referred function's domain, equation 3 returns two values, the chosen value must be equal or greater than 7 and less or equal than 293. Values from 0 to 6 are inside the dead zone and values superior to 293 correspond to the saturation zone.

III.   MOBILE ROBOTICS EXPERIMENT

Following a line with a robot based on the differential kinematics is a classical introductory experiment that allows students to be introduced to the challenges of mobile robotics. Understanding the concepts of sensor, actuator and locomotion are the primary goals of this experience based on the control of a reactive robot [14].

Initially the students develop the robot control using simulation, as shown in Figures 8 and 9. The simulator (SimTwo) sends the sensor data, at each sampling time, to a remote c standard application and the remote application returns the velocity that each robot wheel must have in order to perform its tasks, as shown in Figure 9. Finally the students can test the control algorithm just by compiling the program to be flashed on the microcontroller, as shown in Figure 9. The control function is a c standard function, being used either in the simulated as well as in the real environment.

The presented approach is very useful, whenever reducing costs is a primary goal, because several student groups can develop robot code simultaneously, using simulation, and then test the robot code in a prototype that can be shared by several groups of students, although in this competition each group had its own prototype.
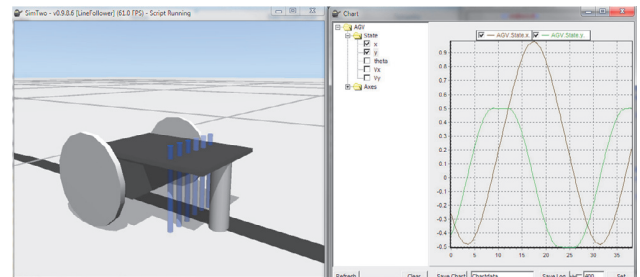

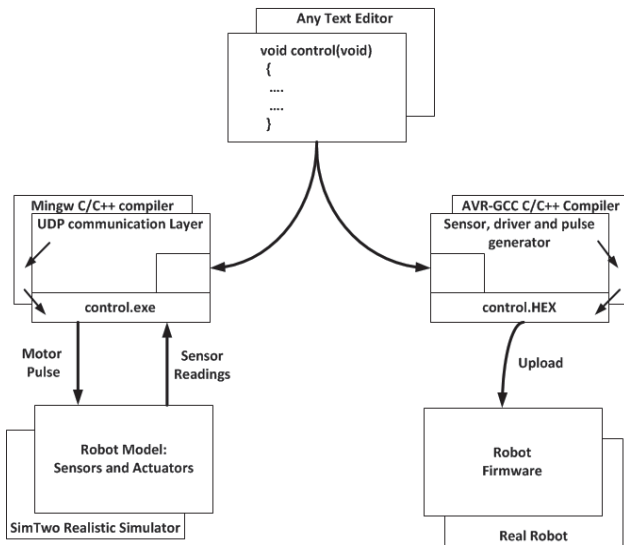Fig. 8.   Simulated Robot Experiment.

Fig. 9.   Robot experiment software development block diagram.

Fig. 10.   Students and their supervisors at the robot competition

In order to calculate the pulse width for the desired servo speed, a lookup table can be applied. On the other hand a more experienced programmer can use a more complexe approach. The previously presented equation model for the Futaba modified servo can be inverted, having in mind that the servo speed will saturate for nearly 5.955 Rad/s, for an input of 293. The input increase beyond this value wont produce a higher speed value. The programmer must also take in account that the inverted equation is valid only for inputs superior or equal to 7, due to the servo dead zone. The pulse value in seconds is calculated dividing the input value by 40000, finally this value is summed to the stopping pulse width for a positive speed rotation, and subtracted for a negative speed.

Each student group had 10 minutes to participate in the competition, making as many attempts that they like to make. Their robot has to complete the circuit three times, if the robot stops after completing this task a 10 % bonus is subtracted from the time spent. That can be done by counting laps, using a special marker present on the track. The winning team is the one that spends the lowest time to complete the challenge. Some students and their supervisors, preparing their robots for the competition, are shown in Figure 10.

IV.   STUDENT FEEDBACK

In order to receive feedback regarding the effectiveness of the mobile robotics experiment an inquire was made to the students that participated in the mobile robots competition. The inquire was performed by 24 Students, having for each question the option to answer from 1 to 5, where 1 is "I totally disagree", 3 is "I am neutral" and 5 is "I totally agree". Bellow the inquire results can be found, where the average results and the standard deviation (STDV) of the students answers are presented.
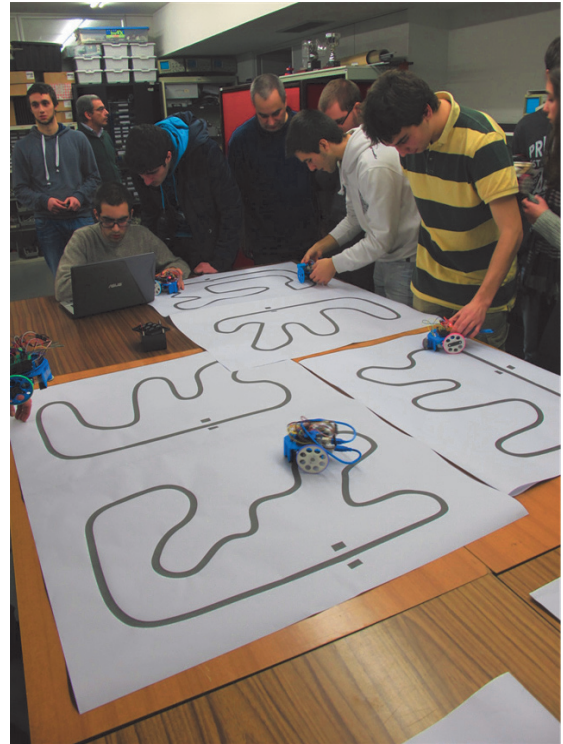
Question:	Average	STDV
The theoretical classes were important for the curricular unit learning process?	3.3	1.3
Practical classes were important for the curricular unit learning process?	4.5	0.8
Were you able to chose the practical work?	4.6	0.7
Laboratory classes were useful for the curricular unit learning process?	4.1	1.0
Do you prefer to be evaluated by laboratory works?	4.5	0.7
The laboratory work is useful for the curricular unit learning process?	4.7	0.6
Would you like to have more laboratory works?	3.6	1.1
Would you like to have complexer laboratory works?	3.3	1.0
The work with the robot was useful for the curricular unit learning process?	4.6	0.5
The participation in the robot competition generated more motivation?	3.9	1.1
Would you like to work again with robots in different curricular units?	4.5	0.7
Working with robots is important to motivate yourself to other curricular units?	4.0	1.1
Working with robots was important to understand the curricular unit contents?	4.0	0.9
Would you like to spend more time working with robots?	4.0	0.8
Simulation was important for the code development?	4.0	0.8

It was concluded from the inquire results that students were substantially motivated for the curricular unit study, mainly because the laboratory work involved mobile robots. The fact that the results of the laboratory work were applied in a final robot competition was an extra motivation, because students like to compete [9][10][11][12]. It was also observed that the students were happy with the fact that the laboratory work reflected almost all the contents of the curricular unit, helping them to be better prepared for the individual written evaluation. It was also concluded that the presented laboratory work was a first option for the major part of the students, there were different options for the practical evaluation and the competition was not mandatory.

V. CONCLUSIONS AND FUTURE WORK

In this paper it is presented an educational mobile robotics experiment based on a low cost mobile robot prototype and its simulation. The mobile robot consists in a 3D printed small prototype, that uses inexpensive hardware, such as servo motors, an Arduino Uno platform and an infra-red detector array. The robot was simulated using SimTwo, which is a realistic simulation software that can support several types of robots.

The chosen educational robot challenge is a classical introductory experiment, that consists in following a line with a mobile robot based on the differential kinematics. The presented experiment has as goal to introduce students to the challenges of mobile robotics, initially programming a simulated robot and finally testing the developed code in a real robot.

The presented approach is very useful, whenever reducing costs is a primary goal, because several student groups can develop robot code simultaneously, using simulation, and then test the robot code in a prototype that can be shared by several groups of students. This approach is very convenient, for example, for schools of developing countries that usually have reduced budget.

The modeling and simulation information of a modified Futaba S3003 Servo-Motor, presented in this paper, is a relevant information, mainly for teams that use this servo in robot competitions, allowing them to learn how to modify it, to understand in detail the servo internal controller and also how to simulate it, testing robot controllers without accessing to hardware.

It was concluded from the inquire results that students were substantially motivated for the curricular unit study, mainly because the laboratory work involved mobile robots. The fact that the results of the laboratory work were applied in a final robot competition was an extra motivation, because students like to compete. It was also observed that the students were happy with the fact that the laboratory work reflected almost all the contents of the curricular unit, helping them to be better prepared for the individual written evaluation. Overall it was observed that students like laboratory works, robots, competitions and stated that simulation can also be a good help to develop robot code without access to hardware.

As future work the authors would like to organize another editions of the robot competition and to evolve the available robot prototypes.

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Using Educational Robotics Research to Transform the Classroom

Establishing a Robotics Community of Evidenced-based Practice using MESH Guides and the TACTICS Framework

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Abstract— **Trends in the USA and UK insist that classroom interventions are supported by evidence of their efficacy. The body of evidence supporting the value of educational robots is growing. However, a perennial problem remains, how can such evidence impact everyday teaching and the use of educational robots in the classroom? MESHGuides are created by an international network of educators who are mapping the research base underpinning educational practice and making it readily available to teachers anywhere in the world. The TACTICS Framework sets a standard for how research information should be integrated into evidenced-based activities and how these activities can be used to inform research. This paper introduces these ideas and shows how they have been applied to the Turtle type educational robot, Roamer.**

Keywords—MESHGuides, TACTICS, Roamer, Educational Robotics, Turtle, Teaching with Robots, TWR, Evidenced Based Education, SBR

I. INTRODUCTION

Educational Robots are tools with the potential to help teachers deliver the curriculum in most subjects and across most of pre-K-12 education. In the UK the use of robots (programmable toys) has been part of the National Curriculum since 1989 [1]. However, despite this Valiant Technology's commercial experience (confirmed with a number of other vendors) shows that few teachers use educational robots to their full potential. To get the most out of educational robots requires a high level of teaching skills and expertise with the technology. To transform this situation requires both and in most cases this requires a systemic change. The Educational Robotic Application (ERA) Practical Principle identifies five elements necessary to achieve such change: Vision, teacher buy-in, training, resources and an action plan [2].

This paper reports on work aimed at supporting this type of transformation on an international scale using Web 2.0 technologies. It builds on previous research relating to Turtle Type robots in general and especially with the Roamer. It reaffirms that appropriate training and the availability of high quality activities that meet the requirements of the ERA Principles are essential for the widespread adoption of educational robots. The ERA Curriculum and Assessment Principle is particularly important. This states "*Educational Robots can facilitate teaching, learning and assessment in traditional curriculum areas by supporting good teaching practice*". Catlin [3] proposed that the approach described as Assessment for Learning (AfL) based on the work of Black and

William [4] captured "good teaching practice" in a series of strategies that bear a natural empathy with educational robotics.

There is another factor, which has increasing importance: the need for educational interventions to be evidence based. Catlin and Blamires discuss the problems associated with this in e-Robot [5]. They proposed that it was important the research informed practice and practice informed research. Moreover, they proposed that such research needed to be ongoing over decades, not years, and the only practical way of doing this was via the internet. Valiant has been developing such systems over the last few years and now has an integrated Activity Library [6] and Training site [7][1]. This provides teachers with "just-in-time" and "on-the-job" training embedded in each activity. There still remains a number of challenges: how does such a system collect data about the effectiveness of each activity, how can such information be coordinated with other research and how can it be made accessible to classroom teachers? The recent launch of the MESHGuide[2] initiative provides an answer to these questions. This is supplemented by the TACTICS framework which provides an organising structure for ensuring that research is built into interventions and that the outcomes of interventions inform research.

This paper first reviews the current demand for evidenced based interventions. It will then discuss how this impacts educational robotics, before introducing TACTICS[3] and MESHGuides. It then illustrates how this is being applied to Roamer before concluding with an outline of work still to be done.

II. SCIENTIFIC BASED EDUCATIONAL RESEARCH

In 2001 the No Child Left Behind (NCLB) Act was launched in the USA. One aspect of this programme was the insistence that Federal funding could only be spent on interventions that were validated by Scientifically Based Research (SBR) [8]. The US authorities presented the medical research model as something education should emulate. A similar sentiment, but without the financial cudgel, was promoted in England by Michael Gove, the erstwhile Secretary

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[1] Apply for a Guest Login to access these sites.
[2] **M**apping **E**ducational **S**pecialist know How
[3] **T**argeting relevant outcomes, **A**nalyzing best practice, **C**larifying environmental considerations, **T**ranslating best practice, **I**nterpreting resulting outcomes, **C**ommenting on transformations, and **S**electing next steps.

of State for Education when he urged Ben Goldacre, the author of Bad Science [9], to write and champion a similar concept [10]. These sources promote a hierarchy of research methods which made Random Control Trials (RCT) the gold standard. Some of the rhetoric supporting this position has been dismissive of the qualitative paradigms like ethnomethodology which when used with educational robots has proven to be a useful tool in revealing the thinking process of students [11]. The debate is not new. Cohen and Mannion review the theoretical aspects of both sides [12] and Darling describes the effect of a previous positivist attempts at eliminating qualitative research [13].

It is easy to agree that evidence based practice can only be a good thing. The issue is what constitutes good evidence? Catlin and Blamires [5] propose the use of the internet as a means of gathering and collating teachers experiences. Hans Rosling, who like Ben Goldacre is an epidemiologist, proposes that this is a new way to gather "valid evidence" [14].

The US Government supported their policy by setting up the What Works Clearing House [15]. The aim of this was to collect and collate evidence to inform teaching practice. So far 10,500 study reviews are available. Yet this has resulted in a moderate 18 practice guides containing recommendations about how teachers can use this research to improve their teaching practice. A similar "what works clearing house" has been established in the UK with the Sutton Trust. For educational robots to gain credibility in this climate, the production of suitable guides is essential.

III. ISSUES WITH EDUCATIONAL ROBOTS

It is difficult to "prove educational robots work" because the robot is a tool. The challenge is akin to proving that a pencil works! Clearly it depends on what you do with it and your skill at using the technology. The nature of the activities vary; for example the Number Grab Activity [16] is radically different from the Roamer Spacecraft Rescue project. The latter was recently subject of a doctoral dissertation [17]. It is a reasonable, but impractical argument that almost every activity deserves similar doctoral scrutiny. This problem was addressed with the publication of the Principles of Educational Robotic Applications (ERA) [2]. This summarised 30 years of empirical experience of educational robots into ten basic tenets that could be used for the purpose of meta-analysis; review of the value of educational robots and the design of new robots and activities.

At this stage ERA is a hypothesis and the e-Robot project was proposed as a strategy for developing and validating the theory. e-Robot criticises the restrictive approach of NCLB Research and states a more eclectic view on what constitutes valid evidence [5]. Thorndike pioneered the application of SBR in education. He was very much the scientist dispensing wisdom to classroom drudges [18]. Teachers were there to apply other people's thinking. Under NCLB a teacher's practical experience is disparaged as anecdotal. Yet the reality is most teachers rely on their experience, which is often by its nature expressed in anecdotal form. One argument against this form of evidence is that "Sometimes they [anecdotes] are very representative, sometimes they're not. The problem is we don't know when." [8]. The e-Robot project proposes that we can use

the web to find out whether such evidence is representative of a wider view.

The e-Robot perspective is that all data and various valid research techniques can contribute to the evidential base. It suggests that there is a constant interplay where research informs practice and practice informs research. Interplay also works between activities and ERA. The data collected from activities can assist the verification of ERA and ERA can help the formulation of the activities. The MESHGuides offer a way of collating and presenting the various forms of evidence in a way that is accessible to teachers. They represent an educational version of the NICE Guidelines used by the medical profession in England and Wales to resolve a similar problem is disseminating research information to medical practitioners [19].

IV. TEACHER SKILLS

The US Department of Education classifies teachers in accordance with their experience [20]. For our purpose we use Resident Teacher (someone just out of teacher training) and Master Teacher (an exemplary educator who models effective teaching practices and acts as a resource for the whole school). Not everyone who uses Roamer in a teaching situation is a trained teacher. The other dimension of the skill is the ability of the teacher to use the technology effectively (see Fig 1).
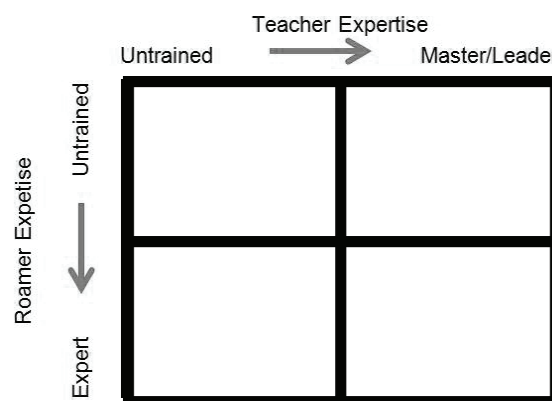
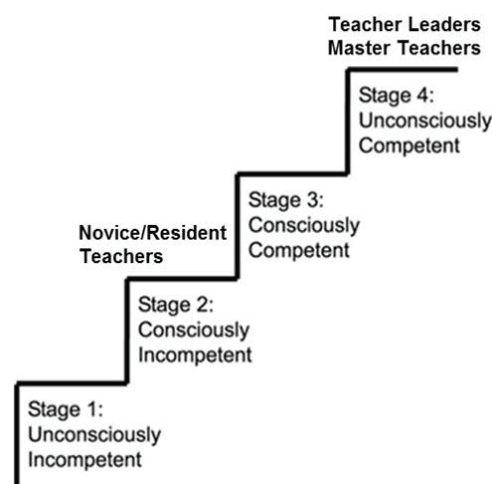

Fig 1 Teacher Skill Matrix

Fig 2 Gordon's Ladder of Competence

The potential of a successful outcome depends on the teacher's position in this skill matrix. To meet the requirements of the ERA Practical Principle, any activity needs to take into account potential short comings in these skills, which essentially means activities must also incorporate appropriate training. Created by Noel Burch, the Gordon's Skill Ladder (Fig 2) offers another way of viewing teacher's competence [21]. While training built into the activity can move people from Step 1 to Step 2, only practice and continual training can help people make the transition from 2 to 3 to 4. TACTICS [22] provides a framework that sets a standard for activities. The standard aims to support the transfer of expertise from master teachers and the process of gathering evidence of practice.

V. THE TACTICS FRAMEWORK

The TACTICS Framework shown in Table I provides teachers with the seven elements necessary for creating an effective activity.

TABLE I. THE TACTICS FRAMEWORK

TACTICS Element	Definition
Targeting relevant outcomes	Links to national or state curriculum standards and the learning intentions identified by the student
Analysing best practice	What is the best evidentially based approach (AfL, MESHGuides, ERA Principles, Practice Guides, etc.)
Clarifying environmental considerations	What are the pertinent characteristics of the learning environment engaged in the activity.
Translating best practice	The contextualization of a known best practice , c.f. a research informed lesson and assessment plan.
Interpreting resulting outcomes	Measuring and recording the outcomes with qualitative comments on what happened in the activity.
Commenting on transformations	A brief comment on the overall impact of the activity on the teacher and learner.
Selecting next steps	Decision on what to do to further improve learning outcomes based on the results.

The design of the TACTICS process reflects a consideration of translational research [23] a methodology, which has its critics [24], but is establishing a presence in the medical field [25] as an approach to rapidly translate research findings into practical setting like classrooms.

Valiant has invested a significant amount of research into the development of a Roamer activity structure, independent of TACTICS. There was around a 90% correlation between the two approaches. The TACTICS framework was used to modify the Roamer Activity Structure and was particularly helpful in regard to the development of the Lesson Evaluation feature which meets the e-Robot data gathering requirements. Establishing a standard approach towards gathering and disseminating research, and incorporating it into the development and presentation of activities has the benefit of making it easier for teachers to quickly comprehend and implement activities (The ERA Practical Principle). The TACTICS Framework offers a structure for this process.

VI. MESHGUIDES

MESH is a key global initiative to understanding how 21st-century technologies can be harnessed to improve the quality, relevance and timeliness of educational research [26]. MESH (Mapping Educational Specialist know How) is a global knowledge management strategy. It produces a MESHGuide: an online resource (equivalent to the US Practice Guides) which links to evidence, collates, cross references and summarises it. It is accessed and supported by an online network, which links practitioners and researchers enabling them to form working groups, or communities of practice.

The MESHGuides initiative was developed by the Education Futures Collaboration (EFC), which is an educational charity in which the founder members were inspired by a variety of approaches in the field of medicine and other public sector organisations with respect to knowledge management strategies. The governance of the MESHGuides initiative is managed by the Education Futures Collaboration charity.

Given that published educational research is rarely focused on the knowledge teachers need to improve their professional practice, MESHGuides seek to change this so practice and theory are 'mesh-ed' together to provide research-based advice for teachers. MESH is a worldwide network of educators freely sharing, and building professional knowledge. MESHGuides synthesise and make accessible the evidence base for educational practice from across the world so that teachers at all levels can keep up to date easily. For researchers, good practice in research writing includes communicating findings to users and this includes teacher practitioners.

To achieve this vision, the MESHGuides website enables research to be accessible at the touch of a button, as any internet enabled device will be able to access the guides or knowledge maps of educational research. This means that the widespread uptake of mobile technologies will enable practitioners as well as academic researchers to connect to a large body of knowledge, in the form of previously published research, which helps to ensure evidence- based professional practice.

The long term aim is to have a completed A to Z index, which covers all curriculum subjects and areas of educational interest, alongside key concepts and generic issues, such as assessment, pedagogy, SEN, threshold concepts, barriers to learning and so on, so that the index is searchable by key term. The use of an A-Z index is how the maps of medicine are organised for the medical profession to access research evidence. The MESHGuides are overseen by editorial boards of academics and teacher practitioners who review the guides once they have been written and submitted. The guides are then subject to peer review and an editorial process, which provides a quality assurance process that is the same as print publishing of educational research. This process allows experts to contribute to a range of guides within their expertise and to interact and network with colleagues in the same field. Thus collaboration is between academic researchers and teacher practitioners, who have a dynamic expertise between them of theory and practice. This frees research from the circle, in which academic research resides behind the firewall of

academic journals (to be read almost solely by other academics), preventing teachers having their practice informed by research, unless they can access the research databases behind University library paywalls. Free at point of access, MESHGuides provide an overview of educational research on a given topic. It references previous published research, and enables the profession to utilise the evidence to inform both future practice and research. While the Guides summarise known research, they also make the raw data and references accessible to other researchers, which enables individual reviewers to make up their own mind about the quality of the evidence.

VII. MESHGUIDE FOR ROAMER

The MESHGuide resolve the issues identified in the e-Robot paper. For the reasons cited above it is an ideal tool for handling evidence on Roamer's effectiveness and the validity of the ERA Principles. The following is structure of the MESHGuide entitled: Educational robots: why use a Roamer robot in the classroom [27]? The rest of this paper will review this structure and use the Roamer Activity Number Grab (Whole Numbers) to illustrate various issues [28].

A key aim of the e-Robot research programme is the verification/development of the ERA Principles. These effectively provide a summary of evidence of why educational robots are effective educational tools. The MESHGuide is focused on the definition of these principles, linked to the currently available evidence. It includes a summary of the status of the evidence supporting the principle and what work needs to be done. The rest of the guide is set up to gather evidence from three different sources: first substantial data available from Logo and Turtle research, relevant data from various scientific fields (developmental psychology, AI, science of learning, etc.) and the information gathered from activities in the Roamer Activity Library. These activities derive from various sources: Valiant's archives, teacher submissions and Valiant's new activity development efforts. TACTICS compliance provides a natural two-way information flow between activity and research.

Fig 3 shows the MESHGuide Matrix. The amount of evidence will be substantial so it requires categorization. It is organised according to its research format (peer reviewed journals, dissertations, action research, etc.). It was considered that this section should be organised around topics. Teachers will want to find evidence for topics. However, the topic range is too large and subject to variations like spelling differences. So the plan is to use tags to identify topics and facilitate a tag search feature. The context will derive from data collected from the schools using the activities. Once sufficient data has been collected it can be summarised into useful categories. The activities are linked to the evidence and cross referenced to subjects, age groups and cultural situation. The design of the activities provide evidence for the ERA Principles: Sustainable Learning, Curriculum and Assessment, and Pedagogical. All of this information is provided within the structure of a Roamer activity.

However, the key element is how successful was the activity? How do we measure this? The normal way is to test against the Lesson Objectives (normally aligned to curriculum). This is unsatisfactory and misleading. Children's understanding of concepts emerges gradually as they experience a variety of interventions. The situation is analogous to a boxer who knocks out his opponent in round 11. Could the "knockout blow" win the fight without the contribution of the other punches delivered in the previous ten rounds? To resolve this problem Roamer activities include a Lesson Evaluation survey which measures performance against success criteria.
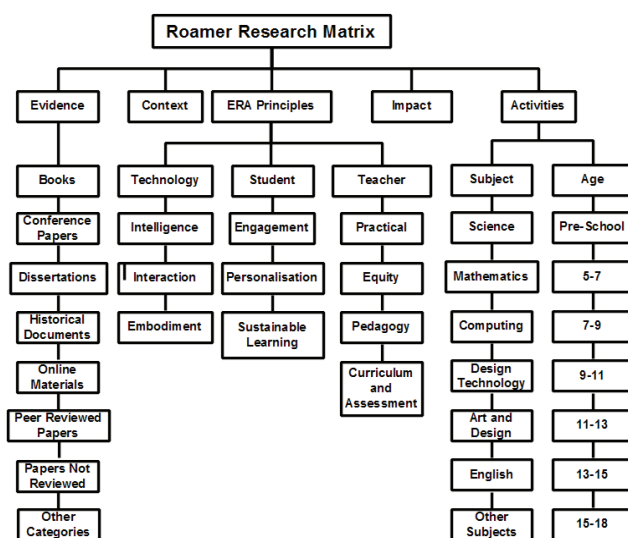
Figure3 Roamer MESHGuide Matrix

Assessment for Learning (AfL) techniques are embedded in Roamer activities. Two of these are learning intentions and success criteria. The learning intention is not the same as Lesson Objectives. It is related, but it is what the students thinks they are learning. It is something set up by the teacher as she engages students in the activity. Part of that set up process is helping the student to understand when they are successful. This is part of the self and peer assessment methods of AfL. It has been shown that students are remarkably honest in their appraisals [25]. This opinion is moderated by teacher's observations of the lesson.

VIII. CONCLUSIONS

The MESHGuides and TACTICS Framework provide useful tools for resolving problems identified in the e-Robot paper. They have been used to modify the organisation of the Roamer Activity library and set up a situation where continuous gathering of information from practising teachers on the effectiveness of educational robots, expressed by the ERA Principles, is possible. Some research is necessary, in particular to validate the notion of using success criteria and no doubt various modifications to the overall structure will take place over time. The main efforts in the immediate future will and existing research to the guide and proactively pursue the collection classroom activity-based data.

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Orbital Robotics: A new Frontier in Education

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Abstract—As part of its Education Programme, the European Space Agency (ESA) is taking several steps towards the development of Educational activities and platforms that use Space Robotics as a mean to support and reinforce STEM (Science, Technology, Engineering and Mathematics) school education in Europe. In this paper the on-going development of an Orbital Robotics educational prototype platform is presented, consisting of a hardware-developed physical platform and an accompanying set of curriculum-based lessons (IB Physics curriculum) that target upper secondary students (16-18 y/o target group). The hardware, a friction-less air-hockey table (physical platform) engineered for this purpose, will be used by students to interactively acquire the necessary experience of the dynamics of space systems, as the environmental conditions and physical constraints that are characteristic of on-orbit systems are emulated. The students will be able to manipulate space robot (satellite) mockups performing basic tasks such as docking, landing and grasping space debris. Additionally, a smartphone application has been implemented to allow the interaction with the platform, via a dedicated User Interface (UI). The lessons are inquiry-based and are structured so that the students are actively engaged in the learning process according to a learner centered approach. The project is jointly undertaken by the ESA Education Office and the ESA Automation and Robotics Section, with the support of the Control Systems Laboratory of the National Technical University of Athens. The development is taking place at the facilities of the Automation and Robotics Laboratory (ARL) of ESTEC, ESA's European Space Research and Technology Centre in the Netherlands.

I. INTRODUCTION

The use of robotic applications in education is increasing rapidly, after the realization of the various benefits they introduce in the learning process. These include both the motivational and pedagogical value provided by a direct hands-on and interactive experience that put the learner at the centre of an educational journey of discovery; during this journey the learners critical and innovative thinking is stimulated, leading to a deeper acquisition and understanding of physics and technological principles [1].

Currently, the approach to STEM (Science, Technology, Engineering and Mathematics) Education in Europe is still extensively based on passive learning (theoretical knowledge transmitted through lecturing); to a large extent, it still lacks the practical, inquiry-based and learner-centered dimension needed by the students to become an active part of the learning process. This leads to an efficient integration of theoretical knowledge into an experimental process of direct acquisition of this knowledge. The current approach also often lacks the context for students to work in groups and develop soft skills such as effective communication and teamwork, qualities needed to work in interdisciplinary research or industrial environment nowadays. Not completely adequate STEM teaching in school is considered by several recent European studies one of the key factors responsible for the relative decrease of the young peoples interest in STEM-related studies and professions in western countries today.

A recent study [2] shows that active learning leads to better student performance and raise of the average grades. By contrast, in traditional lecturing, failure rates are higher. Results from an Interactive Robotics Education Program implemented in the Curriculum of a Mechatronics course in Pontifical Catholic University of Peru (PUCP) [3], show a raise of motivation from the students of different age groups for completing their project, as well as the development of their teamwork, project management, documentation and communication skills. Furthermore, collaboration, cognitive skills, self-confidence, perception, and spatial understanding are some of the skills that the students achieve to learn through the implementation of robotics tools in education [4].

Being aware of the various benefits that educational robotics can bring into learning, combined with the recognized inspirational and interdisciplinary value that the space context can bring into STEM education, the European Space Agency (ESA) has kicked off the development of several space-robotics educational projects, including prototype activities

such as the one presented in this paper, and a space-robotics training school for primary and secondary education (the *ESA e-robotics lab - space robotics in the classroom*, that will officially start its activities in Autumn 2015). Space has always been one of the most wondrous subjects for children: by integrating the space theme with educational robotics, ESA's objective is to raise the students motivation and performance in STEM subjects, as well as to raise the awareness about space and space applications, together with their benefits for modern society, among the young population in Europe. An example of a recent successful ESA space robotics activity, strongly connected with the concept of this project, was the docking of ESA's Automated Transfer Vehicle (ATV-5) to the International Space Station (ISS), as seen in Figure 1.
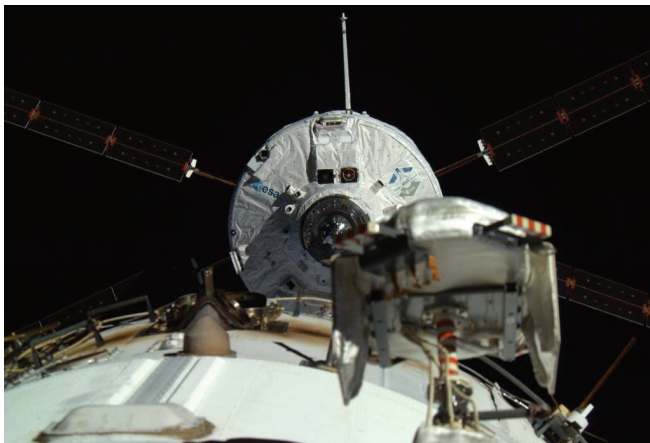
Fig. 1. ATV-5 docking with the ISS, 12 Aug 2014

Under this scope, ESA's Educational Project Orbital Robotics: A new frontier in Education, in collaboration with the Control Systems Laboratory (CSL) of the National Technical University of Athens (NTUA), Greece, aims to provide an active-learning tool for physics and technology under the concept of orbital mechanics and space dynamics. The project, aimed at the upper secondary school target group (16-18 years old), includes the development of an educational space environment emulator using air levitation (planar space emulator platform) and a set of space robot mockups (the 'satellites'), which can float on its surface. A set of lessons, which for the prototyping phase are based on the International Baccalaureates (IB) Physics guide, is also being developed.

In Section three the approach to the educational goals and its application to the lessons structure are presented. Section four illustrates the design and development of the physical platform based on the requirements set by the educational goals. Section five illustrates the lesson plan and how the learning objectives are achieved. Section six presents the authors conclusions, and mentions the next steps in the development of the project.

March 1, 2015

II. Pedagogical Approach

'For the things we have to learn before we can do them, we learn by doing them.'

Aristotle, 350 BC

The methodology consists in deploying a set of inquiry-based lessons that gradually builds the knowledge and the skills needed to complete the final lesson, which makes use of the principles introduced in the previous ones. The learning process and the lessons, whose goal is teaching physics through the students experience of a 2-dimensional representation of space dynamics, implement cognitive neuroscience research and developmental psychology (MBE [5] - Mind, Brain and Education Science). Through an interactive use of the physical platform, the learning process also introduces the hands-on experience.

Methodologies derived from the belief that the human brain is constantly searching for meaning and seeking patterns and connections are being implemented, while the main focus remains on reaching a deep understanding of the basic school physics concepts that lie in the fundamentals of space and orbital robotics.

The lesson plan is based on the 4MAT Theory [6], a use of the extensive research on brain-based teaching methods. The implementation of the 4MAT Cycle into teaching engages the students through all the steps of the learning experience. The movement around the 4MAT cycle represents the learning process itself; it is a movement from 1.experiencing, to 2. reflecting, to 3.conceptualising, to tinkering and problem solving, to 4.integrating new knowledge with the self.

The intention is to provide the students with the chance to perceive information both directly and abstractly and process it reflectively and actively. The different combinations of information acquisition and the path the mind follows to process it, define the four types of *learning types*: Type one learners are those whose mind is searching for the why? in what they see, perceiving information directly and process it reflectively; the type two learners asks for the what? in the stimuli they are given, perceive information abstractly and process it reflectively; type three or how does it what seekers, perceive information abstractly and process it actively; while the fourth, more intuitive type, is interested on the what if , and perceives information directly and processes it actively.

The lessons are structured to stimulate all the channels that these different type of learners use to perceive and process information; they are built upon the Umbrella Concept and follow a Concept-Based Learning. In other words, the learning objectives for every lesson refer to a greater concept that the students can relate to: new subjects are gradually introduced be referring to the students previous knowledge, and experiences and feelings to it, so that the learning experience becomes personal.

All the *personality types* (according to the Myers Bricks type indicator [7] are equally respected. Some people, the sensing types, perceive what is happening around them making logical connections in their mind (the door is wooden), opposite to the intuitive types who use their intuition (the door reminds me of the wood we have at home). Some others take decisions based on their logic and some on their

emotions (thinkers and feelers), while for some, the decision making process is more difficult than for others (perceivers and judgers). Personality types also account for the different channels one uses to express oneself: for the extraverts, the source of energy is external, while for introverts it is internal.

The lessons follow a pattern that provides the students the opportunity to acquire the knowledge in the way that is the easiest and most preferable for them, and are meant to favour the development of their communication skills.

In conclusion, the students are led through interactive activities into the basics of physics principles and of their specific phenomenology in the space environment. Every lesson is structured around a themed assignment, or mission, that make use of orbital robotics and that they have to accomplish as a team. At the end of the assignment, the students have to present the process they have run through, the results of their mission, and the outcome of their teamwork in which every member had specific tasks. Under the guidance of their tutor, they then have to engage into an open discussion to share the trade-offs made, the challenges overcomed, the lessons learnt both individually and as a team, etc. Through this process, the students gain a first-hand understanding and direct experience of the curricular subjects introduced, an experience of project management and teamwork, and the development of their communication skills, self-confidence and awareness in a learning environment that respects the wide variety of personality and learning types.

III. THE PHYSICAL PLATFORM

A. Design requirements

In order to achieve the educational objectives set for this project, the physical platform had to meet a set of requirements:

- emulate the behavior of space robots on orbit, resembling in a 2-dimensional environment the experience and the effects of the 3-dimensional zero-g environment on the bodies;
- allow students interactivity;
- remain small, low-cost, low-weight, low-noise and safe for use in a classroom environment;
- ensure its sustainability and reusability by different generations of students.

These requirements and constrains drew the design decisions and trade-offs made during the development of the prototype: the final layout, the selection of the materials, and the functionality of all the components, have been designed always in correlation with the educational scope of the project. As a 3D emulator is impossible to build easily, a planar space environment emulator that allows space robot mockups to hover on top (a friction-less air-hockey table), simulating a zero gravity and zero friction movement, was selected as a good alternative. This allows a very effective 2-dimensional representation of satellites movement in space.

The planar platform also had to provide working space for two space robot mockups to effectively perform operations on its surface. The mockups had to be light and have small footprint, and be capable of performing basic space tasks resembling at the same time real satellites with a good degree of fidelity. A great effort has been put into reducing to the minimum the power and mass budget requirements of both the satellite mockups and the planar platform.

B. The Planar Space Emulator

From the early stages of the development, one of the main challenges was the design and construction of a system able to simulate free-fall environment conditions, while at the same time taking into account all the project requirements as well as the physical limitations.

The chosen design incorporates the benefits of the planar simulators already developed in the USA (MIT, NASA, Stanford), Europe (U. of Padova, U. of Southampton, National Technical University of Athens) and Japan (Tokyo Institute of Technology, Tokyo University), scaled down to a low-power-budget and simplified system that does not need compressed air. Planar simulators using air bearings are perhaps the most versatile and less expensive method for emulating zero-g environment, in comparison to other methods, and allow for repeated and thorough testing of control algorithms and verification of dynamics [8]. They require minimum preparation compared to other simulation methods and are easier to upgrade and adapt to alternative scenarios.

These systems usually use a thick and heavy (e.g. granite) or fragile (e.g. glass) material as the surface where the air bearing space emulators hover, which however are not suitable for a classroom environment. Moreover, the direct use of air bearings would have introduced a considerable weight, cost and complexity to the mockups due to the required payload for air supply. Therefore it was decided that the platform should follow the example of planar simulators using air bearings, although this time the method of hovering should be reversed: the air flow will come out from the hovering table instead from the mockups. For this reason the planar educational space emulator developed and presented, follows the air hockey principle and consists of an assembly of additive manufacturing derived parts. It also has a custom layout, implementing results from both theory and testing, for optimization of the flow and maximization of the output pressure.

The model prototype that has been created was based on the high level requirements and having two main issues to overcome: lifting a space robot mockup weighing approximately 600g and being made of a low friction material. Moreover, the surface had to be flat and smooth and create a homogenous film of air on its surface to allow smooth hovering of the mockups. The stiffness requirement of the platform sets the manufacturing options for a stable and rigid assembly, using low-cost and easily accessible resources.

The planar prototype platform was designed taking under consideration the constraints set by the limitations of the 3D-printing technology, and the material used which, in this case, is Polylactic Acid (PLA). It is a modular structure consisting

of four smaller modules, as shown in Figure 2, which shall be glued together to provide a working surface (top surface of the upper part) with dimensions 380x300mm. The modules has been, tested and optimised to meet the requirements. The upper part of the module is a box-shaped element with custom-made nozzles on top, which produces the air film. The intermediate part is used for the mounting of the fan (air flow source), while the lower parts used for the support of the whole construction. This way it provides the structure with sufficient support and distance from the ground, while using the least possible amount of material.
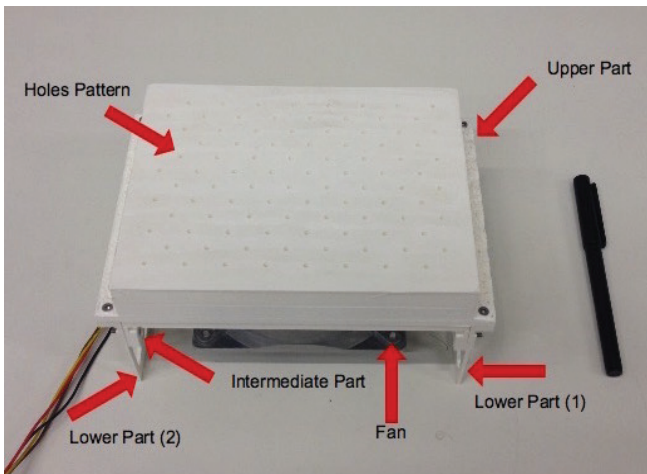

Fig. 2. The module (1 out of 4) of the planar space emulator prototype

The airflow had to be optimised to assure minimum air escape and enough thrust to lift the satellite mockups for undisturbed motion, i.e. there is a small pitch distance between the surface holes where the air flows. For that purpose, the Bernoulli concept was exploited, in order to achieve an increase in pressure [9]; that is, to provide the external airflow through a gradually diminishing-diameter nozzle before escape into the environment, in order to increase the dynamic pressure of the output airflow, and thus increase the velocity, and therefore the thrust, which is the main objective and only known value. Additionally, since the air is not provided directly through a simple cylindrical hole, but it escapes through a carefully designed route (the nozzle), special care was taken in order to decrease its internal friction.

C. The satellite mockups

The space robot mockups represent the bodies orbiting in space they can also represent mini satellites as their basic operational principles are the same. The observation of their movement and the results of the interaction with other objects on the planar space emulator environment are meant to allow the students to study the dynamics of orbiting bodies.

The goal is to make the mockups as light and small as possible. This will enable them to be lifted by the film of air created by the space planar emulator platform and at the same time decrease the required minimum dimensions of the

upper surface due to additive manufacturing limitations. Note however that as the resemblance with real satellites is required, their translational and rotational motion should have been generated by thrusters. This would introduced the problem of using compressed air and the need to add a pneumatic system, that would have increased the mass and power budget, not to mention the complexity.

Instead, the use of small fans enclosed in nozzles was selected, in order to resemble real thrusters without sacrificing considerably the accuracy. The fans only function in a pulse-like mode, so as to emulate rocket propulsion (propulsion through momentum transfer), therefore reducing significantly the inertial issues that emerge additionally their weight is minimal making the previous assumption reasonable. The first system implementation incorporates four fans, as seen in Figure 3; more can be added to allow angular motion.
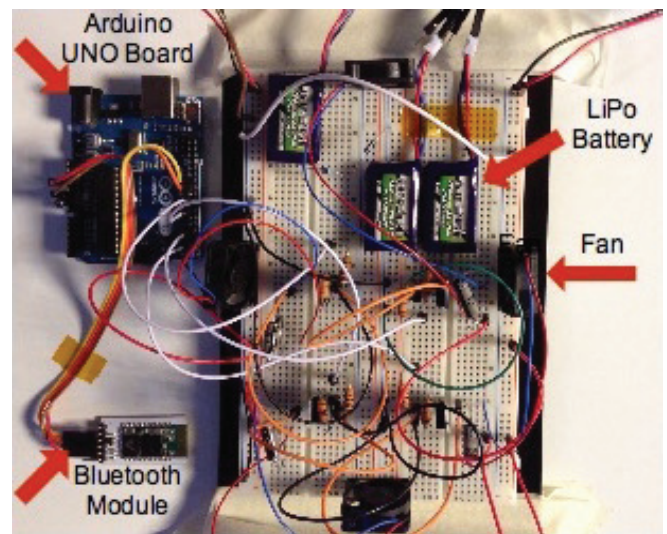
Fig. 3. The space robot mockup in development stage

The fans are connected to an Arduino® system, which is an open-source physical computing platform based on a simple microcontroller board [10], controlled remotely through Bluetooth by use of an android smartphone application, as seen in Figure 4.
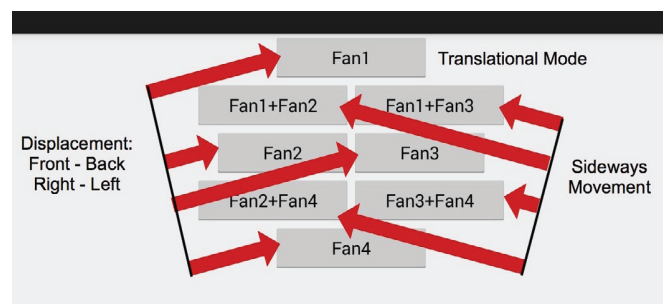
Fig. 4. The Android Application User Interface for moving the robot mockups (communication via bluetooth)

The User Interface of the smartphone application is struc-

tured with buttons, each of them representing the operation of a specific fan, which produces the corresponding impulse force for translational motion.

Finally the mockups disk-shaped base was made of a slightly flexible plastic plate (as thin and light as possible). The base is large enough to allow the mockup to move and to provide enough space for the robotic mechanisms that will be added by the students in the future. LEGO® baseplates will be mounted over the base surface, allowing the students to add LEGO® technic parts, to assembly their robotic mechanisms that they will be asked to make during the lessons.

Figure 5 shows the one Degree Of Freedom (DOF) LEGO® robotic arm assembly used for the docking exercises, and the corporation with a pico-servo motor (weight 4.5g) able to move the mechanism on the z-axis (yaw).

Fig. 5. LEGO® robotic arm with docking mechanism and servo motor

IV. Lessons Plan : Achieving Learning Objectives

The challenge during the lessons is to raise students' interest and engagement in STEM subjects; this is achieved by guiding the students through the application of physics principles in the space environment - a context usually fascinating to children. For example, as th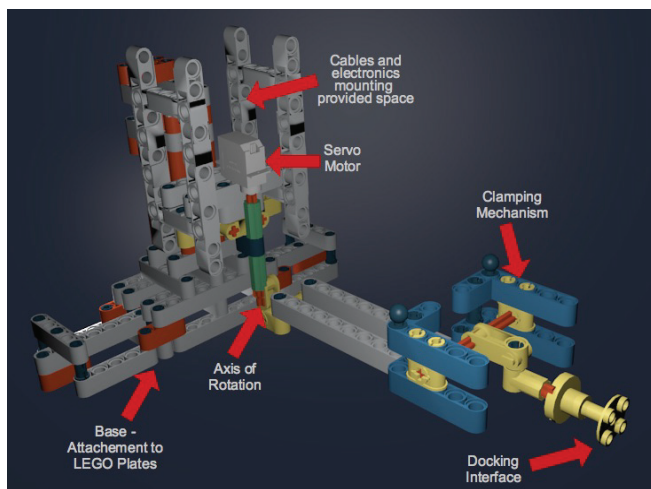e teacher demonstrates a physical phenomenon like rolling a ball on the table which stops at some point, he/she asks the students to describe what they saw and to explain what happened. In this way, the teacher can introduce Newton's Laws and friction. On the same time and in order to highlight the difference between space and Earth dynamics, the teacher shows a video of a satellite on orbit, of landing on an asteroid and of docking between two objects in space.

During such a lesson, the students are called to describe both what they saw and to notice the differences that exist between the bodies behaviour on the Earth and on orbit; this way the students start to think about what they have just experienced. Meanwhile, the teacher keeps stimulating the active learning process by asking questions such as 'where does space begin?', 'why man first wanted to go to space?' or 'when did that happen?'. This leads to the rationale behind a space mission, which aims to fulfill a specific human need. A mission statement thus is introduced together with a top-level definition of its concept, operations and benefits.

In each lesson, the students are grouped in teams and assigned a task which they need to execute, based on the previous inquiry-based educational approach. Preferably they are divided into teams which have equal number of: girls and boys, introverts and extraverts, judgers and perceivers, and thinkers and feelers. The students are asked to decide which are the phases of the assigned mission, which role each team member will play (e.g. Mission Management, Telecommunications, Operations, Science, etc), and what is each roles responsibility. The activity making use of the planar emulator will then commence, with the objective to achieve the assigned mission.

When the task is over the students are called to present their outcomes, choosing their preferred presentation method (whiteboard, flipcharts, papers, post-its etc); the teacher will call the rest of the students to engage into discussion on this presentation. At the end, they are called to talk about their experience working as a team, where the teachers will act as moderators in helping each other understanding and respect of the different personality types whilst favouring communication between the students.

The methodology developed seeks to trigger all the learning routes the students with different personality types choose to follow into perceiving, acting and decision-making. Feelers have the chance to act, so to involve action in the procedure of learning, and thinkers are given the time to reflect and process things in their mind before they can decide on the answer. The perceivers in the team will also seek for further investigation on the problem while the judgers will tend to take fast decisions. Moreover, extroverts will react more spontaneously, while the introverts will need some time to reflect before they choose to act.

Based on these principles, and making use of the physical platform, the set of lessons presented below has been selected. It has to be noted that the construction of the robot mockups will be done gradually by the students: throughout each lesson more parts will be added to meet the learning objectives. Further down we present Lesson 1, 'Introduction to Space'; this particular lesson does not make use of hardware, but provides an example of how all lessons are structured.

- **Lesson One - Introduction to Space**
  This is an introductory lesson about space, aiming to raise students interest about space and its applications. Additionally an introduction to space robotics will take place. This lesson will contain astronomical fun facts and basic knowledge about orbital robotics and space missions. Finally the students will be called to execute a space mission.
- **Lesson Two - Friction -or not**
  This lesson aims at achieving the realization of the difference between the concept of friction on Earth in comparison with its absence in space. It contains observa-

tional exercises on frictionless movement and momentum transfer.

- **Lesson Three - How Rockets Work**
  Here the concept of rocket propulsion using the Newtons 3rd law is explained. The main observation is the action-reaction principle.
- **Lesson Four - Inertial Momentum**
  Students are asked to add a robotic arm to the mockup and, by observing the movement of the whole body when trying to move the arm, the students understand the fundamentals of inertial momentum.
- **Lesson Five - Catch me if you can!**
  The students explore the observational concept by which, in a free-fall environment, when you just touch something it drifts away. The task is trying to the capture a static target object, finding a solution to avoid the drifting away and managing to capture it.
- **Lesson Six - Landing on a Comet**
  The objective of this lesson is to achieve successful approach of the target object and successfully anchoring to a planar surface placed in the simulation environment. The lesson introduces the basics of space propulsion.
- **Lesson Seven - Interacting in Space**
  This lesson presents by practical demonstration the difficulties of two-body interaction in space.
- **Lesson Eight - Space Debris Removal**
  Through this lesson the goal is to raise awareness on the space debris issue and the mechanisms used for cleaning space from space junk. The students are called to design a net mechanism to capture a moving body.
- **Lesson Nine - aMAZE me!**
  The students will have to construct a robot and drive it through a maze. The goal will be to avoid hitting the walls and get to the final destination in the shortest time possible, where the target they need to capture will be positioned.

Lesson Example (prototype)

Lesson 1: Introduction to Space

1) **Educational Objectives Fast Facts:**
   - **Age range:** 16-18 years old
   - **Type:** student workshop
   - **Complexity:** medium
   - **Lesson time required:** 45 minutes to 1.5 hours

   Students should already know:
   a) The concept of gravity
   b) The definition of weight (W = m g)
   c) The concept of vectors (size = value & direction)

   Learning outcomes
   a) Students should be able to make simple calculations using the equation derived from Newtons Law of Universal Gravitation.
   b) Students should be familiar with the concept of free-fall environment and the differences that lie

with earth environment in daily applications.
   c) Students should understand how Universal Gravitation and space environment conditions affect the movement of objects in space.
   d) Students should realise why orbits have elliptical shape, based on Keplers Laws of motion.
   e) Students should be able to state benefits resulted from space exploration.

   Curriculum links
   - **Mathematics** (Vectors)
   - **Physics** (Satellites, Comets, Planets, Stars, Gravity, Friction, Newton's Law of Universal Gravitation, Keplers Laws of motion)
   - **Astronomy** (Movement of space objects)

   Outline
   In this activity students will be engaged in an active discussion which will essentially lead to the realisation of the conditions that define a space environment and its impact on the movement of orbiting objects and space applications. Students are also expected to come to an understanding of why space exploration is of vital importance to our daily life.

2) **Background** Astronomy in early 1600s, Aristotle's geocentric system, Ptolemy, Copernicus, Brahe, Kepler, Newton. First space applications developed, first satellite launched, first spacecraft, man on the moon, first mission on mars, first rover on mars, Rosetta! What it the urge that pushes humanity towards space exploration? What is there to learn and benefit from?

3) **Activity**
   - **Discussion**

   What defines the Earth Environment? Introduce the concept of gravity and friction and the importance of their results in our daily life (humans/animals and artificial constructions:cars, airplanes). Make the first reference to space environment conditions:

- Space: what? why? (different gravitational fields)
  – How do the laws of physics that apply on earth change, in the absence of friction?
  – The gravitational field around objects pulls free-floating objects towards it, and the pulling force is proportional to the mass (Newtons Law on Universal Gravitation).
- How does this affect objects orbiting in space?
  – A small object (satellite) orbits around a bigger one -its gravitational field can create a force large enough to cause the orbiting of an object around it.
  – But the orbit has a specific shape. Which one? What is the reason? (Keplers Laws of motion (1st and 2nd))
- Why do we go to space?

Students are divided into teams and called to fill in their worksheets and present their outcomes to the rest of the class. They are called to write down some arguments that prove correct the statement: *'Space activities are an essential part of modern society'*. Students shall think of society needs -derived by the evolution of technology- that led to the creation of space applications which established space activities as a necessary part of our daily lives and the world as we know today.

- **Discussion Extension**

Mission Scenario:

'You have to repair a solar cell that has been damaged on the rear edge of the ISS. What steps would you follow? Which are the difficulties you think you will have to face and how would that differ if it was taking place on earth'.

The students are involved in an active discussion, with the teacher facilitating the flow. The students are then divided into teams and are expected to write down and present their mission outline, along with the answers to the questions.

In the table below the content that by the end of the activity is expected to have been transmitted to students is presented.

Application	Reason
Telecommunications	Communication, instant access to large amount of information by everyone, eliminates physical distances..
Earth Observation	Meteorology, predict natural disasters..
Planet Exploration	Life on other planets, how life started..
Experiments in microgravity	Materials, fluids, biology, radiation testing..

- **Conclusion**

Talking about space always fascinates children. Through the active discussions and activities taking place in this course, students are led to a deep understanding of basic facts about space environment, orbits and space applications and their impact on modern society. They also learn how to work in teams while improving their communication and presentation skills.

V. CONCLUSION

The learning requirements and objectives set by ESA's educational project on orbital robotics were presented. The educational objectives are reached by the interactive use from students of a set of space robot mockups able to float on a planar space emulator platform. The students are led through a set of inquiry-based lessons, to a deep understanding of orbital mechanics and space dynamics concepts. This is achieved through the experience of a 2-dimensional representation of the physical phenomena happening in space in a 3-dimensional environment, that the manipulation of the mockups hovering on a space emulator is making possible. Additional fine-tuning of the design of the planar emulator platform and of the satellite mockups is intended. Furthermore, it is foreseen to produce a detailed manual on how the lessons can be replicated in a classroom environment. Throughout 2015 and 2016 the concept will be refined by ESA Education Office and tested with teachers in the context of the ESA e-robotics lab Teachers Training. It is expected that the activity may be rolled out for school use in late-2016/2017 (classroom of approximately 20 pupils).

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2. Education and Mechatronic Platforms

Chairperson Richard Balogh

2.1. IniRobot: a pedagogical kit to initiate children to concepts of robotics and computer science
Didier Roy, Pierre-Yves Oudeyer, Gordana Gerber, Morgane Chevalier, Francesco Mondada, Stéphane Magnenat

2.2. Mechatronic Device to Reproduce Virtual Image on Material Plane
Anton Yudin, Andrey Vlasov, Maxim Kolesnikov

2.3. Teaching Robotics in Primary Education: Applying a Constructivist Educational Methodology for the Creation of a Space vehicle with LEGO NXT
Angeliki Theodosi

2.4. Affordable Mobile Robotic Platforms for Teaching Computer Science at African Universities
Ernest Gyebi, Marc Hanheide, Grzegorz Cielniak

2.5. Hedgehog: A Smart Phone Driven Controller for Educational Robotics
Clemens Koza, Christoph Krofitsch, Wilfried Lepuschitz, Gottfried Koppensteiner

2.6. Teaching Intelligent Robotics with a Low-Cost Mobile Robot Platform
Luka Čehovin, Anže Rezelj, Danijel Skocaj

2.7. Continuous Engineering Education Based on Mechatronics and Digital Fabrication
Anton Yudin, Andrey Vlasov, Maria Salmina, Vladimir Kuznetsov, Yuri Poduraev, Vladimir Sukhotskiy, Yuri Tsibulin

IniRobot : a pedagogical kit to initiate children to concepts of robotics and computer science

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Abstract—**We present the IniRobot pedagogical kit, conceived and deployed within French and Swiss primary schools for the initiation to robotics and computer science. It provides a micro-world for learning, and takes an enquiry-based educational approach, where kids are led to construct their understanding through practicing an active investigation methodology within teams. It is based on the use of the Thymio II robotic platform.**

The paper presents the detailed pedagogical objectives and a first measure of results showing that children acquired several robotics-related concepts.

Keywords : Robotics ; Computer; Teaching ; Creative activities ; Primary Schools ; Pedagogy ; Education.

I. INTRODUCTION

A major societal challenge is educating the youngest to understanding the digital world and becoming actors. To reach this goal, it is important to design educational material that fosters motivating, cooperative and playful conceptual and practical experience.

The use of robotics has the potential to be a useful medium to teach computing skills to children, being at the same time stimulating and rich of many important concepts where the digital world connects to the real world [17].

In this context, we present the IniRobot pedagogical kit, which was conceived and deployed in French schools (about 950 schoolchildren) for the initiation to robotics and computer science. It provides a micro-world for learning, and takes an enquiry-based educational approach [16], where kids are led to construct their understanding through practicing an active investigation methodology within teams. It is based on the use of the Thymio II robotic platform and the associated software tools, developed by the Ecole Polytechnique Fédérale de Lausanne (EPFL), the Ecole Cantonale d'Art de Lausanne (écal) and the Swiss Federal Institute of Technology Zurich (ETHZ). The Inirobot pedagogical content is publicly available through a Creative Commons licence[1], and the robot software and hardware are also open-source[2].

We first present the pedagogical framework and objectives of the kit, we propose a brief overview of the state-of-the-art, and then we present the robotic platform Thymio II and justify why it was chosen for this program. Thereafter, we present the pedagogical activities, their targeted users and contexts of use. Finally, we present a preliminary evaluation of the kit.

II. EDUCATION TO ROBOTICS

The first question in this type of activity is whether we want to have an activity of robotics for education or an activity of education to robotics? The issue raises a debate that is relatively strong in the world of education. Hereafter, we discuss its ins and outs and elicit our own take.

The terms *robotics for education*, *pedagogical robotics* or *educational robotics* have been around in education for a few decades [18][19]. These terms refer to a tool suitable for learning situations: robots such as Beebot, NXT, Thymio II. These robots, programmable to a certain extent, are used by teachers in the classroom. The applied practices are as varied as the teachers' knowledge about robotics. Some use robots to discuss robotics in itself, while others use them as mediators of skills and knowledge not related to robotics (collaboration, communication, drawing, reading a map, moving…). Considering this reality, in which the knowledge at stake is very different from one practice to another, we deem the term *robotics for education* to be unsatisfactory.

In this article, we thus present a tool for *education to robotics and computer science*. For us, this approach is in line with skills such as Competence 5 in Quebec, "Build one's understanding of the world", or Competence 2 in France for the scientific and technological culture (Discovery of the world in Cycles 1 and 2), or the Science skills described in the curriculum for French-speaking Switzerland such as modelling and understanding of natural and technical phenomena. Educating to robotics also involves the development of so-called cross capacities (collaboration, communication, …).

We refer to prescriptive standards that now advocate a competency-based approach. Such an approach contributes to

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[1] The IniRobot pedagogical content is available at : https://dm1r.inria.fr/c/kits-pedagogiques/inirobot or http://www.inirobot.fr. This site is also a collaborative platform where IniRobot's users can discuss

and propose their modifications. The activities are directly downloadable at https://dm1r.inria.fr/t/inirobot-les-documents-a-telecharger/

[2] The Thymio 2 robot kit is available at : https://aseba.wikidot.com

the scientific and technical education in schools in that it highlights a "knowledge to" more than a "knowledge that" [20]. However, if these skills do indeed seek the knowledge to act, it is clear that scientific knowledge is concerned too. This begs the question of which knowledge should be built. We believe it is necessary to explain this knowledge and to articulate it in relation within the disciplines. That is why part of the process of dissemination is based on continuing education of teachers. Our approach is to train students to understand the technical processes – not to fantasize about technological promises – and to develop their creative thinking and strategy for problem solving.

The general goal here is that schools would incorporate new knowledge brought by technological developments in order to allow everyone to think about the world, especially robotics as far as we are concerned, in a critical and scientific way, not in a magical one.

III. PEDAGOGICAL OBJECTIVES

IniRobot targets two sets of pedagogical objectives.

A. Learning the scientific method and team work

The first set relates to learning how to learn through the enquiry-based method of working and thinking. Here robotics is used as a tool to foster:

- Understanding and practice of investigative scientific methods: formulating questions and hypotheses, design and run experiments to validate or invalidate them;

- Development of skills for team work: division and integration of work, debating and arguing, revising one's own hypotheses;

B. Learning fundamental concepts of robotics and computing

The IniRobot program targets the acquisition and practical use of a number of fundamental concepts of robotics and computing[3]. The main targeted concepts, expressed as competences, are:

- Understand that robots are composed of sensors, actuators and a computer.

- Know and understand the words "sensors", "computer", "actuator", "electronics", "computing", "mechanics", "instruction", "algorithm", "programming language".

- Know how to provide instructions to a robot, and understand that a sequence of instructions forms an algorithm.

- Understand that several forms of programming languages exist.

- Know how to use basic concepts of event-based programming, and how to use "if … then …" rules.

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[3] Fundamental concepts of robotics and computing are available in the form of dialogue with a child at:
http://www.dm1r.fr/_documents/inirobot_dialogue_objectifs.pdf

- Understand that the behaviour of a robot depends on the interaction between the program, the robot body and the physical environment.

- Know analogies and differences between robots and living animals (e.g. sensors-senses, actuators-muscles, computer-nervous system).

IV. STATE OF THE ART

There is a large set of educational activities based on robots in the literature. Most of them focus on pedagogical objectives that are related to robotics, such as programming or robot building [2]. The systematic review made by Benitti [1] shows that in schools, 80% of the activities "explore topics related to the fields of physics and mathematics". It is also highlighted that robotics curricula address both specific topics such as Newton's laws, fractions or ratios, and transversal skills such as problem solving and scientific inquiry.

For the target age of the IniRobot initiative, focused on children that are from 6 to 12 years old, the number of quantitative studies of the impact of educational robots is extremely low. Most studies report only qualitative observations. Leonard [3] reports about the ability of nursery-aged children to use Lego® Mindstorms® system, describing the type of activities carried out and the difference of attitude of boys and girls toward this brick-based system. Jeschke et al. [4] report the feedback of Lego® Minstorms® workshops for children aged between 6 and 12, where 94% of the participants enjoyed the course. The goal of these workshops was to introduce children to science and technology and was based on the Roberta initiative [5]. Barker et al. [6] studied the use of Lego robots with 9-11 years old pupils in a clearer pedagogical context and with a quantitative analysis of the impact. They show the quantitative improvement of scores (pre- versus post-tests) in concepts related to programming, mathematics robotics and engineering. Some other studies address the use of educational robots with specific target groups such as autistic children [7].

As illustrated by the examples mentioned above, a large majority of the experiments are carried on with the Lego® Mindstorms® system. In her systematic review [1], Benitti shows that 90% or the studies are performed with this product. This shows how important it is to have a commercially available system to enable studies in classes. Indeed, experiments with children require many very robust robots that can be handled by children. Therefore prototypes are often hard to deploy in studies aiming to collect representative quantitative data.

Two other well-spread commercial robots targeting children in the age of 6 to 12 are the BeeBot and the Lego® WeDo®. The BeeBot [8] is a small differential drive mobile robot representing a honeybee. Its movements can be programmed with 7 buttons on its back, allowing the child to define trajectories on a checkerboard. The movement on specific mats can be used to teach a broad set of disciplines. The Lego® WeDo® [9], based on the Lego bricks like the Mindstorms®, is a cheaper solution that allows to connect only

one sensor and one actuator and is directly controlled by the computer through a graphical programming interface.

Recently the open-source Thymio II robot [10] became commercially available and is deployed in schools and informal education events [11][12]. It has a size similar to the BeeBot and a price close to the one of the WeDo system. It has more than 10 sensors and is highly interactive through a set of 39 LEDs placed around its body.

Among these available systems the Lego® Mindstorms® is a clear reference but is expensive, limiting its diffusion in schools. The cheaper WeDo is affordable but has few sensors, like the BeeBot. Thymio offers programming possibilities as the WeDo does, but instead of focusing on construction, offers a rich and varied set of sensors.

V. THE ROBOT : THYMIO II

A. Why choosing Thymio II

There have been several factors pushing us to choose Thymio for the IniRobot pedagogic kit. Thymio is affordable, allowing schools and private people to buy it with a reasonable budget. The full robot design is open source, allowing developments in software and understanding of hardware. Thymio has a large set of sensors, has a rich user interface and can be used directly out of the box. Finally, programming the robot is possible through a graphical and text-based programming interface.

B. Features of Thymio II

The Thymio II is a small ($11 \times 11 \times 5$ cm), self-contained and robust mobile robot. It is driven by two wheels allowing it to move like a caterpillar vehicle (differential drive). The robot has five proximity sensors on the front and two on the back, and two sensors on the bottom that measure the ground reflectivity and thus its colour. There are five capacitive buttons on the top, a three-axis accelerometer, a microphone, an IR sensor for a remote control and a thermometer.

As output, in addition to the two motors, the 39 LEDs on the whole body display localized information, for instance sensor activity. This distributed display of the internal state of the robot makes the visualization extremely intuitive, more than with a classical screen display. Finally, the robot provides a sound synthesizer. Figure 1 shows the robot.

Fig. 1. The Thymio II robot (left) and a screenshot of the VPL programming environment for children (right).

C. The visual programming environment

While the Thymio comes with six pre-programmed behaviours, its main feature is to be programmable. The Thymio II is built on top of the Aseba robot programming framework [13][21]. Aseba features two programming environments: a classical, interactive and robot- independent development environment called Studio and a visual programming interface called VPL, specific to Thymio. The Aseba programming language is based on the construct *onevent*, which is used to create event handlers for the sensors. Aseba programs are downloaded through a USB cable, which also recharges the internal battery. Once the program is loaded, the robot can run untethered. One program can be stored in flash memory. The IniRobot learning material uses the VPL environment.

VPL is a visual programming environment designed to be accessible to young children [14]. The environment is minimalistic and the block icons are large. Figure 1 (right) shows the environment and a program for following a black think line on a white floor. On the left, there is a column of *event blocks*; and on the right, there is a column of *action blocks*. Dragging and dropping one event block and one action block to the centre pane creates an event-action pair. Both event and action blocks are parameterized, enabling the user to create many programs from the small number of blocks. VPL programs are automatically compiled into Aseba programs. Previous research has shown that VPL is effective to teach a fundamental computer science concept such as the one of event handling [15].

D. Comparison with other platforms

In respect to the Lego® Mindstorms®, Thymio is two to three times cheaper, has a larger number of sensors, does not need construction to be used, has a less technical look, is completely open source and has a more accessible programming interface. As disadvantages, it allows fewer possibilities in construction and has a fixed set of sensors.

In respect to the BeeBot, Thymio costs nearly the double, but has a much larger set of possibilities in behaviours and programming. In respect to the Edison platform, the cost of Thymio is three times higher, but Thymio has also three times more sensors, has a rechargeable battery, better mobility control and much better programming environment enabling debugging, variable visualization and interface with other systems, all features not available on Edison.

In respect to all other platforms, Thymio has a unique programming environment allowing switching smoothly from graphical to text programming.

VI. SEQUENCE OF ACTIVITIES

IniRobot relies on a sequence of activities designed to introduce progressively the targeted concepts and competences. These activities are organized around missions that must be realized with the Thymio II robot. The full pedagogic kit, assembled in a "missions book" as turnkey solution, is available in open-source documents (creative commons).

The missions were designed by a group of teachers and researchers, in a cycle of prototyping and evaluation with children.

A. *Enquiry-based approach*

IniRobot uses the enquiry-based pedagogical approach, where children actively and autonomously discover, through debating, experimenting and validating of their hypotheses [23]. Activities are designed so that children can always make progress on their own, based on the experimental method, on the group dynamics and on their own creativity. To foster the pleasure of learning and intrinsic motivation to search for information, missions are scenarized so as to include a dimension of playfulness.

Activities are conducted within groups of 3 children, a preferential size which has been found empirically to be well suited to running the program in primary schools. A robot and a computer equipped with the Aseba VPL software are provided to each group.

B. *Uses and deployment*

1) Uses

We designed IniRobot to be used in different contexts, for primary school level children (between 6 and 12 years old). It can be used either inside the classroom, with teachers, or outside the classrooms within activities proposed by educators of associations (in France, this corresponds to "perischolar time", where public funded educators of association organize activities just after school or in dedicated afternoons).

According to the context of use, the priorities in the pedagogical objectives can vary. Within the perischolar time the priorities can be learning how to work in a team, and discover robotics and computing per se, as these disciplines are not part of the official program of French schools.

Within class time, IniRobot can also be used as a tool to support other disciplinary objectives, for example: learning language, writing and reading; learning the scientific method; introduction to artistic practices through the capability to program the robot to dance and draw.

Finally, outside the context of schools, an adaptation of the IniRobot program can also be used as a driver for what is called in French "coding gouters". These events gather children and their parents around a piece of cake and a set of activities to discover the basics of computing and robotics.

IniRobot is intended to be easily adaptable. Initially, the series of activities IniRobot was designed for 6–10 sessions of 30–75 minutes each. But it is easy to organize them differently, depending on constraints and objectives.

2) Deployment

For the school time, teachers use IniRobot in their schools in various French areas such as Gironde, Hérault, and Haute-Savoie.

All educational advisers of the Gironde county, counting about 900 schools, were trained with IniRobot and can now train teachers gradually. Currently, in France, about 38 teachers

use IniRobot with about 950 children aged from 6 to 12. In Switzerland, 30 teachers were trained to the use of IniRobot.

For the extracurricular time, which in France is managed by the municipalities, the city of Lille (250,000 people) uses IniRobot, and has planned to double its initiation activities to robotics for the next academic year. In Gironde, the cities of Talence, Bruges, Merignac, Floirac, Lormont, Pessac, Quinsac, Cenac, started or will soon start using IniRobot.

The Flowers team Inria trained facilitators of these cities, who have now the responsibility to train their colleagues. Currently, the cities have about 40 trained facilitators who initiate about 600 children to robotics and programming.

To facilitate the dissemination of IniRobot, it is available under an open-source licence, free, ready to use, with technical and pedagogical advices, corrections of the activities. Its modularity makes it very flexible to use.

To facilitate its deployment, we created the accompanying website http://www.inirobot.fr, which contains sheets to download and users discussions. A MOOC is also planned.

VII. THE MISSIONS

A. *Order of missions*

There are 12 missions that come in a specific order that has been designed so that children can be kept within their zone of proximal development [22], where they experience a challenge that is difficult enough to motivate them, but not too difficult so that they feel that can address them.

B. *Main missions*

Here is an overview of the most important missions designed within the program. As far as possible, the missions are inquiry based, the instructions are very few and minimal: the children have to discover, to experiment by themselves. The first mission 1 is emblematic of this strategy. Indeed, the "thing" (robot) is given to them, with the unique precision that "nobody knows what it is and how to use it".

1) Mission 1: What is that thing?

Groups discover an object given to them without any indication (the Thymio robot). At the end of the mission, they have to know how to turn it on, activate the pre-programmed behaviours identified by colours, and name it as a "robot". At the end of the mission, it is only verified that they know how to turn the robot on and off..

2) Mission 2: colors and behaviors

Groups discover the integrated behaviours. They have to complete a grid where the inputs are the colours of behaviours, and they have to describe the behaviours they observe and indicate on a drawing which parts of the robot are involved. No other instructions are given to them, not even how to enable behaviours.

3) Mission 3: If ... Then ...

Groups fill in a sheet where they have to connect elements associating events and actions that match with the behaviour of the robot (in each colour). They need to make experiments with

the robot to test whether elements should be linked or not within a rule "If … Then …".

4) Mission 4: What if we programmed?

Groups discover the visual programming software. They have to fill in sheets to explain what the different buttons or instructions do, experimenting simple predefined programs written on a sheet.

5) Mission 5 : Inside the robot

Groups open one of the robots, observe and dialog to identify which subsystems are for actuating, sensing and decision. They have to complete schemas on a sheet.

6) Mission 6: Good detection

Groups test programs that include detection of events to understand how they function. Then, two programs to be finished are proposed on a sheet they should complete.

7) Mission 7: Robots and humans

Groups identify similarities and differences between the systems for sensing, acting and decision-making in robots and humans. For this, they have to complete a sheet where there are schemas.

8) Mission 8: Little challenges

Groups have to address two challenges. The first consists in creating a musical instrument (one sound for each sensor). The second consists to program the robot to go forward if he detects nothing, and go backwards if it detects something. No other instructions are given to them.

9) Mission 9: Obstacle avoidance

Groups realize a program that allows the robot to move around by avoiding obstacles. No other instructions are given to them.

10) Mission 10: What beautiful Thymio!

Groups decorate the robots thanks to a small paper shell that they cut and colour.

11) Mission 11: The great route

All robots, equipped with the program of mission 9 and decorated in mission 10, are put in the same large but closed environment with obstacles. With coloured pens fixed on the robot, they move around interacting with obstacles and the other robots, leaving on the ground the trace of their displacement. They can update their programs live.

12) Mission 12: Top!

Groups have to build programs that use a timer.

13) Mission 13: What do you know?

Groups have to respond to a multiple-choice questionnaire about what they have learnt during the preceding missions.

14) Mission 14 (advanced): Using states

Groups discover the principle of "states". A "state" is a 4-bit internal state of the robot and accessible in the advanced mode of VPL. The states permit to do different things with the same events. According the states of the robot, event-action pairs are active or not.

In the first part of the mission, children complete a program. In the second part, they create a program using states.

VIII. EVALUATION METHOD

Tests were carried out with 24 children on the twelve missions experienced in the extracurricular time in Talence (Gironde, France). The same questionnaire (Table I) was submitted in a pre-test one week before the start of the robotic activities and a post-test one week after the end of them.

The success rates were calculated by dividing the number of correct answers by the total number of questions.

TABLE I. QUESTIONNAIRE

	Questionnaire		
		Yes	*No*
1	Do you know what a robot is?		
2	Does a robot necessarily have a head?		
3	Can we talk to a robot like to a human?		
4	Are there robot vacuum cleaners for the home?		
5	Does a robot necessarily have sensors		
6	Is there electronics in a robot?		
7	Is there a computer in a robot?		
8	Is a robot alive?		

IX. PRELIMINARY RESULTS

TABLE II. TESTS RESULTS

Tests results						
Age	*Gender*	*Number*		*pre-test success rate*		*post-test success rate*
7	Girls	2	6	63%	71%	100%	92%
	Boys	4		75%		88%	
8	Girls	3	6	79%	71%	96%	90%
	Boys	3		63%		83%	
9	Girls	3	3	83%	83%	96%	96%
	Boys	0		-		-	
10	Girls	3	9	63%	71%	100%	96%
	Boys	6		75%		94%	

The overall success rate in pre-test is 70 %, moving up to 93% in the post-test. The girls have an overall score of 77 % in the pre-test and 97 % in the post-test. The overall score of the boys is 70 % in pre-test and 88 % in the post-test. The results are in Table II and synthetized in Figure 2.

Figure 3 shows that all ages benefit from IniRobot. Figures 4 and 5 indicate that the 11 girls seem to progress faster than the 13 boys. This is an interesting indicator as many education actions consider gender issues, especially in robotics.
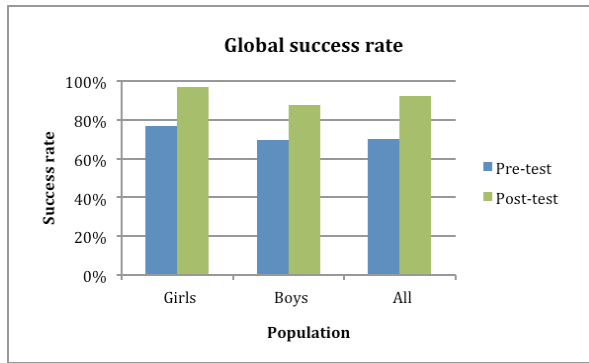
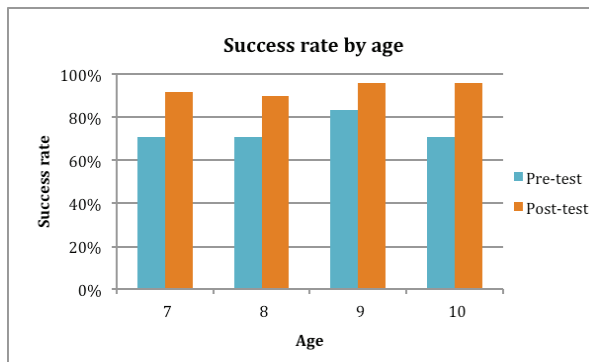Fig. 2.   Global success rate at pre and post-tests.
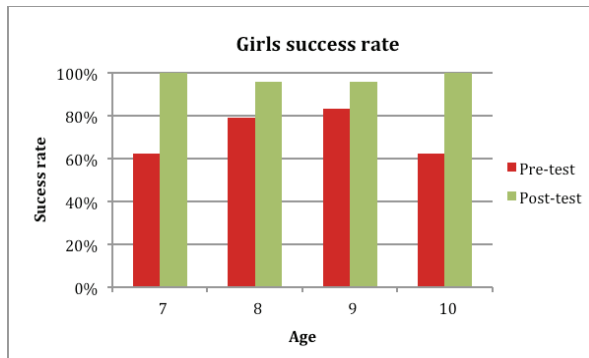

Fig. 3.   Success rate at pre and post-tests by age

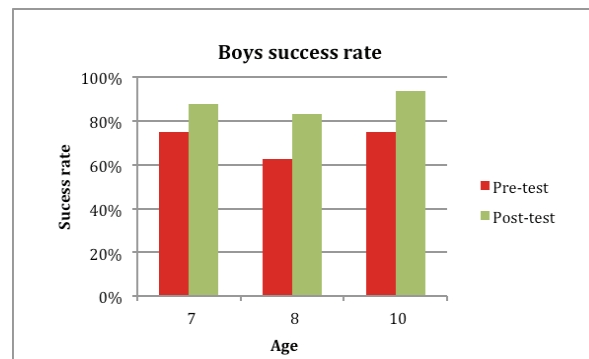Fig. 4.   Girls success rate at pre- and post-tests depending on their age.

Fig. 5.   Boys success rate at pre- and post-tests depending on their age.

X.   LIMITATIONS OF THE STUDY

The number of children who took part in the test was small and the questionnaire was limited in scope. This study was only intended to collect a first, quick and partial feedback on the relevance of IniRobot.

To get more data, we use now two new questionnaires, one for teachers and facilitators, one for children[4]. The goal is to gather broader information and focus in particular on the effectiveness of IniRobot to achieve its goals and its ease of use. To improve analysis, we have planned in future to use more open-ended questions, to monitor the children's progress with more accuracy.

However, these initial results are encouraging. The increase of the success rate from pre-test to post-test shows that children have a better understanding of core robotics concepts after being exposed to IniRobot.

XI.   CONCLUSION AND NEXT CHALLENGES

We presented and validated a pedagogical kit that is spreading in France and Switzerland. The results of the survey on children and the acceptance by the teachers are very encouraging. We plan to exploit the new results collected through the new questionnaires to validate the relevance of the scheme and also to use them to improve the IniRobot activities.

Through the questionnaires, we want also to evaluate the impact on children having learning problems. Indeed our kit seems to have a very positive impact as noticed by several teachers who work with these children. For example, in a school in Lormont (Gironde, Aquitaine, France) ranked as one of the most disadvantaged schools in France, a teacher used IniRobot with six years old children and found that through these activities, children were making efforts to read they were not making before[5].

The next challenge is now to scale-up on the basis of the actual deployment. For this, we continue to use the strategy that consists in training teachers and facilitators who, in turn, train other people.

With this aim, we now work with institutional and associative worlds, which use their own competences to support the strategy. We have dedicated organisms in France and Switzerland, which facilitate this effort. Beside the schools, the cities have to organise the extracurricular time and activities for children.

XII. ACKNOWLEDGMENTS

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[4]   The survey forms are accessible at:
https://dm1r.inria.fr/t/questionnaires-pour-ameliorer-et-developper-inirobot/
[5]   Teacher feedback at: https://dm1r.inria.fr/t/thymio-a-lormont-du-cp-au-cm2/

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Mechatronic Device to Reproduce Virtual Image on Material Plane

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Abstract—**The paper describes the original mechatronic device, which with the help of the developed control software reproduces virtual images on a material plane. Device mechanics allows various tools and materials for drawing. High-level user programming interface is written in Smalltalk with an idea to be user- and education- friendly. Low level control is carried out by an eight-bit Atmega microcontroller. The paper presents general ideas, describes prototype device developed and underlying problems and solutions occurred during the design process.**

Keywords—Mechatronics, robotics, smalltalk, drawing device, user interface.

I. INTRODUCTION

This work is devoted to the description of the device, which connects the virtual and material.

The authors' idea is to show potential of virtual computing, the aim of which is the creation of material structures and devices in the real world. The use of capabilities of the modern computer technology is not always linked to the physical world and developers often forget about the true purpose of the computer and do not go beyond the imaginary virtual spaces, inventing alternative "physics" and thus giving rise to an alternate universe at the end, with its laws and rules.

Two examples of approaches for use of the computer technology that could show the difference are: virtual reality and automation of production. Originally similar to each other (both simulate reality by copying the known laws of nature), these examples differ in the application of their results: computer games and the production of material objects, respectively.

Of course, the authors do not question the approaches, but rather pay attention to the productive and unproductive use of their results. In this regard, it should be emphasized that within the engineering sciences we are primarily interested in the creation of real objects, which would have the needed functionality and would allow people to integrate organically into their surroundings.

Therefore, the simulation result should always be correlated with real natural process. Simply put, any modeling must end with real world application of its results and thus withstand or not withstand a test of the reliability of used approaches.

The purpose of this work is the description of a device capable of mechanically reproducing an image, set by a user in a virtual two-dimensional canvas, on a material flat canvas.
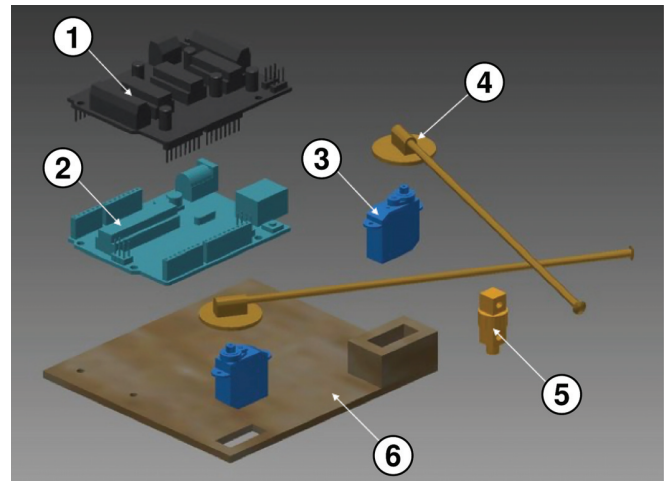
Fig. 1.   Exploded view drawing of the device

The most common tasks the authors face during creation of such a device are the following:

- Understanding a servo operation principle and control;
- Exploring the Arduino platform;
- Choosing and learning a programming language to create the user interface;
- Ensuring a consistent rotation of the servos and moving the fastener (intersect) element.

II. THE DEVICE

The mechatronic device we propose is described below in four subsections: Block Diagram, Servo Control Circuit and Applicability Analysis, State Machine And Algorithm and The Hardware Part.

A. Block Diagram

In order to understand what kind of the device this article is about, it is important to consider the block diagram shown in Fig.1 - elements presented are:

1) Arduino board
2) Servo (expansion) shield
3) Servo

$$arctg \, \frac{AB}{AC} = \alpha$$
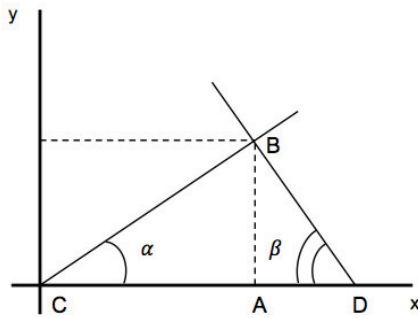
$$arctg \, \frac{AB}{CD - AC} = \beta$$

Fig. 2.   Scheme for determination of angles of servo rotation

4)   Guide
5)   Fastener (intersect) element
6)   Platform (backbone)

The device is operated with a computer, which will send data to the Arduino [1]. The microcontroller processes it and sends signals to the servos through the expansion shield. As power obtained through the USB-port of the computer may be insufficient to manage several servos at once, it was decided to carry on the delivery of energy via an expansion shield. Guides are attached to servos and the fastener (intersect) element is able to move along each of them freely. It performs several functions: connecting guides in one point, holding and interchanging of drawing tools.

B. Servo Control Circuit and Applicability Analysis

Since it is possible to control only the angles of rotation of the servos, it is necessary to derive a formula that will set the appropriate angle for each of the 2 servos for given coordinates. We represent them in the coordinate plane (see Fig.2) and taking position of one of them (servo C) as the origin, so that the second (servo D) is on the X-axis in the positive direction. Then the position of a given point B will be determined by the angles BCA and BDA. It is easy to calculate the angle of the guide line CB by the given coordinates of the point, and thus the angle of rotation of the servo C. To calculate the angle of the guide line DB, it is necessary to set the distance between the points C and D (CD segment - constant, AC and AB - variables) defined from experiments and accuracy calculations of the servos.

Servos used in this project have mediocre accuracy, which requires separate analysis of areas in which the painting is stable and those in which errors achieve too much importance. According to preliminary calculations, for a servo having a $\theta = 2°$ step (nominal error of servos used in this unit), an area with reasonable accuracy (region I in Fig.3) will be a circle of radius R = 80 mm, since the further away from the servo (region II in Fig.3), the error
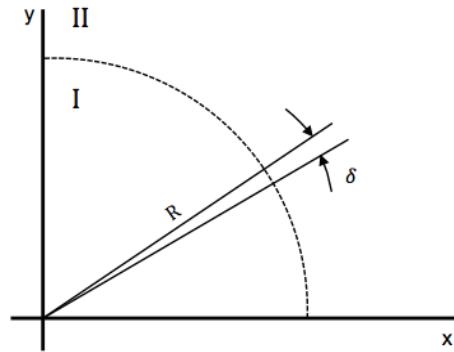
Fig. 3.   Servo accuracy areas
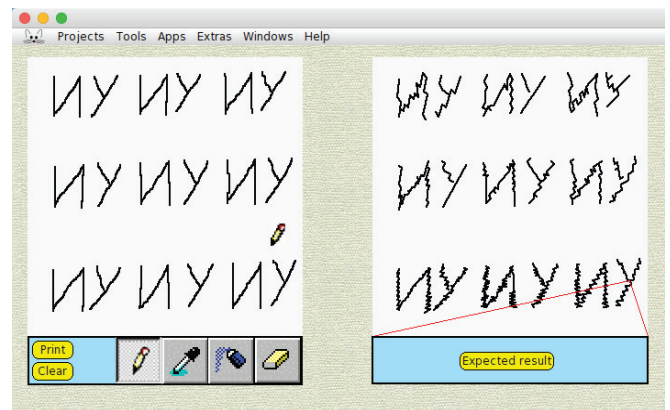
Fig. 4.   Computer model of the drawing expected result

$$\delta = 2R \times sin(\theta/2) \qquad (1)$$

becomes more than 3 mm (excluding servo assembly defects), which in practice will lower the image quality strongly enough.

For a more accurate assessment of the quality of the joint work of the two servos a mathematical model of the created device was implemented in the Squeak development environment [2] [3] (Fig.4), which allows to judge about the region with reasonable accuracy, formed by simultaneous work of two servos.

Analyzing the results obtained using a mathematical model and calculation of accuracy zones for each of the servos, together with the experimental results, we can conclude that the area of quality usage of the developed device (at the given parameters of components) is a semi-circle of 70 mm radius centered between servos (green area in Fig.5).

C. State Machine And Algorithm

The developed device has 6 main states shown in Fig.6. States 7-9 are complementary and describe the moving process of the tool.

Software part of the device comprises two interconnected parts.

Fig. 5.   Area of quality application of the device

Fig. 6.   State machine

Fig. 7.   Management interface
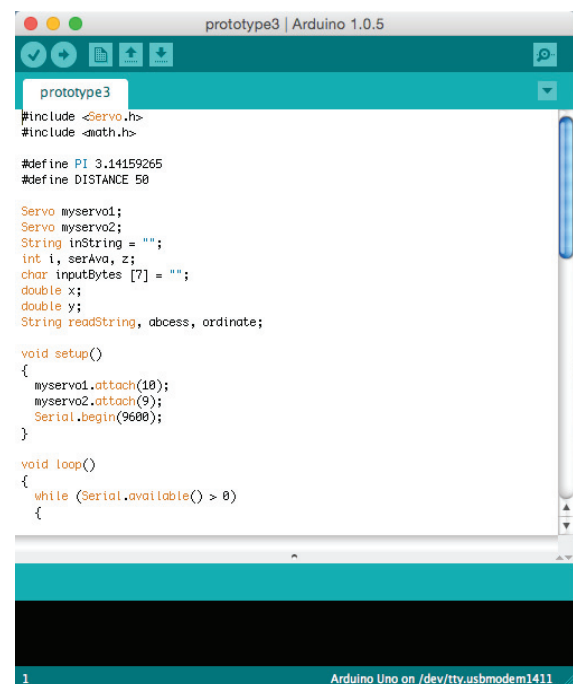
Fig. 8.   Arduino development environment

The first - the user interface on a computer (Fig.7), developed in Squeak dialect [4] of Smalltalk programming language. It was chosen because the code written in it has a graphical interpretation. It made possible to create a user interface without using additional software.
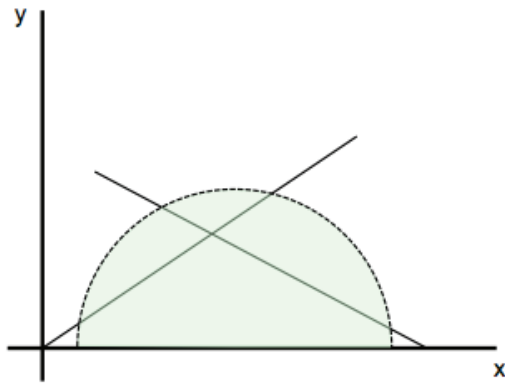
In its current state the user interface is an area of adjustable size, within which the user, using computer mouse, can create or load the preferred virtual image, and the action tool-bar. With its help, you can select one of the modes: pencil tool for drawing lines, marker - for points, sprayer - for bulk materials, eraser - to correct the image. Also the tool-bar has two buttons: Print to start the device to plot (print) the created image and Clear, to erase the entire virtual canvas.

When operating in the airbrush mode the software has to track the velocity of the fastening element to which instruments are attached, since the picture quality depends on the constant velocity of the tool. Which is tricky because of changing distance from the servos (local centers of rotation) in movement. To address this problem, in the shaded area in Fig.7 dosing bulk material per time unit is proposed to be increased.

The second part serves to interpret the data received from the computer and to control the servos. It is implemented on a software platform Arduino - one of the most common and easy to program (Fig.8).

The general algorithm of the system is shown in Fig.9.
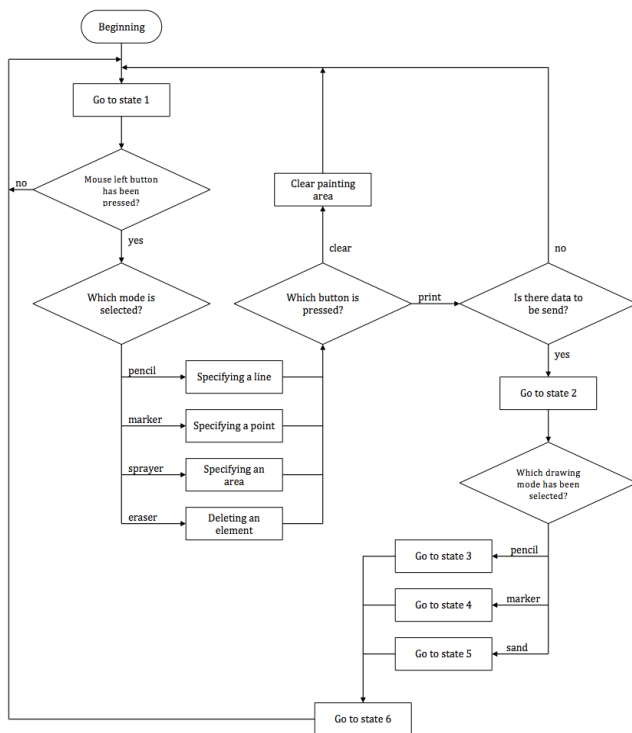
Fig. 9.   Algorithm of the software part
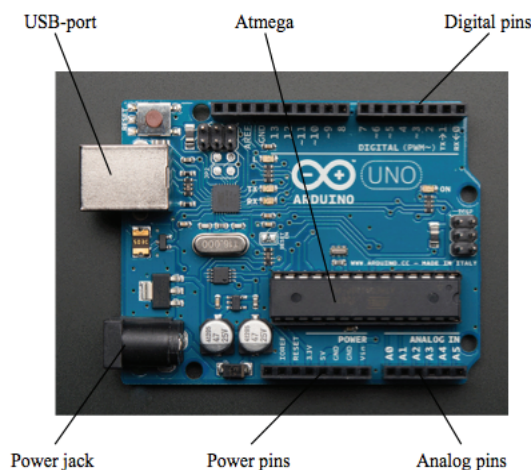
Fig. 10.   Structural-functional diagram of Arduino Uno shield

The algorithm allows to control the hardware by forming complex control actions [5] in a chain: computer-microcontroller-mechanism.

D. The Hardware Part

Rapid prototyping was used to build the current version of the device. Its electronics is represented by a common Arduino Uno board. This board is a standalone programmable electronic device consisting of 6 analog and 14 digital outputs, 5 power outputs, power connector and a USB-port, through which the connection to the computer is performed (Fig.10).
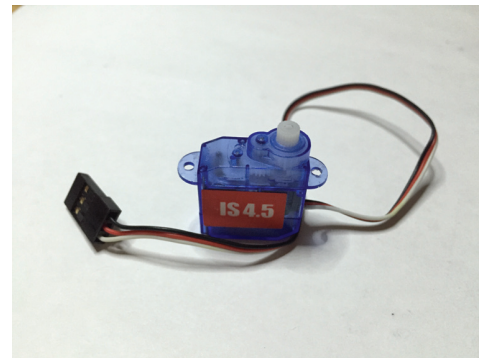
Fig. 11.   Servo Impact IS 4.5
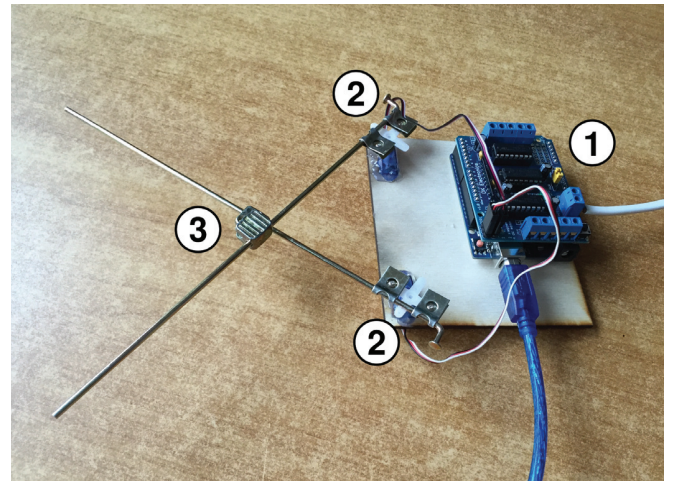
Fig. 12.   General view of the device

Arduino programming is carried in a C programming language dialect.

Two standard servos were used to ensure movement of the fastening (intersect) element (Fig.11).

A general view of the device is shown in Fig.12.

Arduino shields and servos for convenience were placed on one platform (backbone), which was cut with a laser cutting machine from a sheet of plywood.

III.   CONCLUSION

The implemented mechatronic device satisfies the goal indicated in the introduction, which consists in connecting virtual and material worlds.

It should be noted that the developed device is a working prototype and this work reflects the current state of the project, which is still far from completion.

The device is rather large and has mediocre accuracy, which still is not a dead end, because it can be overcome using higher quality materials and components together with programming techniques. The results confirm the practical realization possibility of the authors' ideas and validate further work to complete the project.

Born as educational the described project can also be used for educational goals: as an example of using and applying an Arduino microcontroller or solving different program tasks with Smalltalk language. The required skills for this design are very close to those in robotics in general. Detailed educational appliance of the proposed project could be a subject to describe and publish in the next paper.

The authors plan to continue the work towards improving the quality, accuracy and ergonomics of the device, and add the ability to remotely control it from a smartphone. Interesting direction considered for further research is usage of augmented reality, ensuring connection between virtual reality devices and the real world.

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Teaching Robotics in Primary Education: Applying a Constructivist Educational Methodology for the Creation of a Space vehicle with LEGO NXT

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Abstract—**This paper presents the methodology applied on a project that took place in the academic year 2013-2014, in the Robotics Club of Ralleia Model Experimental Primary Schools in Greece, within the framework of the Hellenic contest for World Robotics Olympiad in Open Category, the theme of which was "Robots and Space". The presented workflow was chosen in order to inspire pupils to work on a common goal as well as to stimulate their interest in Robots, Astronomy and Space, fields that are out of the Primary School educational program. The results extracted through external evaluation of the outcome of the applied methodology, as well as the mostly positive evaluation remarks that were extracted by the pupils through the completion of a questionnaire were very promising as this project won the second place in the contest. In addition, the pupils that were voted to be members of the contest team were so excited about the whole process that they were eager to participate again.**

Keywords—Constructivism, robotics, primary education

I. INTRODUCTION

During the last two decades robotics has been the new challenge through all levels of education. Either as a S.T.E.M. or as an interdisciplinary project based learning activity like the World Robotic Olympiad's (WRO) 2014 Open Category challenge was, robotics are gaining continuously more supporters. This is not a coincidence, as it offers to the pupils involved the joy of creation through discovery, learning and knowledge of how things work.(ref) This paper presents a brief description of the theoretical context, which is mostly based on constructivist principles, as well as the steps followed for the preparation and the choice by the pupils themselves of the three-member team that was to participate in the "WRO 2014 Robotics Competition". The evaluation took place into two directions; first comes the presentation of the comments of the pupils as they were recorded on the teacher's diary during meetings and second, the final outcome of the contest.

II. THEORETICAL CONTEXT OF SCIENCE IN EDUCATION

To the question "Why robotics?", none could actually answer better than J. Piaget, who claimed that our aim should be "An education with scientific spirit and a Science teaching which insists on research and discovery rather than repetition" [1].

According to J. Solomon [2] there are two distinct areas for young pupils, Science domain and real life/world domain. Their thought spontaneously arises from the second and can hardly be moved to the first. According to Solomon, the language used by the teacher is of particular importance for the transition from one domain to the other. The teacher should make use of scientific terminology. Robotics as an educational tool assists in the transition to the science domain and the scientific way of thinking by naturally following the procedure:

1. Observation/ Hypothesis

2. Application (Building/Programming)

3. Experiment (Observation/Measurement)

4. Conclusion/Feedback (When feedback is necessary).

At this point, the teacher should use the appropriate scientific terminology as well as the appropriate expressive means to lead students from the specific to the general, the science behind their work.

Due to the nature of the subject -Astronomy, and robots in space are far from the primary school subjects- there was an urgent need that the teacher should take into consideration apart from her own dynamic, the other two dynamics which function along. These dynamics- Folklore, Internal and Teacher's dynamic- are described by Osborne in [3] and they are all functional at the same time. Thus, the teacher provided them with appropriate tasks and material in order to modify and rebuild Folklore dynamics and create new internal dynamics through experiential activities.

III. CONSTRUCTIVIST EDUCATIONAL METHODOLOGY FOR INTEGRATED INTERDISCIPLINARY ROBOTICS PROJECTS (C.E.M.- 4-I.I.R.P.)

Working on an Integrated and Interdisciplinary Robotics Project with a class, demands a very well scheduled and organized plan of activities, especially if the number of pupils exceeds the provided resources. The particular project was goal-oriented as its aim was to create an integrated Robotic application model along with a scenario as a proposal to the challenge set by WRO2014 for Open Category: "Design and create robots which will assist humankind in solving different tasks in Space. "

This was a totally interdisciplinary project as pupils in order to work both effectively and creatively had to take a glance at Astronomy, climate conditions in planets and their satellites and the difficulties and obstacles that humans have assigned to robots to deal with. The project plan was set based on the principles of learning by design [4], [5],[6]. Learning

tasks were organized as a sequence structure though young learners were encouraged to express themselves and unleash their imagination. The pupils were organized into teams of three so they could share experiences and exchange opinions and ideas on the tasks they had to fulfill. This process produced a bit of noise but created also a pleasant and constructivist learning environment for the pupils as they experienced the feeling of being creative while having multiple degrees of freedom.

Their tutor mainly acted as facilitator and mentor mostly rather than a source of knowledge. The introduction to the new and unexplored field of Astronomy and Space was approached in different ways such as through visiting the exhibition "Return to the Moon", watching a movie, attending a presentation in the classroom. Material from multiple sources was uploaded on the Robotics Club blog (http://ralleiarobotics.blogspot.gr/) in order to modify Folklore dynamics and possible diversions. A source that pupils found very interesting was the one where they could access and explore our solar system with simulation software (http://www.solarsystemscope.com/) Furthermore an Astrophysicist from the University of Athens was invited to present the Greek mission of Cassini to Titan, the satellite of Saturn. This was an inspirational moment for the pupils as they were inspired to create their project-mission to Titan. The pupils chose themselves the theme of their project after brainstorming and supporting their ideas into a plenary session in class and, after discussing about it, they ended up with the idea of a mission to Titan.

IV. IMPLEMENTATION OF THE METHODOLOGY

The Robotics club began its meetings at the end of October of the academic year 2013-2014. The theme announcement took place in January 2014. Until then, the students had become familiar with the use of Lego Mindstorms NXT programming as well as the operation and the function of the sensors through the implementation of short projects. Twenty three pupils of 5th and 6th grade expressed their interest in participating in the school's robotics Club. Their statement which was confirmed by the teacher's observation mentioned no previous knowledge and/or experience with Lego NXT.

A. Project Plan

1. The theme of WRO 2014 was announced to the pupils who were excited at the idea of taking part in a National contest.

2. Multiple sources of information and extra material were given to the pupils and were uploaded to the Robotics Club blog online, as mentioned above.

3. A presentation by an expert took place and real scientific problems were introduced to the pupils. A very interesting discussion followed where questions were answered.

4. The pupils visited the exhibition "The conquest of space -Mission to the future" and watched the movie "Back to the moon...for good". They had the opportunity to see simulations of robotic vehicles and space equipment.

5. The members of the club had to choose one topic related to the contest issue. The previous steps 2-4 provided them with the information, knowledge and inspiration that they needed. The adoption of a single topic for all the members of the club was a necessity due to the fact that only one Lego NXT kit was available and this was achieved through brainstorming. They drew their scenario- proposals and presented -supported them into a plenary session in class. Then, after observations on the feasibility of implementing the scenario that was made by the class, some of them were amended to become possible. They designed their ideas on paper and they built models of their designs with simple everyday material, increasing in this way the creativity and Imagination. They created their vehicles with Lego bricks and they presented their construction into a plenary session in class. The pupils voted for the best scenario in order to build it with Lego NXT.

6. Pupils also voted for the team that would represent them at the contest. Three basic members and three runners-up were chosen.

7.

    a.Construction and programming of the robotic vehicle.

    b.   Construction of the model by the rest of the members of the club.

8. Video and poster creation.

9. Presentation to the plenary of the school.

10. Presentation to the 6th National WRO contest 2014 Scientific Committee where the project and the team totally gathered 515 points for the presentation, the construction, the program and a set of predefined scoring criteria on the rules of WRO 2014 (http://www.unitbv.ro/Portals/9/Lego/Rules-Open-Category.pdf).

V. EVALUATION OF THE METHODOLOGY

The evaluation of this work was done using three different tools. The calendar of the Robotics Club for the period of the project, the questionnaire with open-ended questions which was given to the students after the completion of the project and finally the evaluation of the result /score that the team managed to achieve by participating in the nationwide educational robotics competition WRO 2014.

A. Teacher's evaluation

The teacher's evaluation of the project took place after studying the diary of the project. This diary was kept by the teacher along with photos of pupils' work during the project. Other than a means of reflection and an assessment tool, the collection of this material enabled students to monitor their work and its evolution through time after the completion of the project.

Furthermore, as occured from the observation of the remarks from each day, pupils very often complained when they had to write or read an assignment and they were excited each time they had to build their models and propose/share

ideas with other members of the club. Many times there were complaints about not having enough time for all to test and play with Lego NXT, something which was a fair complaint as the number of pupils in the club exceeded the provided resources.

B. Pupils' evaluation

A questionnaire with four questions and space for their own suggestions and ideas was given to pupils.

As the competition took place after schools had closed (June 2014), the questionnaire was given to the pupils in September. As a result, only 12 out of the 22 returned it, as the rest members of Robotics Club had graduated from primary school.

1. What was the best thing you can recall from this project?

2. What was the worst thing you can recall from the preparation of this project?

3. Are there any points you believe that we should insist more on? If so describe them.

4. Are there any points we should insist less? If so describe them.

5. Make your suggestions to improve our lesson.

The pupils replied according to their personal experience about their best and worst moments during this project. The majority of the pupils' statements on what their best moments were, had to do with their work as team. "My best experience was when we all had very good ideas", "my best experience was the time that models of all teams were exposed and we observed and played with each other's model like an interactive museum". The rest of the pupils mention building the robot as their best experience: "My best experience was the time when we put the logo "SPACE" and the ejector on the robot"

TABLE I.

My Best Experience		
Category	*Example Statement*	*N*
Teamwork	My best experience was the time that models of all teams were exposed and we observed and played with each other's model like an interactive museum	8
Building/ programming the robot	My best experience was the time when we put the logo "SPACE" and the ejector on the robot	4

The fact that almost the 1/3 of the pupils recall as the best thing happened to them the activity of building and programming the robot, is reasonably expected. The young pupils expressed their enthusiasm whenever they were working with NXT Lego Mindstorms. A rather surprising point of view came from the other 2/3 of the answers given to the questionnaire. It seems that pupils enjoyed the process of the teamwork wherever it took place and they expressed their disappointment if they had disagreements. During the project, the trainer's effort was also focused on creating a harmonious team culture which helps the personal improvement and evolution of each of the members and the team as a whole. The pupils observed themselves that they may reach a better result whenever they exchanged their ideas without fighting and they understood the importance of teamwork.

As for their worst experience, the pupils' opinions were equally divided into four quarters. The first, named the quarrels between members of their team as their worst experience. Their statements were like "I wish we had fewer quarrels». The second, complained about the fact that none of their ideas for building the robot was adopted "None of my proposals was adopted even when I had been told that it was quite good…" The third stated that they could not recall any bad experience at all, whereas the fourth, stated that their worst moment was when they could not the team of the Club the day of the contest due to other commitments.

Half of the pupils had either no worst experience or their worst experience had to do with their unavailability to participate to the activities of their team, which is a very encouraging result. The rest of the pupils are underlying the fact that they all have understood that teamwork is a prerequisite for a good result. The rest of pupils' worst moments had to do with their estimation about their contribution to the team. As the ratio of equipment regarding the pupils was very low, many good ideas of the pupils could not be applied and that was a point of disappointment for them.

On the third question, almost all pupils stated that they would like to have more time to spend on building and programming the robot. Whereas in the fourth question, 11/12 mention they had not spotted any activity that the team should have spent less time on.

Finally, all their suggestions about the activities of the robotics Club and the points that they thought that needed improvement had to do with the equipment requirements and the need to improve the ratio of MINDSTORMS kits to suit the number of the students. "We should have more robots and better computers."

Almost all of the pupils mentioned that would like to spend more time on building and programming the robot. This need is totally justified due to the above ratio. The fact that 11/12 pupils stated that there was no activity that should have spent less time on, highlights that pupils understood the necessity of each of the activities they had to cope with.

TABLE II.   TABLE STYLES

My Worst Experience		
Category	*Example Statement*	*N*
Quarrels between team members	I wish we had fewer arguments	3
Personal disappointment: none of their ideas was adopted	None of my proposals was adopted even when I've been told that it was quite good…"	3
Could not follow to support the their team	I was so sad that I could not follow and support our team to the contest	3
Could not recall a bad experience at all	I didn't have any bad experience at all	3

VI. DISCUSSION AND CONCLUSIONS

Through the whole project, it was observed that pupils were very enthusiastic and worked hard for the final result. According to pupils' responses to the questionnaires, this seems to be related with the fact that more than just a new interesting activity, robotics seemed to inspire their team spirit and to actually involve them to decision making and solution finding throughout this project.

This statement is enhanced by the fact that the choice of the project theme was based on pupils' ideas which, of course, were triggered by the pluralism of information provided by experts and sources. Their achievements were mainly based on their active involvement and their commitment to the successful completion of the project.

An important improvement would be the enrichment of the project with further evaluation methodologies. To this direction the idea of pupils keeping a diary of their meetings as in [7] and [8] would be a good practice.

Obviously, it is clear that the presented methodology should be re-applied under better conditions on the field of equipment in order to draw more reliable conclusions for robotics in primary education.

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Affordable Mobile Robotic Platforms for Teaching Computer Science at African Universities

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Abstract—**Educational robotics can play a key role in addressing some of the challenges faced by higher education in Africa. One of the major obstacles preventing a wider adoption of initiatives involving educational robotics in this part of the world is lack of robots that would be affordable by African institutions. In this paper, we present a survey and analysis of currently available affordable mobile robots and their suitability for teaching computer science at African universities. To this end, we propose a set of assessment criteria and review a number of platforms costing an order of magnitude less than the existing popular educational robots. Our analysis identifies suitable candidates offering contrasting features and benefits. We also discuss potential issues and promising directions which can be considered by both educators in Africa but also designers and manufacturers of future robot platforms.**

I. INTRODUCTION

Higher education these days is considered one of the biggest challenges but also opportunities for developing countries. This is especially true for Sub-Saharan Africa which did not even experience the growth of wealth seen by other developing countries [1]. The challenges faced by African institutions are diverse, ranging from limited economic capabilities to old-fashioned pedagogic methodology failing to engage and teach students effectively. However, and in particular in computer science, the effectiveness of hands-on exercises and collaborative learning has been identified [2] and is promoted by many of the western higher education institutions.

There were some recent efforts made by selected African institutions to improve the quality of teaching and learning by the adoption of educational robotics. Such initiatives, usually joint ventures between western and African universities (e.g. [3], [4]), follow a belief that robots are an effective means to facilitate more engagement, higher motivation, and the development of practical skill sets, beyond the focus of robotics itself. In our own work [5], we have analysed the effectiveness of robotics as a subject to convey a larger skill sets to students. The positive effect, to a large extent is gained from the "embodiment" and physical presence of robots, which make the outcomes of programming very vivid and immediately accessible, providing a continual formative assessment of learning progress and encouragement to students. Following these ideas, robotics has begun to attract educators attention [6] and is being used as an educational tool. Teaching with robots will encourage learners to participate actively in the learning process and also assist them to appreciate the importance of existing knowledge, conceptions and varied learning styles. In robotics, learners are invited to work on experiments or problem solving with selective use of available resources, according to their own interests, search and learning strategies [7].

In this paper, we are looking at one of the key challenges for adopting robot programming in the curricula of African universities: identifying robotic platforms which are *suitable* for education purposes in computer science and at the same time are *affordable*. Affordability has to be seen differently than normally looked at in developed countries: for example, a minimal wage in Ghana is an order of magnitude (more than 15 times) lower than in the UK [8]. This specific challenge also gave rise to a number of initiatives discussed in Sec. II which focus on the design of particularly affordable platforms.

In this context, the key contributions of this paper are (i) the identification of *assessment criteria* for affordable robotic platform in education, weighing in the challenges and limitations imposed by the affordability constraint, and (ii) a unique assessment and comparison of ten different platforms that are generally deemed suitable for the tasks at hand. Hence, this paper is complementary to other existing surveys, such as [9] and [10], which provide an extensive review of educational robotic platforms suitable for tertiary education. These surveys target a rather broad spectrum of STEM subjects and therefore follow assessment criteria based on modularity, re-usability, versatility and affordability. Some of the platforms are relevant in our context (e.g. Microbot, Scribbler) but many are outside of our criteria: either their suitability for teaching computer science is limited or they are simply not affordable for educational institutions in developing countries (e.g. Khepera, NAO). Affordable robotic kits are very popular in Japan - a subject of a survey presented in [11]. However, many of the products are targeted at the Japanese market only and have limited support and distribution outside of the country. Researchers in swarm robotics focus on developing hardware and software platforms which are by necessity of limited functionality and very low cost (see for example a comparison of such platforms presented in [12]). The functionality provided by the hardware of these robots makes them perfect platforms for educational purposes, but with a few exceptions (e.g. E-Puck robot), the software and supporting materials are not focused on educational use.

II. Educational Robotics in Sub-Saharan Africa

In order to take advantage of the benefits provided by educational robotics, some institutions in Africa have started to use the robots for teaching activities. In Ghana, for example, Carnegie Mellon University, USA in partnership with Ashesi University in Accra, developed an undergraduate introductory robotics course teaching students how to design, build and program robotic systems [3]. The main purpose of this initiative was to encourage students to recognise the scope of computer science and to enhance their technical creativity and problem solving abilities. Despite the positive outcomes, the organisers mentioned lack of suitable, low-cost robot platform as one of the key limitations. In South Africa, University of Cape Town teamed up with Aachen University, Germany to design an inexpensive robotic platform for use in RoboCup Junior competitions and education [4]. The main motivation behind this development was lack of available commercial products within financial abilities of African institutions. The presented, promising initial design has not been followed up, however which prevented us from including this platform in our survey.

There are also initiatives outside of academia which involve building and using robots for educational purposes in Africa. The most prominent example, of pan-national relevance, is African Robotics Network (AFRON) [13]. AFRON brings together a number of organisations from the entire world interested in developing robotics-related education, research and industrial projects in Africa. One of the main activities organised by AFRON is the "Ultra Affordable Educational Robot" project featuring two robot design challenges to date. The scope of the competition is to design and build functional robotic platforms directed at engaging young pupils into STEM subjects and costing an order of magnitude less than commercial robotic products. The first "$10 Robot Challenge" from 2012, focused on very low cost robotic hardware platforms whilst the follow up competition, "Design Challenge: Robot Enhancements, Software, and Teaching Plans" brought the scope further by considering also accompanying software and educational material. This competition highlights the current trend in designing modern educational robotics platforms, which need to provide not only functional hardware components but also easy to use programming environment and supplementary teaching material. We include all these aspects in our assessment criteria presented in Section III. Selected contestants from both challenges were also included in our survey (see Section IV).

Educational robotic activities are also part of events organised by the iHub Research from Kenya - a community outreach innovation centre aiming to promote interest in technology, especially amongst young people. The activities include for example development and programming of robotic platforms based on Arduino boards during boot camps and hacking events [14].

III. Assessment Criteria

1) Affordability: Affordability is a very important factor to be considered which, due to economic inequalities between different parts of the world, has no global point of reference. There is a number of very popular and attractive robotic platforms used for education in developed countries which fall into the affordable category (e.g. [9]). Educational institutions in many African countries face regularly insufficient budgetary allocations, cuts in budgets and resource rationalisations [15] which make even reasonably priced robots such as LEGO Mindstorms beyond their reach. Some of the recent initiatives, such as the aforementioned AFRON robot design challenge address this issue by finding ways to overcome high prices that have put a hold on robotics education in the developing world [16]. The price target in a recent competition in that challenge was set at $20 whilst the limit of $100 was set for any contestants. In our survey, we assume a similar figure of $150 as the maximum price for an affordable robotic kit.

2) Kit Type: Following work of [9], [10], we restrict our survey mainly to a mobile robot category and disregard other platforms (e.g. electronic kits, manipulators) as not suitable for teaching computer science. In addition, we had to reject a number of popular flying platforms (e.g. Parrot drone) as their safe and convenient operation in a class environment is somehow difficult. Commercial mobile platforms are sold as a complete product and may be proprietary or open source. The proprietary platforms are difficult to adapt to suit the specific requirements. Open source commercial platforms on the other hand can be freely adopted and modified by users. The assembly kits are commercial products which come with parts, modules and accessories that need to be assembled and typically can be re-configured. The DIY kits which are available as open source projects need to be built from scratch but are usually cheaper than the commercial platforms and can be made from materials and components available locally.

3) Platform Features: An important aspect of any educational robotic platform is its hardware platform features such as processing power, sensory capabilities and software deployment. The majority of the affordable robots are equipped with on-board microcontrollers which, depending on specification, can process high-bandwidth sensors such as cameras, load and run programs autonomously, or be only limited to providing an interface between sensors/actuators and a PC. The popular sensors include tactile devices such as bumpers or whiskers, odometry, infrared or ultrasonic proximity sensors and video cameras. In addition, robots may feature LED indicators and displays which can be useful for debugging purposes. Deployment of the robot software is usually implemented by a tethered connection or a more favourable wireless connection, and may in addition require a special programming equipment and software tools. When scoring this criteria we looked at relative processing power of the built-in microcontrollers, variety and number of sensors and the convenience of software deployment.

4) Software Development: The software environment supporting popular programming languages with appropriate software libraries and development environment is essential to make the robotics platforms useful in education. For teaching computer science, high-level programming language support

is crucial so that programming concepts like variables, loops, subroutines could be introduced. The software libraries provide helpful abstraction of low-level operations allowing at the same time access to all hardware resources of the robot. This feature is especially important for teaching computer science, so the students can focus more on programming techniques rather than on low-level technical details. Similarly, a well integrated development environment will assure more efficient and effective learning experience. When scoring this criterion, we looked favourably at platforms with a dedicated software environment, high-level language support and simulators.

5) Educational Material: The effective and widespread use of educational robots should be supported by the existence of educational material helping teachers to design subject curricula [17]. The importance of this feature was recently highlighted in the second AFRON robot design challenge which included not only hardware platforms but also accompanying software and supplementary teaching material. These additional features will allow educators in Africa for preparing lesson material for different study levels without having to change the platforms. Platforms which come equipped with detailed tutorials can support teachers with little or no previous experience in educational robotics which may encourage others to participate in such initiatives to make them sustainable. In our scoring, we looked at availability, quality and variety of provided tutorials and lesson plans.

6) Maintenance: In light of poor maintenance procedures, inadequate training and under-utilisation of equipment in Africa [18], the maintenance of the robots needs to be considered in order to assure their continuous functioning and sustainability. Even though many commercial platforms are available through on-line sales globally, in reality they are not easily accessible in Africa due to prevalent problems with poor credit rating of many institutions and unreliable shipping [4]. This situation makes it difficult to easily procure new platforms to replace or repair faulty ones or add to the existing pool as student number increases. Therefore platforms which are easier to maintain due to their reliability and easy to set up procedures will be preferred. When scoring this criterion, we looked at the presence of enclosure, quality of assembly, convenience of charging and requirements for any additional equipment.

IV. REVIEW OF ROBOTIC PLATFORMS

We have considered over 30 platforms which were identified by analysing related work [9], [10], [12], the results of the AFRON competitions and additional Internet search. Following the proposed criteria and discarding platforms that went out of production in recent years (e.g. Parallax Toddler, Wowee Rovio), we have narrowed our choice down to 10 platforms which we present in this section in more detail.

1) Thymio II: is an open source platform which is also available as a commercial product at the price of approximately $130. The robot uses a 16-bit PIC24FJ128GB106 microcontroller and includes a number of IR proximity sensors, odometry, temperature sensor, accelerometer and microphone.

The robot can generate sounds and is equipped with an array of LEDs. The programs can be developed and uploaded from a PC through a USB port which is also used to charge an internal accumulator. The programming environment is based on Aseba, an open-source scripting language, which also includes a visual programming environment. There are some supplementary teaching materials provided with tutorials and project ideas. Thymio II has been used in teaching subjects such as physics [19] and computer science [20].

2) Scribbler 2: is a commercial robotic platform [21] with open-source hardware design available at a price of $130. The robot uses a custom-made, 8-core, 32-bit P8X32A microcontroller and is equipped with odometry sensors, photosensors, microphone and IR proximity sensors. The robot has also a speaker and status LEDs. The robot can run stand alone programs and be programmed through a serial interface using a USB dongle (provided with the kit) from a PC. The robot is powered by a set of replaceable batteries. The software environment is based on BASIC-like Spin language and comes also with a visual programming environment. Support for other high-level programming languages (e.g. C) is also provided. The robot comes with a rich set of educational materials both for students but also educators. Scribbler 2 (and its predecessor Scribbler) is supported by the Institute for Personal Robots in Education [22] which provides a large spectrum of teaching material for different groups and subjects.

3) Kilobot: was developed for swarm applications [23]. It is an open-source design but it is now produced and distributed as a commercial product at a price of $116. Kilobot is the winner of the first AFRON robot design challenge with parts costing only $14. The robot has an 8-bit ATmega328 microcontroller and is equipped with ambient light and IR sensors for proximity readings and communication. The robot has an alternative moving principle based on vibration motors which requires a fairly smooth surface and results in a relatively slow movement. The robot's microcontroller can be programmed through a serial interface requiring a dedicated programming device. The robot is powered by a rechargeable battery which requires a separate charger. Kilobot comes with a set of basic software libraries for sensor reading and motion control and requires a basic knowledge of microcontroller programming. High-level programming language support is provided by the microcontroller's development environment. The robot has simulation support through the V-REP simulator. Since the platform is directed at swarm robotics, there is no supplementary teaching material provided.

4) Jasmine: is a robot platform designed for swarm applications [24] available at approximate cost of $113. It is an open source hardware and software platform with simulation capabilities. The basic version of the robot comes with an 8-bit ATmega168 main microcontroller and uses a number of IR sensors for proximity sensing, communication with other robots and light measurements, and LEDs for status monitoring. The capabilities of the robot can be extended by a number of customised boards including improved sensing, connectivity, etc. The robot's microcontroller can be programmed from

a PC by a dedicated programming interface. Jasmine comes with software libraries simplifying the use of sensors and controls and requires a basic knowledge of microcontroller programming. High-level programming language support is provided by the microcontroller's development environment.

5) AMiR: is a robot designed for swarm applications [25]. It is an open-source platform which costs about $100. The robot uses an 8-bit ATmega168 microcontroller and is equipped with a number of IR proximity and communication sensors and LEDs for status monitoring. The robot's microcontroller can be programmed from a PC by a dedicated programming interface. AMiR comes with a set of basic software libraries for sensor reading and motion control. The programming requires a basic knowledge of microcontroller programming. High-level programming language support is provided by the microcontroller's development environment. The robot has been simulated in Player/Stage and has been used for teaching computer science courses at University of Putra, Malaysia [25].

6) Microbot: is a platform which comes as an assembly kit at an approximate cost of $65 for the basic kit [26]. Although requiring prior assembly, no soldering is required. The basic set comes with an 8-bit PIC-based PICAXE-20X2 microcontroller, two bumpers, a line tracking sensor, LEDs and a speaker. Robot sensing and communication capabilities can be further expanded by a range of additional modules. The robot can be programmed through a serial port requiring dedicated USB cable. The software programming language is based on BASIC but there is also a graphical programming tool called Logicator. Microbot is specifically designed for education but no supplementary teaching material is provided.

7) Colias: is a robotic platform developed at the University of Lincoln, UK for swarm robotic applications [12]. It is an open source platform and costs about $40. Colias is based on an 8-bit ATmega168 microcontroller and comes with IR sensors which provide proximity measurements and communication means with other robots, and there is an extra light sensor and LEDs. The robot's microcontroller can be programmed from a PC by a dedicated programming interface. Colias comes with a set of basic software libraries for sensor reading and motion control. The programming requires a basic knowledge of microcontroller programming. High-level programming language support is provided by the microcontroller's development environment. There are ongoing plans to develop Colias as an educational platform, but so far no supplementary material has been released.

8) SEG: is a winner of the second AFRON robot design challenge. It is an open source platform, with mechanical parts fabricated by 3D printing and assembled into a complete robot for an approximate cost of $20. The main hardware contains an Arduino Pro Mini board, which uses an 8-bit ATmega328 microcontroller. The basic set is equipped with a single photo sensor and LED only. The basic capabilities can be expanded by additional sensors, actuators, and communications modules which can be added for an additional cost. The robot's microcontroller can be programmed by a dedicated programming in-

terface. The robot can be programmed using a graphical drag-and-drop interface through ArduBlock graphical environment which also automatically generates C++ code. SEG comes equipped with teaching materials in the form of curriculum that has been developed into worksheets, video lectures and labs for students to learn basic robotics and programming concepts.

9) AERobot: is a modified version of the Kilobot robot designed specifically for educational purposes [27]. The reduced cost and enhanced educational capacity was achieved by removing the Kilobot's swarm capabilities. It is available as an open-source project at a price of $11. AERobot was also one of the winning contestants of the second AFRON robot design challenge. It uses similar hardware platform as Kilobot but additional IR sensors and an colour LED have been added. The robot has been also enhanced by an addition of a built-in USB port allowing for direct programming from a PC without a need of special programmers, and for charging its battery. The robot comes with a modified miniBloqs software suite which is an open source graphical programming environment for Arduino boards. It comes with teaching materials made up of a set of lessons helping students to learn the basics of robotics and programming.

10) Lollybot: is an open-source platform with an approximate price for components of $9. The robot is a winner in the tethered robot category in the first AFRON robot design competition. The robot's main body and drive system are essentially built from a recycled PlayStation controller. Lollybot has bump sensors, LEDs and photoresistors which act as line detectors and are accessible through the controller's built-in USB interface [28]. This makes the robot directly controllable by a tethered PC which provides the robot's processing power. The robot software environment supports high-level programming languages such as Delphi, HTML and JavaScript. There are some suggestions provided for teaching different concepts and the robot was used in teaching activities which were part of the second AFRON robot design challenge.

V. ANALYSIS AND DISCUSSIONS

Table I presents a comparison of the affordable robotic platforms based on our assessment criteria. The provided scoring is ordinal and each criterion is considered independently. The following analysis justifies the scores given for individual criteria, extracts general trends, highlights prominent examples and discusses the relevance for our teaching context.

Almost all platforms (excluding Microbot) have open hardware and software designs allowing for easy expansions and modifications. A general trend that can be observed is that cheaper options are available only as DIY kits, requiring a prior assembly, and that the price for commercial robots is above $100. It seems that affordable robots still pose a business challenge even in mass production, which should in principle result in more compelling prices.

The processing capabilities of all considered platforms are provided by inexpensive microcontrollers. One exception is

			Platform Features					
Robot	Kit Type	Price	Processing	Sensors	Deployment	Development	Edu. Material	Maintenance
Thymio II	commercial/DIY	$130	***	***	***	***	**	***
Scribbler 2	commercial	$130	***	***	**	**	***	**
Kilobot	commercial/DIY	$116	**	**	**	**	–	*
Jasmine	DIY	$113	**	**	**	**	–	*
AMiR	DIY	$100	**	**	**	**	–	*
Microbot	assembly	$65	**	*	**	**	–	*
Colias	DIY	$40	**	**	**	*	–	*
SEG	DIY	$20	**	*	**	**	***	*
AERobot	DIY	$11	**	**	***	**	***	*
Lollybot	DIY	$9	–	*	*	**	**	**

TABLE I
AFFORDABLE MOBILE ROBOTIC PLATFORMS (RELATIVE SCORING: *** = VERY GOOD, ** = GOOD, * = BASIC, – = MISSING).

the cheapest option, Lollybot which has virtually no on-board processing power and serves only as an interface for sensors and actuators and a PC. The most popular are 8-bit platforms from leading microcontroller manufactures (Atmel, Microchip) with two platforms (Thymio II and Scribbler 2) offering slightly higher specifications. Although all these devices provide sufficient resources for handling rather limited sensory capabilities of the robots, more powerful platforms could support more complex behaviours and richer functionality. It is likely, that future educational robots will see the adoption of recent developments in affordable computing platforms such as Raspberry Pi or Intel Edison.

All presented robots feature relatively simple sensors such as bumpers or light detectors. Odometry is present only in a couple of more expensive platforms (Thymio, Scribbler 2). A very popular sensing principle (not present in Microbot, SEG and Lollybot) is based on IR sensors which can be used as proximity sensors, light detectors but also for remote communication. The simplest and also the cheapest solutions (Microbot, SEG, Lollybot) support only a couple of simple sensors. More sophisticated sensors such as cameras and sonars are usually available as extension modules which unavoidably affect the final price of such a setup.

All considered robotic platforms are programmable through a serial interface. Some platforms such as Thymio II, AERobot and Lollybot feature a standard USB port, but all other robots require a dedicated programming interface which is not always provided. Lollybot is a unique example of a robot that needs to be tethered to a PC all the time. Platforms designed for swarm robotics (Kilobot, AMiR, Jasmine, Colias and AERobot) have short-distance wireless communication which is used for communication between individual robots but unfortunately none of these solutions is used for remote programming or control. Other wireless communication solutions such as Wi-Fi are only available as expansion modules in selected models. The remote deployment is essential in teaching environments and can simplify the ease of use and flexibility of the platforms.

All presented platforms come with some form of software libraries abstracting robot's low-level functionality. Platforms such as Kilobot, Jasmine, AMiR and Colias rely solely on microcontroller programming environments (e.g. AVR Studio

by Atmel). In addition, Kilobot and AMiR provide simulation capabilities which is an important education feature enabling for example teaching of large classes or individual learning outside teaching activities. Jasmine supports also higher-level commands written in Motion Description Language. The remaining six platforms provide some dedicated programming environments based either on the existing open source projects (Aseba, minibloqs, ArduBlock) or specifically designed for the robot (Sribbler's Spin, or Lollybot's Delphi libraries and GUI). These platforms also support graphical programming environments which may have some use for teaching students new to programming. It is surprising to see no explicit support for ROS in any of the presented platforms, with an exception of Thymio II, which can provide more sophisticated off-board functionality and be useful for teaching robotics and software engineering in later stages of university education. This can be explained however, by a general lack of wireless communication in the presented robots which is essential for interfacing with a networked system such as ROS.

Supplementary educational material is typically not provided with platforms designed for swarm applications (Kilobot, Jasmine, AMiR, Colias), even though there is some mention of their use in education (e.g. [25]). Commercial educational platforms such as Scribbler 2 come with a rich set of teaching material targeting different groups and skills but also educators. The three cheapest platforms in our ranking (SEG, AERobot, Lollybot) which were all participants of the AFRON robot design challenge have also excellent teaching support. This demonstrates importance of such initiatives and hopefully sets a precedent for future designers and manufacturers of affordable robotic platforms.

Several aspects affect the scoring of the maintenance criteria in our survey. Platforms such as Thymio II, Jasmine, Colias and AERobot support convenient charging directly through a USB port without the need for additional charging equipment or disassembling parts of the robot. Platforms such as Scribbler 2 and Microbot require replaceable battery packs whilst Kilobot, SEG and AMiR need additional chargers. Commercial platforms (excluding Microbot and Kilobot) come with suitable enclosure which protects the circuitry and improve robustness of the design. The three cheapest robots also

provide some form of shielding. Robots available as assembly or DIY kits require prior assembly and therefore their robustness will depend much on the skills of a person building the robot. In selected cases (SEG, AERobot), assembly will require access to specialised equipment (e.g. for mounting SMD components, 3D printer) which might not always be available at African institutions. This is less of a problem with a solderless assembly required by Microbot. Kilobot and AERobot feature alternative moving principle and may therefore require additional smooth surface for operation.

From the presented analysis, the most compelling platforms in our context represent the top and bottom cases in Table I. Commercial robots like Thymio II and Scribbler 2 score high in all considered criteria presenting rich platform features, good software support, available teaching material but also pose the least problems with maintenance. Therefore their use at African institutions would be recommended despite relatively high prices. One missing aspect which would help spreading the use of such robots in Africa is related to missing customer support, distribution and service centres locally. On the other end of the price spectrum are robots such as SEG and AERobot which are excellent educational platforms with somehow limited functionality and posing various maintenance issues. A compelling aspect of these platforms is that they can be sourced and made locally, but their wider adoption requires skilled technicians and also specialised equipment. It is disappointing to see that platforms in the middle price range which were designed for swarm applications have currently strong limitations in software development and educational material, which would prevent their straightforward adoption in Africa.

VI. CONCLUSIONS

In this paper, we have presented a survey and analysis of currently available affordable mobile robotics platforms suitable for teaching computer science at African universities. We have proposed a set of assessment criteria and reviewed a number of platforms costing under $150. Our analysis has identified suitable candidates from both commercial and DIY categories offering contrasting features and benefits. Potential issues and promising directions were also discussed which could be considered by both educators but also designers and manufacturers of future robot platforms. The presented survey can only be treated as a snapshot of current developments in affordable robotic platforms as there are ongoing initiatives taking place. There is a number of interesting projects currently seeking funding through crowd sourcing platforms such as Kickstarter with examples such as Tiddlybot, a Raspberry Pi based robot platform or RoboCORE, an inexpensive computing platform specifically designed for making own robots. Therefore we should expect more compelling and affordable robot platforms in near future. Educational robotics can play a key role in addressing some of the challenges faced by higher education in Africa and its successful implementation will partly depend on the issues discussed in this paper.

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Hedgehog: A Smart Phone Driven Controller for Educational Robotics

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Abstract– **Robotics represents an ideal tool for teaching science, technology, engineering and math (STEM) due to its interdisciplinary nature and appeal for young people. This paper gives an overview of the Hedgehog controller, a robot controller developed with education as an explicit use case. Mobile devices are part of the architecture for increasing the appeal to students and decreasing the costs of the controller hardware. The peripheral interfaces in conjunction with the capabilities of today's smart phones and an optional single-board computer make the platform suitable for sophisticated applications in and beyond the education domain.**

Keywords–controller; smart phone; tablet; Android; iOS; app

I. INTRODUCTION

Robotics is a suitable tool for teaching science, technology, engineering and math (STEM) due to its interdisciplinary nature and its appeal for young people. The lack of adequately trained workforce in these domains make efforts to introduce students to STEM more important than ever [1], [2]. Early exposure to these fields increases the impact of taken efforts.

However, school budgets are often too small for introducing robotics at young ages due to the required investments in equipment. Furthermore, teachers trained adequately in robotics are often not available for these ages. As a consequence, only individual teachers' efforts dominate robotics education [1], [2], [3]. This led to the development of Hedgehog [4], a low priced robot controller that involves smart phones and similar mobile devices.

Smart phones provide a rich user interface via touch screen, network capabilities, fast processors, a lot of memory, and internal sensors, such as gyroscopes, acceleration sensors, and cameras [4]. With smart phones getting increasingly common among even young school children, duplicating these capabilities in a robot controller unnecessarily increases costs.

At the same time, using the smart phone further engages students in the subject matter. Supplementary material and intuitive user interfaces support teachers without specific training and aid teachers and children in a shared learning and exploration experience.

Using mobile devices lets Hedgehog automatically benefit from innovations in the field of consumer electronics. Network capabilities and other features less important for introductory

robotics courses open up a wide area of applications in and beyond the education domain [5], [6]. These benefits make Hedgehog less susceptible to obsolescence and thus a versatile long term investment.

II. CONCEPT

A. Modularization

Fig. 1 shows the Hedgehog architecture. The Hedgehog controller is composed of two layers, the high-level control (HLC) and low-level control (LLC), named so for their deliberative and reactive roles, respectively [4]. The HLC consists of the mobile device and its software; the LLC is composed of the hardware controller (HWC) and the software controller (SWC). Inter-module communication is done using a simple stateless protocol.

The HWC is responsible for time-critical tasks and is effectively a black box to the user. These tasks include generating pulse-width modulated signals for motors and servos, providing WIFI connectivity, or communicating with external hardware such as an iRobot Create via additional interfaces like universal synchronous/asynchronous receiver/transmitter (USART) or inter-integrated circuit (I²C). The SWC is a single-board computer on which the user can run arbitrary applications. The current implementation uses a Raspberry Pi as SWC and an Android device as HLC, but an iOS variant is currently in development.

B. The Hedgehog App

Like the SWC, the HLC can run arbitrary software – apps in the case of Android or iOS – but the use of the Hedgehog app is assumed for education purposes. It provides

- overview screens to test actuators and sensors. This eliminates the need for a screen found on most conventional educational controllers.

- an integrated development environment (IDE) with debugging facilities to create programs to run on the SWC. This makes separate development machines unnecessary for courses.

By writing applications for the SWC, development license issues, especially on the iOS platform, are avoided. All of these measures reduce costs for schools.
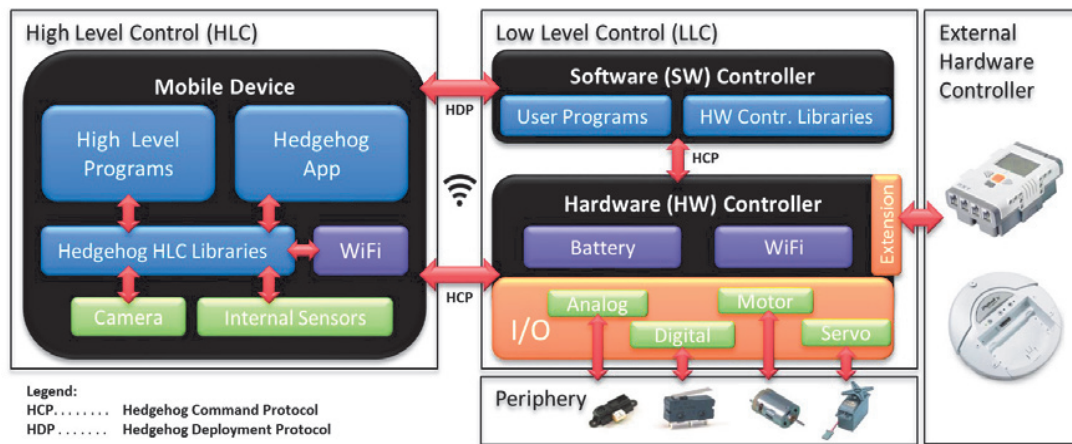
Fig. 1. Schematic overview of Hedgehog's architecture, showing modules, interfaces and protocols [4].

III. HEDGEHOG IN USE

In its current stage, the Hedgehog app's IDE supports programming in C. Support for other popular languages, such as Python or Java, is planned for the future. To accommodate for the heavy use of punctuation in most programming languages, additional code template buttons, e.g. for inserting loops, are provided in the IDE.

During deployment, the source code is sent to the SWC and compiled there. Compilation results, i.e. return code and any compiler messages, are sent back to the HLC. The alternative, compiling on the HLC, would require cross-compilation support. This is not viable on most mobile devices, and would introduce tighter coupling between HLC and SWC, which is not desirable.

For debugging, commands such as "Debugging Break Action", which suspends the running SWC program, are available to the HLC. These commands correspond to commands and events of Gnu Debugger (GDB), although the use of GDB on the SWC is an implementation detail. Fig. 2 shows two screen shots from a Hedgehog debug session.

IV. CONCLUSION AND FUTURE WORK

The Hedgehog controller represents a powerful platform for educational robotics. Using smart phones facilitates existing resources and provides a well-understood, attractive working environment. At the same time, Hedgehog can leverage future improvements in those devices. Overall, this makes Hedgehog a worthwhile low-cost, long-term investment for schools.

As mentioned before, iOS support and debugging features are currently in development. Additional programming languages will make Hedgehog attractive to a broader audience. Graphical programming for the Hedgehog platform, based on Catrobat's Pocket Code [7], is already in its planning stages and will make Hedgehog suitable for young children.
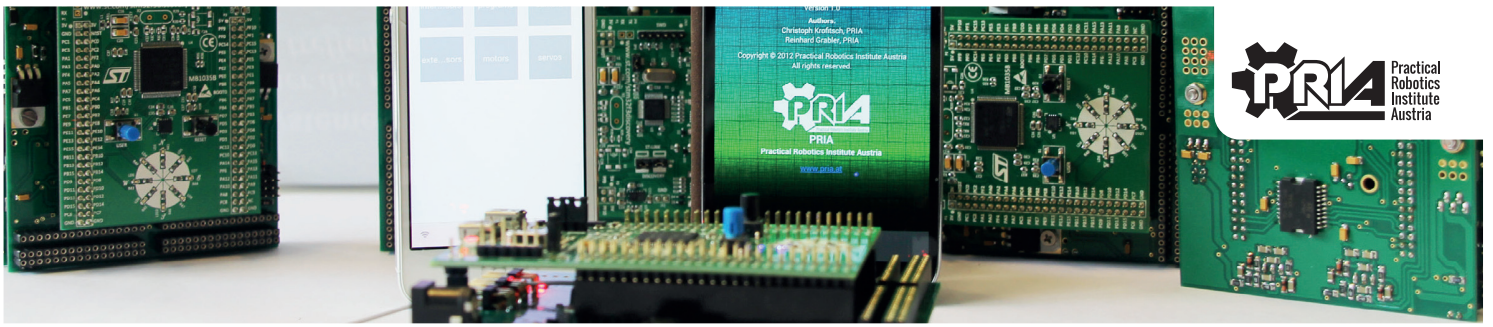
Fig. 2. Two screenshots (cropped) from a debug session. Left: Standard output. Right: Setting breakpoints in the source code while the program is suspended.
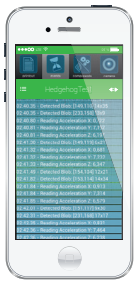
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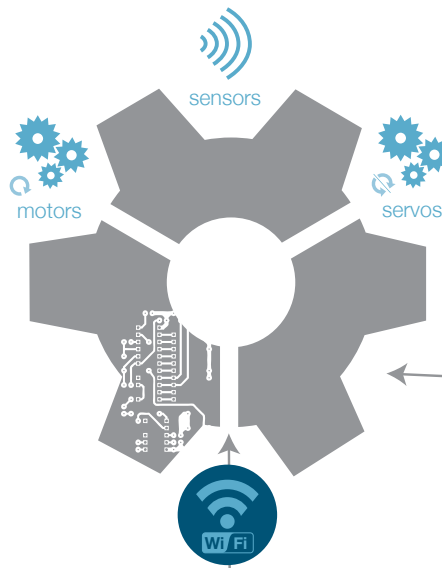
Hedgehog

Smartphone-based   Low-Cost Robot Controller

Version 7.0
Authors:
Christoph Krofitsch, PRIA
Reinhard Grabler, PRIA

PRIA
Practical Robotics Institute Austria
www.pria.at

PRIA Practical Robotics Institute Austria

Traced events are shown on a dedicated screen in real time during program execution.

sensors

motors   servos

Runs on both Android and iOS

The Hedgehog app contains controls to directly test connected components.

The Hedgehog controller, plus a smart phone with the Hedgehog app, are all that is needed to program robots.

The component screen shows sensor values and actuator information, e.g. current position, or speed.

Wi-Fi

Using a standardized protocol for all communication allows supporting multiple mobile platforms.

Easy calibration allows students to efficiently use the phone's camera.

Hedgehog works with the built-in sensors of the phone, such as accelerometer, gyroscope or camera.

Besides testing and configuring, the Hedgehog app includes an IDE to code directly on the phone.

●●●○○ LTE 📶   97 % 🔋

programs

Hello World   version 1.0
                     10/01/2014 03:14   ⓘ

Line Following   version 1.7
                     10/13/2014 17:42   ⓘ

Color Tracking   version 3.0
                     10/16/2014 08:30   ⓘ

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The SCORE! project of the Practical Robotics Institute Austria aims to enhance robotics for the educational domain by providing a simple, flexible and affordable robot controller. This controller consists of the user's smartphone, an electronics board and software making robot programming intuitive and easy to learn.

Teaching Intelligent Robotics with a Low-Cost Mobile Robot Platform

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Abstract—In this short paper we present the requirements and implementation of a mobile robot platform to be used for teaching intelligent robotic classes. We report our experience of using the platform in university courses and various extracurricular activities.

I. INTRODUCTION

Selection of a suitable robot platform plays a crucial role when teaching advanced intelligent robotics classes. It is very desirable that the students are able to build upon solid theoretical foundations on one hand, and get a direct hands-on experience on the other hand. The robot platform that is used in a such pedagogical process should therefore preferably fulfill the following requirements. (1) It should be robust, durable and non-fragile, enabling students to work with it on a daily basis. (2) It should be accurate and reliably controllable; the actions should be sufficiently repetitive. (3) The sensors should be sufficiently rich, and the computational power should enable demanding computations; the system should be scalable and upgradeable in terms of software and hardware to enable extensions for tackling more advanced tasks. (4) The price should be reasonable to enable the purchase of a larger number of robots for small groups of students. (5) It should enable transfer of learned knowledge to other more expensive robots that are used in the practice.

In the past decade a lot of different robot platforms designed for educational use have been presented [1]. When starting a new course on development of intelligent system, however, we tried to find a solution based on the requirements mentioned above. The requirement (4) clearly rules out powerful yet expensive robotic platforms that are usually used in research. The requirements (3) and (5) mostly rule out the use of Lego Mindstorms, Thymio robots or similar educational platforms. The requirements (1) and (2) discouraged us of using some other hobby robotic platforms. We brought a decision to build our robot on top of the low-cost iRobot Roomba vacuum cleaner and to extend it to meet all the requirements mentioned above. Since at that time, in late 2011, the TurtleBot platform based on the related iRobot Create platform became available, we decided to make use of it; to extend it and to adapt it to our needs. In this paper we describe these modifications and report our three year experience of using the platform in university courses and various extracurricular activities.

II. THE ROBOT

In the design of our robot platform we have largely followed the TurtleBot concept, but made some changes and improvements in terms of robustness and hardware maintenance. The robot system is composed of the robot base, a processing unit, a depth sensor and a camera, and a framework connecting all the components in a unified device. A schematic overview of our platform is shown in Figure 1.
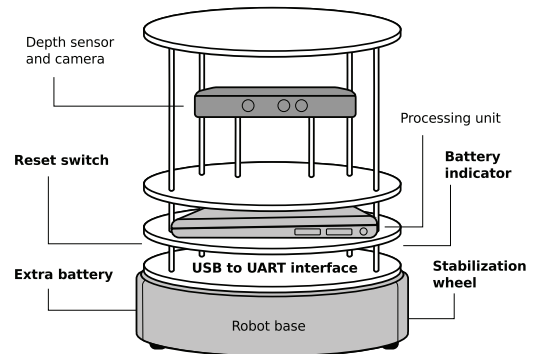

Fig. 1. An overview of our robot platform. Our modifications of the original TurtleBot concept are written in bold.

A. Robot base

Due to unavailability of iRobot Create in Europe at the time, we have opted for a modified version of iRobot Roomba 531, a commodity autonomous vacuum cleaner robot. By default this robot is equipped with a front bumper sensor, an IR cliff sensor, IR proximity sensors, and an odometry sensor. The internal battery suffices for around 3 hours of work. We have removed the vacuum unit and replaced it with an *extra battery* for the depth and color camera. Since it turned out that shaking of the original robot base in case of rapid accelerations decreased the navigation capability, we have added a *rear wheel* to increase the stability of the robot. The robot base is controlled by a laptop computer using a *custom USB to UART interface* that is also able to turn the base on when the communication is started. The base is also equipped with a *hardware restart button* that enables fast reset.

B. RGBD camera

As a primary sensor we use the first generation of Microsoft Kinect (released in 2010, a year before the start of our course)

as a depth sensor and a color camera. Immediately after its release Kinect became extremely widely utilized in robotics community [2]. Unfortunately the sensor needs additional external power, which is supplied by the extra battery in the robot base that suffices for around 2 hours of work. We have also included an external battery status indicator so that users know when to charge the battery.

C. Processing unit

The central processing device of the robot is an Asus X301A laptop with Ubuntu operating system and Robot Operating System (ROS) [3] middleware. The usage of a laptop for controlling the robot base offers a great deal of flexibility: it can be used directly or it can be accessed over the WiFi network. Similarly, all the computations can be performed on-board, or they can be distributed over several computers using the WiFi network and ROS distributed computing environment. Being able to use ROS modular architecture and numerous available packages is also a great advantage. The laptop contains Intel i3 processor, 4GB of RAM and was upgraded with a 120GB SSD drive that is more resilient towards vibrations and rapid accelerations. The laptop only has two USB slots, which suffices for the basic use, however, we also added a USB hub to allow for the use of additional devices (e.g. an additional camera, external speakers, etc.). The integrated battery offers around 4 hours of autonomy (depending on the computational load).

III. TEACHING ROBOTICS

The robot platform was used during the practical part of the course Development of Intelligent Systems. The students worked in small groups and had to program the mobile robot to accomplish a given task that involved robot navigation, object recognition and localization, dialogue, and planning. The examples of the tasks were a slalom ride, object search, and mini Cluedo. In the latter task the robot had to autonomously detect and recognize persons' faces, approach them, and in a dialogue with them found out where they had hidden which object; then the robot had to find and show these places. The tasks could therefore be quite challenging involving different functionalities that the students have to develop and/or integrate. The assessment was organized in the form of competitions, which enabled the students to compare their solutions in a competitive manner. The students accepted such form of work and assessment very well and were highly motivated for the work.

Keen students also use our robot platform for their diploma and master thesis projects. Several functionalities and systems have been developed, such as people following, autonomous exploration of space, autonomous object search, autonomous building of 3D model of an object, a mobile landing platform for a quadrocopter, etc. It turned out that the robotic platform is very suitable for such work that definitively increases the interest of students as well as provides a very important set of skills for the prospective students that are willing to continue

their work in the field of intelligent robotics, either in research or industry.

Our robot platform is also used to promote robotics among children. To make the robot more approachable we have created an external shell that resembles the famous R2-D2 robot from Star wars movies. The shell is equipped with a USB camera, a microphone and speakers. At the events the robot was quickly recognized by children who then easily interacted with it.

IV. CONCLUSION

The robot described in Section II fulfills the requirements presented in Introduction. (1) A very robust and durable domestic robot is used, which turns to be (2) sufficiently accurate and reliably controllable. (3) Since it is controlled by on-board computer running ROS, the system is very scalable and enables the usage of numerous ROS packages implementing various functionalities, as well as it enables the usage of different sensors; the RGBD camera Kinect suffices for our purpose. (4) Since the system is composed of off-the-shelf consumer products, the price is kept relatively low (below 1.500 EUR). (5) However, since most of the software used is portable to almost any ROS-enabled mobile platform, the knowledge learned is fully transferable to significantly more expensive and widely used robotic platforms.

By using this platform for educational purposes for three years we also identified several problems and found adequate solutions. A robot platform that is used for teaching mobile intelligent robotics has to be robust and composed of easily replaceable components as frequent use by many users that are less familiar with the system wears down the hardware. Having a lot of user shifts on the same robot in a short period of time also requires a lot of coordination. Users have to take care of status of multiple batteries in one system which is hard to achieve when students have a deadline. Using multiple robots at the same location (in a class) can also be problematic when using WiFi networks to monitor the status. Image or point cloud transfers can cause a lot of traffic and even clog most commodity-level wireless routers.

Our future work will include additional modifications to the platform to increase its robustness. We plan to unify the charging mechanism so that all devices will be charged at once. We have been already testing the dual-band wireless networking for higher network throughput. With these additional improvements we will create a very robust and efficient platform for teaching intelligent robotics classes.

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Teaching Intelligent Robotics with a Low-Cost Mobile Robot Platform

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ViCoS
sual cognitive
ystems lab

Premise

Selection of a suitable robot platform plays a crucial role when teaching advanced intelligent robotics classes. The robot platform that is used in a such pedagogical process should therefore preferably fulfill requirements like robustness, accurate, richness in sensory input and computational power, reasonable price, and easy transfer of acquired knowledge to other more expensive platforms.

In 2011 we started with a novel course on development of intelligent systems. We chose a modified TurtleBot platform as our target general-purpose mobile robot platform for hands-on experience. We report on our three year experience of using the platform in courses and various extracurricular activities, on the modifications that we did to make it more robust and on the lessons learned.

Teaching

The practical part of Development of Intelligent Systems course requires students to work in groups and program a mobile robot to accomplish a given task that involved robot navigation, object recognition and localization, dialogue, and planning.
At the end of the course we have organized a competition which enabled students to compare their solutions and motivated them to work on the project.

Final Projects

Keen students also use our robot for their diploma and master thesis projects. Several applications have been developed, e.g. people following, autonomous exploration of space, autonomous object search, autonomous building of a 3D model, a mobile landing platform for a quadrocopter, etc. The platform increases the interest of students as well as provides them with a very important set of skills in the field of intelligent robotics, either in research or industry.
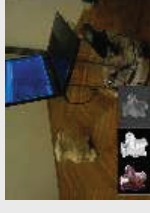
Promoting robotics

Our robot platform is also used to promote robotics among children. To make the robot more approachable we have created an external shell that resembles the famous R2-D2 robot from Star wars movies. The shell is equipped with an USB camera, a microphone and speakers. At the events the robot was quickly recognized by children who then easily interacted with it.
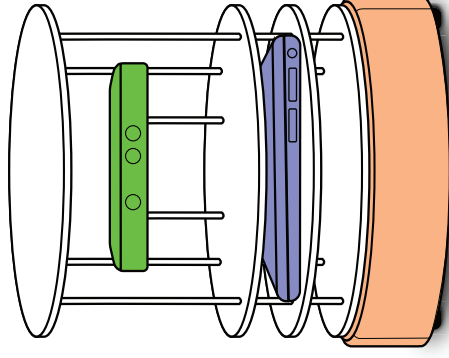
Robot base

Due to unavailability of iRobot Create outside of the USA, we are using a modified version of iRobot Roomba 531, a commodity autonomous vacuum cleaner robot. By default this robot is equipped with a front bumper sensor, an IR cliff sensor, IR proximity sensors, and an odometry sensor. The internal battery lasts for around 3 hours of work.

We have removed the vacuum unit and replaced it with an extra battery for Kinect. Since it turned out that shaking of the original robot base in case of rapid accelerations decreased the navigation capability, we have added a rear wheel to increase the stability of the robot.

The robot base is controlled by the processing unit using a custom developed USB to UART interface that is also able to turn the base on when the communication is started. The base is also equipped with a hardware restart button that enables fast reset.

Depth sensor and camera

As a primary sensor we are using the first version of Microsoft Kinect (released in 2010) as depth sensor and a camera. Kinect needs external power supply that is supplied by the extra battery in the robot base that suffices for around 2 hours of work. The platform also contains an external battery status indicator.

Processing unit

The central processing unit of the robot is an Asus X301A laptop with Ubuntu operating system and ROS middleware. Using a laptop offers flexibility: we can use it directly or access it over WiFi network. It can be also quickly replaced in case of malfunction. The integrated battery offers around 4 hours of autonomy (depending on computational load).
The laptop contains Intel i3 processor, 4GB of RAM and was upgraded with a 120GB SSD drive that is more resilient towards rapid accelerations. It has only two USB slots, which is enough for basic use, however, we have also included an USB hub to allow use of additional devices (e.g. extra camera, external speakers).

::: ROS

Lessons learned

A robot platform that is used for teaching mobile intelligent robotics has to be robust and composed of easily replaceable components as frequent use by many users that are less familiar with the system wears down the hardware.

Having a lot of user shifts on the same robot in a short period of time also requires a lot of coordination. Users have to take care of status of multiple batteries in one system which is hard to achieve when students have a deadline.

Using multiple robots at same location (in a class) can also be problematic when using WiFi networks to monitor the status. Image or point cloud transfers can cause a lot of traffic and even clog most commodity-level wireless routers.

Using ROS as a software base was a good decision as it offers a stable software base and is used on various robot platforms. Students that got familiar with ROS during the course were able to use their knowledge on other ROS enabled robot platforms in the scope of education or research projects.

Future work

Our future work will include additional modifications to the platform to increase its robustness. We plan to unify the charging mechanism so that all devices will be charged at once. We have been already testing the dual-band wireless networking for higher network throughput. With these additional improvements we will create a very robust and efficient platform for teaching intelligent robotics classes.

Continuous Engineering Education Based on Mechatronics and Digital Fabrication

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Abstract—The paper briefly discusses major points of concern for the group of educators with different professional background united to find and share best practices of continuous engineering education. Target age groups for the educational process include: kids of 7-10 years old, children of 11-14 years old, teenagers of 15-18 year old, young specialists of 19-22 years old and young professionals of 23-30 years old. The material could be of interest to active educators looking for better ways of organizing project-oriented studies and learning environment in a modern digital fabrication setup.

Keywords—robotics, mechatronics, engineering education, digital fabrication, international cooperation.

I. INTRODUCTION

Organizing continuous engineering education starting in an elementary school and naturally continuing in a university seems reasonable but at the same time is a non-trivial task. In the time when the concept of education around the world is changing the authors address this task to find a working solution and integrate it in the global education system.

The authors share their work [1] [2] and best practices [3] [4], popularize technical sciences and education because it is important to stimulate further dialogue and integration of the interested community around the world.

Education in different countries having a lot in common still has individual details sharing of which could benefit the rest of the world and finding a way to cooperate is seen as a very important factor of the global success.

II. EDUCATION AND COMPETITION

Experience of more than 10 years of practice proves that using competitive robotics in engineering education brings very distinct results. Experiment of a group of people (the Group) united in a competition organizing committee [5] shown that schoolchildren taking additional practical training based on Eurobot [6] mobile robot competition were able to compete with best student teams even before finishing secondary school.

While being successful in competition the young also are able to share their knowledge, finding understanding even with older students. Such classes (when the teacher is younger than the students) have been presented on international conferences [3] by one of the youngest teachers in the Group. Such successful experience is used in forming mixed-age learning environment stimulating communication and self-education.

For students the competition approach to education gives definite aims in the form of an object (a mobile robot, a mechatronic device...) to be built by the end of a training course. Participation to a contest shows quality of the team's knowledge and technical results. Creativity allowed in the competitions and the concentration of interested public and participants lead to natural self-education and communication skills' practice.

Learning basic ideas about engineering could be easy even with a limited set of hand-tools. Though continuing education and mastering the known technologies is not possible without the proper infrastructure and specialists sharing their knowledge. Those students who pass the full proposed educational process show outstanding engineering practical knowledge [7] and beat significantly older students in engineering competitions [8].

III. INFRASTRUCTURE AND CAPABILITIES

Humanity is now experiencing a change in the development of technologies that are comparable in scope to such achievements as the industrial revolution, the development of agriculture, and perhaps even the very beginning of the use of tools [9].

The emergence and development of digital fabrication technologies has led to a significant convergence of such phenomena as matter and information. Just as the progress in the development of computers has led to multiple processes cheapening production, storage, transmission and dissemination of information, the development of digital manufacturing technology leads to the democratization of production processes, which creates prerequisites for profound changes in the technosphere.

Current and expected changes in manufacturing systems start to dictate qualitatively new requirements for training and education.

To date, a typical digital fabrication laboratory [10] from a technical point of view is a set of commercial machines of digital fabrication. Currently operational open labs of such type are only prototypes of the near future distributed network nodes. The mission of these sites now is less associated with the development and manufacturing of products - the main problem is formal and informal training of creative engineering personnel to meet new challenges of the improving world.

IV. THE EXPERTISE AND KNOWLEDGE

Robotics is an interdisciplinary system area, integrating knowledge from many previously separate areas of science and technology. The quest for a new quality of robots requires functional, structural and constructive connectivity of devices of different physical nature into a single machine on the basis of principles and technologies of mechatronics. Mechatronics technologies include engineering design, manufacturing, information and economics processes that provide the full life cycle of mechatronics products [11]. The development of mechatronics is a priority of modern science and technology in the world.

The method of mechatronics includes the expertise and knowledge in previously separate scientific and engineering areas. Mechatronics systems are built by synergistic integration of constructive modules, technologies, energy and information processes at all stages of the product life cycle, starting from the design stage to production and operation. Interdisciplinary tasks and problems determine the content of educational programs for training of engineers who focus on system integration of devices and processes in mechatronics systems.

Connection of education, academia and industry provides up-to-date expertise and knowledge, showing actual trends and future of the selected engineering field for a student. This allows bringing up the best engineers.

V. NETWORK AND COMMUNITY

The power of the chosen approach to education made it possible to grow the community of sympathizing and collaborating people. Since the very first step of the Group it involves such cities and regions in Russia as: Astrakhan, Ekaterinburg, Saint-Petersburg, Novosibirsk, Saratov and Moscow with its vast suburbs and country side towns.

International cooperation since the early Eurobot contacts [12] proved the very high potential of such activity and united effort of different countries to bring best practices and learning possibilities in their homelands.

VI. POPULARIZATION AND VISIBILITY

Simple problem solving and system building is not enough - it is also important to attract attention of many people to the cutting edge of the happening processes in education and production. Without the popularization and visibility among the general public all the work results are depreciated.

The educational process in teams [13] preparing for another round of robotic competitions shows that the lack of any connection and communication with other teams during the preparation period generally yields lower results on a competition day. Previous experience shows that stimulating of such

an activity even on local level [14] motivates students and results in generally better robots and competition quality.

All the visibility aspects could be addressed in preparing and managing a proper website with all the latest news and activity [5].

VII. CONCLUSION

10-year experience of building a continuous engineering education process shows high potential in bringing up students (starting with kids of 7-10 years old) through a series of steps to an advantageous position compared to someone of the same age.

Besides time such an approach requires appropriate tools of motivation and subject (e.g. competitive educational robotics), digital fabrication infrastructure, connection to academia and industry expertise, networked community building methods, visibility and popularization among the general public.

The academic result of the work was and still is fractionally presented in just a few conference papers and the practical result proved to be positive in many robotics competitions local and international.

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ROBOTICS [step by step]

Continuous Engineering Education Based on Mechatronics and Digital Fabrication

EDUCATIONAL PROCESS

Tested and Approved Educational Methods
Practical Engineering Knowledge
Educational Kits & Equipment
International Cooperation

Educational Events,
Competitions
and Conferences,
Mixed-age Learning
Environment

hi-tech inspiration...

eurobot 2015

2015 RiE
International Conference
on Robotics in Education
Yverdon-les-Bains, Switzerland

EDUCATIONAL PROGRESS

Step 1
Age 7-10 y.o
Kids

start with kits

Step 2
Age 11-14 y.o
Children

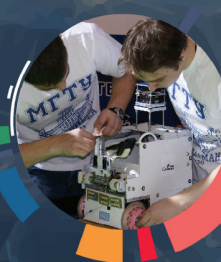add self-made
parts

Step 3
Age 15-18 y.o
Teenagers

build your own
robot

Step 4
Age 19-22 y.o
Young
specialists

add autonomous
parts

Step 5
Age 23-30 y.o
Young
professionals

master complex
robotic systems

hitech-school.ru

Moscow Technological Support of Education

ЦТПО

3. Curriculum Aspects

Chairperson Boualem Kazed

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.

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[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.

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[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
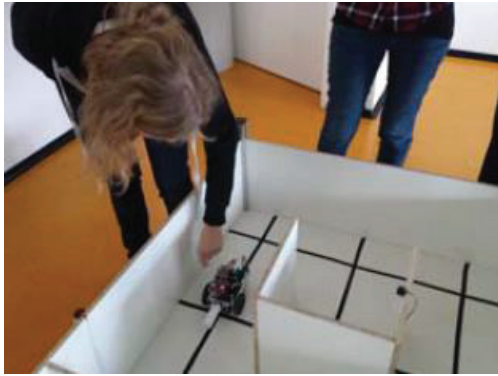

Fig. 6. Workshop in middle school © OCG

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.

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Introducing Educational Robotics through a short lab in the training of future support teachers

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Abstract—**This paper discusses the design and evaluation of an introductory laboratory in Educational Robotics during a specialization course in support teaching for special needs. The trainees were mostly in-service teachers. We provided various practical examples with different robotic platforms (essentially Mindstorms EV3 and Bee-bot) on the basis of the level. The evaluation was based on a questionnaire the trainees filled at the end of any session: the paper contains some summarizing results of the analysis of the questionnaires.**

Keywords—Educational robotics; Learning Support Teachers; Teacher training; Course evaluation

I. INTRODUCTION

The inclusion of special-needs students in a 'normal' class is more and more a common case. In our context we consider in this category of students not only those with severe disabilities but also with mild forms of dislexia, dysgraphia, dyscalculia and ADHD. The responsible school system adopts all the specific interventions to allow a significant intellectual and practical development of these students, while a good and coordinated formulation of the didactical work of all the involved teachers may take advantage, and not suffer limitations, of this apparent inhomogeneity [1] [2].

Some of these interventions need the specialized and dedicated help of a *Learning Support Teacher* (LST) who collaborates with the other teachers to fully respond to the above-mentioned needs. This kind of teachers need to be specifically trained in order to be able to effectively apply special approaches and specific technologies [3] [4]. The School of Human and Social Sciences of the University of Padova is in charge of providing such training to young teacher students or in-service teachers eager to receive this specific competence. The one year course is organized in different disciplines, seminars and laboratory activities, presenting a wide spectrum of methodologies and tools oriented to special-needs [5].

This year, in the framework of the so called TIC (Tecnologie Informatiche e della Comunicazione – ICT) labs the authors have been asked to start a new experimentation consisting in an introduction to educational robotics, i.e. the use of robots in the class as inclusive teaching/learning tools. The idea was to offer a more up-to-date element of educational technology during this practical part of the course to be used in class, possibly as a coordinated action of the general curricular teachers and the LST.

In spite of the numerous experiences of the authors in teacher training, this was the first case where we had to adapt the usual introductory arguments we present in more general frameworks, to this specific purpose. The paper describes the preparatory activities and how the expected issues related to the specificity of the course should have been faced. Section II shows some motivations of the described activity, section III is a detailed description of the lab, section IV deals with its evaluation and finally section V contains some conclusions.

II. ROBOTICS IN A CLASSROOM WITH SPECIAL NEEDS

A. Motivations and challenges

Educational robotics (ER), though not widely known and adopted in the Italian school system, is no more a sort of exotic technology. Experiences in literature and good practices show its relevance as a valuable multidisciplinary tool for any age and any kind of school, from kindergarten to university and beyond [6]. It strongly motivates project-based learning and team working in open teaching/learning scenarios, whatever specific activities are designed, from simple laboratory experiences to structured robotic competitions [7] [8] [9]

Apparently ER seems precluded or seems to offer too hard tasks to disabled students, or at least to be discriminating when different cognitive potentialities are present in the class. Actually literature mentions several counterexamples which show that, not only these problematics are essentially

unmotivated scruples of the teacher, but on the contrary ER provides new and interesting occasions for better forms of inclusion [10] [11] [12].

Consequently a claim of specific teacher training arises in order to overcome the initial mistrust a teacher can feel and to provide suitable cues to make both the 'normal' and the future LSTs aware of the real possibilities they can exploit.

B. Keypoints

One of the first conquests a trainer should aim to is to make the trainee aware of the natural attractiveness of a robot with respect to any kind of observer or practitioner [13]. The best way to reach this objective is to start with a very simple problem which requires a very little technical knowledge to realize the solution, both for the construction and the programming of the robot. Because the practical result can be tested very soon, the usual reaction of a not previously experienced trainee is such an enthusiasm that this is the best proof of what she can expect from her students as a good premise of future satisfaction and interesting experiences. Obviously this is just a first step and some other and more demanding examples must be presented to improve sufficiently her technical familiarity and, above all, for having pretexts to introduce typical problems/solutions that have learning meaningfulness.

In the frame of classes with special-needs students, the specific training regards the attitude of the LST and the knowledge of specific limitations and opportunities ER may imply. Just to provide an example, when pupils with autistic spectrum disorders (ASD) are requested to interact with robots, they often reveal improvements of their degree of concentration, their communicative richness and their social skills [14] [15] [16]. Another example, coming from one of our direct experience, is that very young pupil with an apparent cognitive disease or some social interaction difficulties, may reveal an unexpected capacity in term of problem solving, personal initiative and manipulation abilities when requested to construct a robot, with a further improvement of her social capabilities.

In the case of a pupil with more or less severe physical disabilities, this must not prevent her to participate actively to a group in a project-based learning activities. The collaboration between the LST and the group of teachers of the different disciplines (or at least with that or those who are actually involved in ER) must find a good balance between the role of the disabled pupil and the others of her group [17]. The aim is to obtain, on the one hand a fruitful contribution of the disabled and on the other hand a good synergy which makes it possible to promote spontaneous help in favor of the disabled which does not limit the effectiveness of the experience for the entire group. Again the experience of the authors shows that this is not only feasible but it can lead to unexpected improvements in term of social skill for the whole class [10].

Another keypoint is the choice of a suitable robotic platform. Ignoring economic or other not controllable constraints, the choose of the robot, available on the market, should be strictly inspired by educational and methodological issues, possibly with a eye of attention for the specific special needs. The first criterion of choice must be the age of your students which corresponds to a certain level of complexity, both for the construction and the programming point of view. In our presentation we show the different educational platforms the market offers emphasizing that some robots do not require a computer to be programmed (like Bee-bot and Roamer [18]), some of them are bundled with an icon-based programming environment, others are programmable in a wide variety of languages. So the teacher is invited to make choices in harmony with her objectives and the familiarity of the students with the proposed technological level.

III. DESIGN AND REALIZATION OF THE LAB

The variety of trainees suggested to divide the whole group of about 250 people in smaller groups, of about thirty people homogeneous with the school level, kindergarten, primary, junior and senior secondary. Consequently we designed a general structure with some specific objectives but together with some adaptations related to the specific group. The common part includes an introduction with general motivations which explains why in this context we are more interested in robots as tools instead of as objectives of study, and what is the common methodology acclaimed as basis of educational robotics, that is the Papertian constructionism [19].

As already mentioned, the first part of the practical lab has the specific aim to convince the trainees that the robot is worthy to be examined as an educational tool because simple to learn and exciting, and, concurrently, to overcome their initial skepticism. We found that the example of a simple *line follower* is completely suitable for this purpose: immediately understandable both in the problem and in the solution, programmed with a few but very significant commands (motion control, if-the-else, loop) (Fig. 1). The programmed solution is extremely powerful in spite of its simplicity: every small group (2-3 people), provided of a Lego Mindstorms EV3 robot and its iconic programming environment (EV3-G), very soon realizes the influence of the two parameters (steering and power/speed) on the practical quality of the solution. Moreover this example makes it also possible to smoothly introduce the concept of flow graph and why choices are often necessary in the control program to make the robot correctly react to external solicitations.
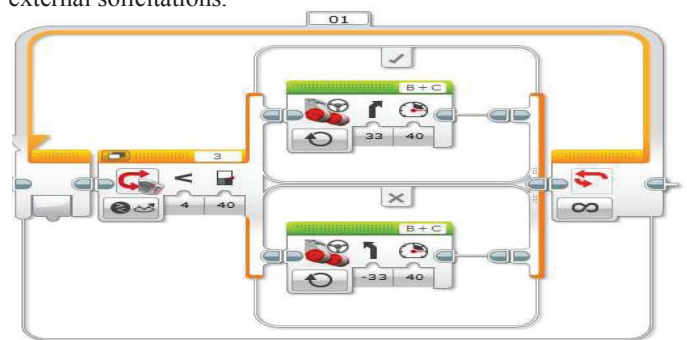

Fig. 1. A simple line follower program in EV3-G

At this point the question we ask the trainees is: did you enjoy the experience? It is a pleonastic question because we have every time already observed an increasing enthusiasm during the realization of this first simple example, but the

question is useful to make them conscious of what reaction they can expect from the beginning from their students.

The following example introduces the concept of *motion profile* which shows a designing approach that considers the robot action as a sequence of behaviors. The transition from one behavior and the successive is triggered by conditions signaled by some sensor(s). The sequence and the triggering conditions can be straightforwardly represented through a state graph which can be introduced at this point in a constructivist way. In the example of Fig. 2 the profile in made by the following behaviors: approaching fast to the obstacle; when a certain distance D1 from the obstacle is reached, approaching slowly; when a second distance D2<D1 is reached, the robot must stop for at least 2s and then restarts when the obstacle is removed or moved farer. The distances are measured by an ultrasonic sensor. The state diagram can help the design of the program more effectively than a simpler flow graph: a transition between two states is labeled by the triggering condition (Fig. 3).
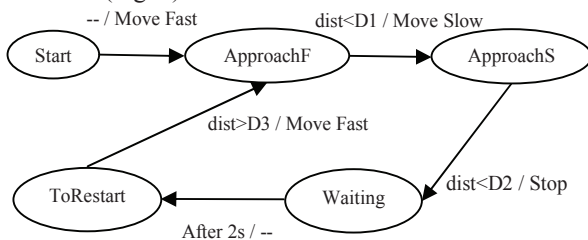

Fig. 2. Approaching state diagram

Fig. 3. Motion profile program (EV3-G)

This example leads the trainees, and eventually their students, to think in terms of state evolution. The diagram can be drawn on a black/whiteboard and it helps finding the correct control solution. Depending on their age, after the experience the students could be asked to reproduce on a cartesian space/time plane the motion to reflect on the already observed robot behaviors.

At this point the lab activities differentiate on the basis of the class. With secondary school teachers we go on with other more complex examples: usually they are looking for examples which can convey some math or geometry concept or some disciplinary competence for their students, particularly in the case these concepts are difficult to understand or felt not particularly interesting or useful. For example, at the junior secondary level important concepts are proportionality, angle and its measure, space and speed. All these concepts are pleasantly introduced with an example called *the metro* (a type of straight-line robot, see [20]). The robot represents a tractor of a subway moving on a straight line: it starts from a terminal station and must stop for a while on each following station until it reaches the opposite terminal station. The track in between each couple of stations has a common and known length. Pupils often apply a trial-and-error approach trying to discover, through successive approximations, the exact time to

set for the motor rotation in order to make the robot move precisely along one track. After this step the teacher is invited to introduce a simple geometrical model of transformation from a circular motion to a straight-line motion, rendering the students aware of the importance of applying such models to obtain more precise settings (in this case, the model allows to derive the setting of the angle of rotation of the wheels from the track length, which entails a more precise, speed and battery charge independent, solution). At this point the adaptation to a different track length is only a matter of proportionality.

In a similar scenario but with stations at different distance each other, we suggest to identify the position of the stations with markers, put on the path, which can be recognized by a light or color sensor. Not requiring a specific geometrical model, this example is suitable also for younger students.

For trainees working in kindergartens or with pupils of the first primary cycle, a robot like Mindstorms could be too complex. For them we first emphasize the necessity to contextualize any experience using story telling and dramatization. This is very important to motivate the inclusion of a robot in a project dealing with different cultural aspects like geography, history together with math and geometry [21]. We also present various platforms which can be used at this level (Bee-bot & Pro-bot by TTS Group, Roamer by Valiant Tech., WeDo by LEGO are the most famous). We mention also Arduino as a possible low-cost hardware to be considered by the most technological-oriented of the group of trainees ([22] presents some other available options).

Though ignored so far, the economical feasibility of robotic-enhanced projects can be hard particularly for primary schools, therefore we briefly present the possibility to have robotic-like experiences also with some free authoring software, among which Scratch [23] and BYOB/Snap [24] are the most known. Effectively these environments are enriched with (the equivalent of) sensors and motion control commands which make projects realized in these environments a sort of simulation of robotic applications [25] [26]. For example, with Scratch is easy to simulate a Bee bot (Fig. 4). Some mixed solutions can be further adopted, like Arduino and WeDo (external hardware) with Scratch (the programming environment). Following these reasons, we present some examples in Scratch and BYOB, showing the relatively easiness to have robotics experiences using these environments (Fig. 5). Because their programming style is again iconic, their adoption anticipates the familiarity with other environments, waiting for a successive availability of real robots to be programmed.

To trainees going to teach to the second cycle of primary schools, we suggest an operative compromise: the teacher prepares some sub-blocks (using the myblock feature, in the case of EV3-G) which represent macro-commands, too complex to be implemented by the students, but simply understandable for using them in a higher level programming style like library components. For example these macro-commands could be the four basic commands of a Logo-like turtle plus a pause and possibly some grasping primitives if the robot is provided of a grasping arm. This allows to maintain the

level of complexity already experienced with simpler robots like Bee-bot but with the prospect to skip to more challenging examples without changing the platform, in a smooth progression. For example we helped the developed of an experience of a couple of teachers with two 3rd grade classes in a context of geography, street safety, quarter life [27].
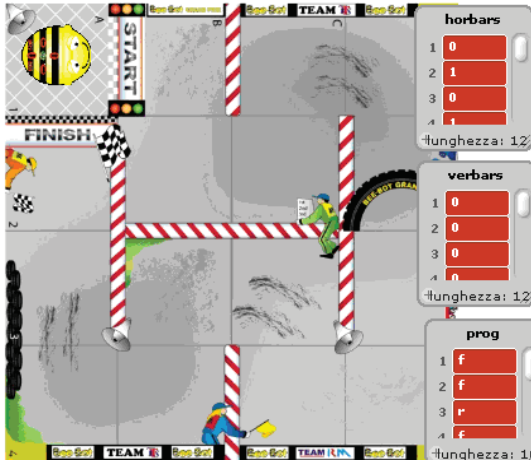

Fig. 4. Simulation in Scratch of a typical scenario with Bee-bot (notice that obstacles and the Bee-bot program are stored in Scratch arrays)
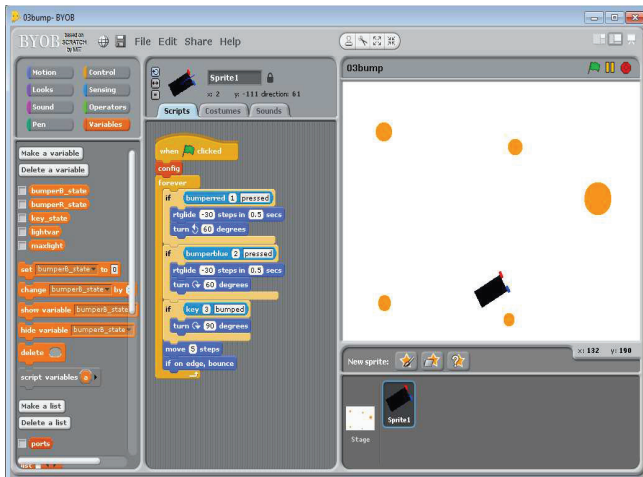

Fig. 5. Simulation of a robot with bumpers in BYOB

For older students the variety of possibilities is great and the Mindstorms platform offers a wide flexibility: apart the infinite combinations of assembling, EV3-G includes a complete set of commands for elaborating and store data and a tool for data logging, useful for more deeply examining the physical phenomena. We suggest for example to exploit the color coding, which is a native function of the color sensor, to simulate a run-time way to send commands to the robot presenting different colored plastic pieces or cardboards.

In technical vocational schools of course the examples can be much more elaborated, and the programming complexity is afforded explicitly exploiting the design of callable subcommands. For example a simple line follower can be improved implementing a simplified PID controller, and multi-actuated constructions can be controlled by multitasking solutions.

While in primary and junior secondary school it is common that a LST is asked to help the special needed student for all her general learning limitations, at the senior secondary level this may be more challenging due to the higher specificity of the taught disciplines. For this reason for the moment we focused our attention to the lower levels where, as we tried to show previously, an active collaboration among all the teachers involved can exploit all the potentiality educational robotics may express.

IV. EVALUATION OF THE LAB

A. Instruments and procedures

A short questionnaire was administered to participants at the end of the classes. The questionnaire comprised 4 sections: (1) a semantic differential including 12 bipolar pairs of adjectives to measure the participants' perception of robotics; the respondent was asked to choose where her position lies, on a 5-point scale between two bipolar adjectives (e.g. bad-good, difficult-easy, passive-active; cold-warm) [28]; (2) attitudes toward robotics in education was rated on a 5-point Likert scale (16 items; e.g. I think that robotics can be a valid didactical tool; I think that robotics can foster autonomy in learning process, see [29] [30] [31] [32]); (3) the positive and critical issues of the course were grasped via 5 open-ended questions (e.g. In your opinion, what are the most interesting aspects of the course, e.g. the contents, the approach, the learning environment etc.); (4) Socio-demographic items such as gender, age group, school level where participants are currently teaching (e.g. primary, junior secondary), years in the position, role. Thus, the questionnaires were substantially anonymous and in such a way might be perceived by the respondent.

B. Participants

The study involved 193 participants, 32 males and 158 females (females = 83.2%; missing = 3): the not surprising difference is due to the usual predominance of female teachers, particularly at kindergarten and primary school in Italian educational system. Almost 38% is less than 35 years old, 50% is from 36 up to 45, and around 10% is more than 45. 40 participants (20.7%) teach at kindergarten, 51 (26.4 %) in a primary school, 71 (57.4%) in a junior secondary school, and 24 (12.5%) in a secondary one (missing = 3). 99 of them are LSTs (51.3%) and 85 of them (44%) are teachers with other specializations (e.g.: music, mathematics, foreign languages, literature, and others; missing = 9). Almost 52% of them is teaching since more than 8 years (ranging from 1 up to 25 years; $M = 8.97$; $Mdn = 8$; $SD = 5.04$; missing = 3) (Fig. 6).

C. Data analysis

According to the semantic differential, binomial test revealed that the majority of participants considered robotics is good (26/161, $Binomial \ p = 0.001$), desirable (46/140, $Binomial \ p = 0.001$), and pleasant (40/146, $Binomial \ p = 0.001$). The majority of participants affirmed robotic is difficult (145/40, $Binomial \ p = 0.001$) (Fig. 7) [33]. According to the attitude toward robotics, the majority of participants answered that robotics is a valid didactic tool, fostering students' autonomy, motivation, technical competence, and social

competence (respectively: 129/63; 135/57; 171/22; 166/26; 144/48; *Binomial p's* = 0.001). The majority of participants do not think robotics is difficult for their students (128/65; Binomial p = 0.001); furthermore, they consider robotics could help students to autonomously collect didactic information (129/64; Binomial p = 0.001) (Fig. 8).
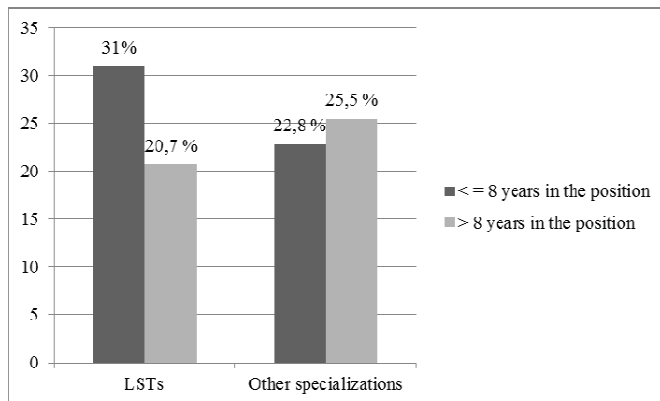

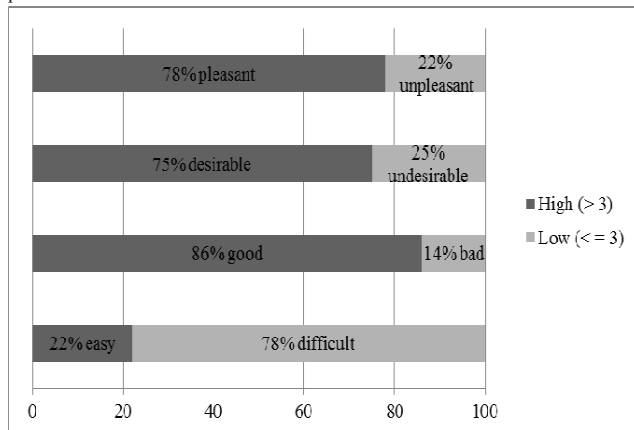Fig. 6. Percentages of participants distributed for school role and years in the position

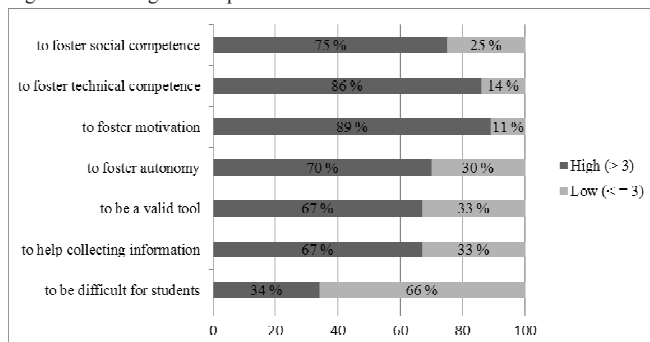Fig. 7. Percentages of responses to the semantic differential items

Fig. 8. Percentages of responses to the attitude items

Available data (*N* = 77) shows that participants are satisfied with the course and would advise their colleagues to take the same course in the future (*M* = 3.73; *Mdn* = 4).

One open-ended question asked participants whether they had already an idea about how to use robotics in class, in which subject, for which pupils and to reach which aims. Approximately 61% of participants declared they had already

an idea on how to integrate robotics in class [34]. Specifically, they recognized that scientific disciplines such as maths, physics, geography and orienting are the most suitable ones. Multidisciplinary activities are also mentioned (e.g. together maths and physics).

"It would be useful to teach some aspects of scientific, technical or geographical disciplines using robotics in a group context" (participant n. 67, women, between 36 and 45 years old, music teacher in junior secondary school, 7-years experienced).

Participants declared that robotics could involve the all class as divided in small groups, including special-needs children too. As for disabilities, participants named Autism Spectrum Disorders (ASD), attention deficit disorders (ADHD), mild mental retardation, among others as needs to be properly addressed with robotics in class.

"In maths, sciences, in particular with children with ASD and ADHD diagnosis" (participant n. 38, women, under 35 years old, German and LST in junior and senior secondary school, 8-years experienced).

Participants underlined the importance of robotics to increase some important learning aspects.

"To strengthen logic, activity planning and problem solving, maths. With children with attention difficulties, to improve motivation and attention" (participant n. 69, women, between 46 to 55 years old, LST in junior secondary school, 10 years experience)

D. Evaluation summary

In summary, after four-hour classes, participants revealed to considered robotics as a desirable, nice, and valid tool for learning process, fostering student' autonomy in school, their motivation in learning, technical competence, and even social competence. They consider robotics could help students to autonomously collect didactic information. Participants do not think robotics is difficult for their students, however, participants answered that teaching robotics is more a difficult than an easy didactic tool. The majority of participants declared they had an idea on how to integrate robotics in class, including special-needs children with Autism Spectrum Disorders (ASD), attention deficit disorders (ADHD), mild mental retardation. Participants underlined the importance of robotics to increase individual skills such as problem solving, attention focusing, motivation to learn and social skills such as cooperation in groups. They are satisfied with the course and would advise their colleagues to take this course in the future.

V. CONCLUSIONS

The design and the evaluation of an introductory course in Educational Robotics if the framework of special-needs training has been presented. We showed that it is important to choose well calibrated examples to convey at least some basic general principles about how to implement robotics at school, and the training has been carefully adapted to the school level. Literature proves that ER is effective also for and with special-

needs students provided a good collaboration is established between the support and the curricular teacher to promote project-based activities involving the entire class. The outcome of the questionnaire shows that there is a common awareness of the power of ER as an inclusive learning tool.

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Examining the Experiences of Upper Level College Students in 'Introduction to Robotics'

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Abstract— **With the increase of automated technologies, artificial intelligence, and advancement of low cost microprocessors, many university programs have added courses, certificates, and degree programs in robotics. While many papers detail the development of these programs, they provide little information about the students' learning and experience. This paper presents a summary of ten interviews conducted with senior level undergraduate students after a semester long robotics course. Results indicate students built on their previous technical knowledge and learned a significant amount of problem solving skills.**

Index Terms—**Robotics, engineering education, undergraduate course, LEGO Mindstorms EV3, LabVIEW.**

I. INTRODUCTION

With the increase of automated technologies, artificial intelligence, and advancement of low cost microprocessors robotics, the number of courses in undergraduate and primary school have grown significantly in the last twenty years. Workforce demands [1] have made it necessary to offer at least one robotics course in the undergraduate curriculum. Robotics has also emerged as an opportunity to involve students in multidisciplinary projects [2] where students gain experience working in teams [1].

Faculty and graduate students at the Center for Engineering Education and Outreach (CEEO) observed that ill-defined, open-ended robotics projects were highly motivating for students. The students dedicate extra hours to completing their projects going above and beyond the assignment by adding extra features to their robots. While these students spent an exceptional amount of time on these projects, we had very little insight into what they learned during these many dedicated hours. Our investigation began by studying freshman completing various types of robotics projects [3-5]. This study continues by examining fourth year (senior) mechanical engineering students after completing a twelve-week course in robotics. Interviews were conducted with ten students to investigate the students' ideas about the field of robotics, their learning in the course, and their thoughts on the learning style.

II. REVIEW OF LITERATURE

Previous studies conducted by the CEEO [1-3] examined freshman students as they completed open-ended, ill-defined robotics challenges. The first study examined students as they competed a short in-class design competition. Compared to previous examinations of students and experts completing open-ended design challenges [6-8], this study found students spent a significant part of their discourse communicating their project progress and discussing their ideas. Comparing this work to other studies, the authors concluded design practices are contextually dependent. This work also suggested it might benefit students to tackle problems that vary in "style, scope, and size" and focus on building different design skills. Two studies [2-3] examining a week-long design challenge found students were prone to idea fixation, a common fault of beginning designers [9]. These students spent a significant portion of their time on design ideas they did not have the "skills, resources or tools to efficiently implement."

Previous studies of students working on robotics problems have reported students of all ages gain numerous skills in electronics, computer science, teamwork, as well as developing excitement about the discipline of engineering [10-11]. Previous studies of undergraduate robotics courses provide a significant amount of detail about the laboratory exercises and course objectives, but little about what the students learned. In some instances robotics is used during the freshman year to retain students [11], while other schools build degree and certificate programs through integration of multiple disciplines' courses [1]. One study examining the design and implementation of a LEGO Mindstorms NXT course [12] reports after eight laboratory exercises students improved in their ability to understand basic problems in mobile robotics, use LabVIEW, integrate sensors, and construct mechanisms with LEGO. Kirchner & Geihs [13] present an iterative course design for an interdisciplinary robotics laboratory. Their results report the students' evaluation of how the course was run. The students found the lessons suitable, the final project motivating, and the basic exercise a manageable level. In a freshman introductory course Mataric, Fasola, and Feil-Seifer [11] developed robotic laboratory exercises based in robotics to excite freshman students about engineering. In course reviews, students reported wanting to spend more time on robotics and preferred using the physical robots over the simulated ones. Previous studies demonstrate the excitement robotics brings to

the classroom as well as the technical and teamwork skills students learn while participating in these projects.

III. COURSE DESCRIPTION

Introduction to Robotics is a junior and senior level elective course offered by the Mechanical Engineering department at Tufts University. The goal of the course was to teach students to design and build their own robots, with the goal at the end of the semester to have their robots cook a meal and serve it to a high ranking administrator in the university. The major topics outlined on the syllabus were actuators and sensors, building your own sensors, image processing, programming, and electronics. Both LEGO Mindstorms EV3 and National Instruments myRio hardware paired with LavVIEW software were used during the course. There were a total of 29 students in the course, ten females and nineteen males. The students in the course were all fourth year students, with the exception of one third year student and two graduate students. The author – as a graduate student - served as a participant researcher in the course.

The course was comprised of two 75 minute lectures each week for thirteen weeks. Lectures included the introduction of new topics, small group hands on activities, demonstration of homework projects, and guest speakers from local robotics companies. Homework consisted of one project per week that was presented to the class on the day it was due or participated in the in-class competition. Each project had an intended to teach a piece of the major topics outlined on the syllabus. One midterm was given on LabVIEW programming and robotic system design in the middle of the course.

TABLE I. Course Projects

Project	Hardware	Technical Topic
Distance following car	EV3	PID control
Segway balancing robot	EV3	PID control
Game	EV3	Brick interfaces
3D video game with haptic feedback	EV3	Haptic feedback, virtual environments
Racing a car using image processing	myRio, EV3, USB camera	Image processing
Battle Bots	myRio, EV3	Accelerometers
Final Project: Robotic food maker	myRio, servos	Actuators and sensors, electronics

The course began with two simple projects intended to teach implantation of control systems and basic knowledge of motors and sensors. First, students were asked to make a car that followed another car at a specific distance, an implementation of proportional control. The in-class test of this

included all the cars lined up like a parade and observing the reactions of each robot.

Fig. 1 Distance following car

The second assignment was to make a self-balancing robot like a Segway and implement a proportional-integral-derivative (PID) control system. Students presented their robots in class. If the robots were able to balance on the desk themselves, students wiggled and kicked the desk to attempt to get the robot to fall and demonstrate the durability of their control system.

Fig. 2 Game robot

The Game assignment tasked students with making a game using the sensors and actuators in the kit and the small display screen on the brick. Many of the students made variations of

the game Bop It (as show in the photo above) or the video game Pong.

The 3D video game assignment tasked students both with creating a virtual world and creating haptic feedback for the user as they were navigating or playing a game in the virtual world. Students used a toolkit designed by the professor and students were very creative with graphics. Common game themes included balancing balls, dodging items, shooting games, and navigating through a maze.

The next two assignments introduced the use of the National Instruments myRio. Students build cars using the EV3 Mindstorms kit and drove them in a battle bot style competition using the accelerometer in the myRio.
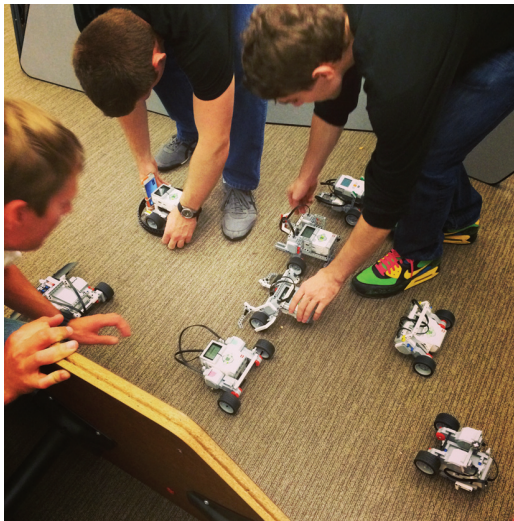

Fig. 3 Lining up cars for the race

The last week-long assignment tasked students to drive a car using an image from a USB camera. It was the professor's intention the driving would be done by using hands or a dance like motion. In reality, students created wands or used the light from their cell phone to direct the car. The tables in the classroom were turned on their side to design a horseshoe shaped course in which students raced their robots.

The final month of the course was dedicated to the final project, building a team robots that cooked and fed a senior administrator in the university lunch. Students were allowed to order any items they wished for construction. Many of the teams used Tetrix, OpenBeam, wood, laser cut acrylic, and 3D printed ABS parts. Each team used a myRio and choose their own actuators and sensors depending the requirements of their creation. Teams of two or three created many different food preparing robots such as a deep fat fryer, a salad maker, a grilled cheese sandwich maker, and a taco maker. Other robots were created to add sauce and salt and pepper to the food, deliver the food, and a menu to order the food. Lastly, there a was robot that lit a candle and played music to provide a pleasant atmosphere. Students were given little constraint and guidance in the creation of this project. Students chose their robot tasks and constraints themselves. This freedom led many

students to over-dream their projects, resulting in an unfinished product.

Each project was demonstrated in front of the whole class on the day of the deadline. Depending on the robot product, this took the form of a competition, a gallery walk or a design critique. For each of the game projects, students walked around the room playing each others' games and were asked to vote for the one they liked the best. For the final project, students presented for a number of design critiques, presenting their problems and receiving feedback from their classmates. These presentations were a chance for the teaching assistant and professor to evaluate students' projects but also created a social pressure for well-performing and designed robots. The teaching assistant and professor graded each robot but it was really up to a student how much they learned on each project. Projects that demonstrated a clear effort were given good marks.

IV. METHODS

Ten interviews were conducted with student volunteers. Interview length was dictated by the students' answers. No interview went over an hour; the average length was 39 minutes. The interview questions were created in a collaborative effort by the researcher, professor of the course, and a visiting professor who observed pieces of the course and was highly interested in the "active learning", open-ended, project-based teaching method. The questions aimed to have the students reflect on several aspects of the course, including: their participation and learning in the course, the content they learned, and their ideas about the robotics field. Each interview was videotaped and partially or fully transcribed for analysis.

V. DATA

Students were asked a total of 27 questions with additional follow-up questions when necessary. The data set is too lengthy to be included in its entirety here. For the purposes of presentation, the answers presented are abbreviated or the results are summarized to attempt to provide an overview of what was discussed. Questions were asked in three major categories presented here: ideas on robotics, project-based learning, and technical content.

A. Student Ideas on Robotics

Students' definition of robotics centered on the intersection of mechanical, electrical, and computer controlled systems or automation. Some definitions specified the system was built to complete a certain task. Others specified without human intervention or the ability to make decisions on its own while others acknowledge humans can control parts of the system.

While students' definitions of robotics centered on the technical aspects, students believe a roboticist should not only have technical skills such as the ability to program, build circuits, and construct robust mechanical systems, but also the ability to plan, iterate, and deal with failure. The compilation of each student's list is listed in Table I. If multiple students reported the same skill the number of times is noted in the parenthesis following the skill.

TABLE II. Important Skills of a Roboticist

Technical Skills
Programming (x3)
Electrical engineering (x2)
Knowledge of hardware
Knowledge of software
Understanding of mechanics
Robust mechanical building
Program a lot of different robots
Systems integration
Know what you want your robot to do and have an idea of how to make it do that
Good understanding of the environment
Create a robot that's easy to understand

The largest surprise of the interviews was the diversity of the list of the "biggest thing" students learned. It also was very surprising that most of these are not technically based but centered on problem solving and project management. The complete list is in Table II.

TABLE III. The "Biggest Thing" students learned in the course

The "Biggest Thing" Learned
LabVIEW
Project/time management (x3)
Whatever can go wrong will
The simplest way is probably the best
The first time is never going to work
Finding out where to find help
Don't be afraid to try a different solution
How to design a mechanism
Do things before because it will all break
The ability to look at a problem and not be intimidated by it (regardless of "head banging" that goes on after a while)
Prior planning is understanding what you're capable of
To be a little bit more independent in projects
Going out on a limb and hope it works

B. Project Based Learning

As expected, students enjoyed the project driven format of the course. On average, students reported spending more time on this course than other courses. Students did not mind spending this extra time because they really enjoyed and engaged in the work they did and believed the time was well spent for the learning outcomes. A number of students expressed they were not always sure what they were supposed to be learning from each project, but they felt they learned a lot anyway. Most students thought this course was more difficult than other courses since students were given a very few requirements for each project and most of the project definition was up to them. Yet, many talked about the different skills they learned (see Table II above) from solving such open-ended problems every week. One student described how

he would get so engrossed in making his robot function, he would finish his robot at eleven o'clock on Sunday night and realize he had forgotten about his other homework. Many students also cited enjoying learning in this way because "it's more like the real world" and they are able to recall and retain the information once the course is over. A number of the students discussed wanting more guidance for some projects, especially the coordination of the final group project.

C. Technical Content

Throughout each interview students discussed the many LabVIEW skills they learned over the duration of the course. Students saw a lot of connections between their work and the field of controls systems, listing a number of different controls systems they built for this course including the Segway and different things they made for their final project. When asked specifically about building their own sensors, many students were confused but either cited the haptic feedback or image processing assignments. Many students expressed they did not feel like they learned much about image processing (except that the environment is key) and would have liked to spend more time on that topic. Students also felt like they needed more concrete electrical engineering background to aid in the construction of circuits for the final project. While the students were given a lecture to aid in understanding how to choose actuators and sensors for their final project, about half the students just used what they found at the CEEO. Students who needed more specialized pieces consulted specifications and ordered various pieces. Many times these pieces ended up being the wrong size or were not strong enough but students learned through these errors. Many students also found that most lectures that focused on technical content went too quickly, and they were not able to pick up most of the information. One student suggested the in-class activities should require students to turn something in at the end of the class to ensure everyone learned from the activity.

VI. DISCUSSION

While the title of the course is 'Introduction to Robotics' it is evident from the students' discussion of the course that the largest takeaway for most of the students was a collection of problem solving skills. In their discussion of the course, students identified the problem-solving skills as essential to robotics engineering, and cited this as the most important lesson. For many students the greatest learning in the course came from the continual frustration and learning how to move onto another solution. For almost all the students, this course was taken in parallel with their senior design capstone course. Before these courses, students had little experience with large building projects. Therefore, project management and other problem solving skills may have been in the forefront of their mind as these two courses took up a majority of their time at the end of the semester.

Compared to other studies [4,5,11,12], the technical content learned in this course was greater and more sophisticated. While freshman are still learning the basics of computation, senior students can build on these skills and make connections between other subjects they've learned such as controls or

mechatronics. Students were able to discuss concepts from electrical engineering, mechanical engineering, and computer science fluently and describe how they were integrated together in systems, especially in their final project.

Limitations to this study included the small population of students and need for a stronger methodology to analyze the data. Despite the small population, a significant amount of data was collected from each student about their experience. This amount of data required time intensive analysis that did not fully uncover all the richness of students' responses. Refinements to this study should include more questions about how students approach and solve problems as well as video data of students working on projects.

VII. CONCLUSION

This study contributed to our ongoing investigations of open-ended, ill-defined robotics design challenges. Compared to freshman, seniors demonstrated an understanding of the need to set realistic constraints, methodically solve problems, try multiple solutions quickly, and design projects based on their skills and capabilities. Their greater technical abilities allowed them to find more diverse solutions and employ a greater amount of resources to aid them in their problem solving. While seniors did not entirely avoid problem fixation, experience had taught them to move to other solutions quickly and to design based on the knowledge they already possessed. More research is needed to validate these findings and to more fully understand student learning during open-ended, ill-defined robotics problem solving.

VIII. Implications

Based on the results of this study, a few suggestions were made to the professor to modify the course for the next year. First, the students wanted more structure to the lecture sessions. While not all wanted in-class assignments, many felt the time was not utilized well and at the end of many of the sessions they felt confused and behind. Second, many of the students wanted to know more about image processing. While there wouldn't be enough time to cover all the material, an increase in the number of lectures or projects using the topic would give students a little more time to learn the subject.

While there are many learning benefits to letting students define their own project goals and constraints, the final project could have benefitted from more structure of leadership. Having the class elect a number of leaders to coordinate the different aspects of the project and ensure all bases of the operation are covered before having everyone decide their own projects. It's clear the open-ended design of many of the projects allowed for a wide range and depth of student learning, a little more structure would benefit the overall course design.

ACKNOWLEDGEMENT

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Crazy Robots – An Introduction to Robotics from the Product Developer's Perspective

with the 5-Step Plan and the Mattie Robot Project Assignment

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Abstract—**Robotics is an excellent tool for teaching science and technology, so current approaches in educational robotics mostly focus on these domains. However, besides engineering we also need social sciences, design and business approaches in robotics. Crazy Robots is a top-down approach to educational robotics from the product developer's perspective. Curiosity, creativity, persistence, and teamwork are in focus. In three consecutive workshops at five high schools, children aged 11-13 work through three incisive phases of product development: "ideation", "prototyping", and "evaluation". The approach follows the educational goals of empowering children, providing a structure for creative processes, and teaching the product perspective (top-down). Feedback from teachers and students reflects the positive achievements of the concept.**

Keywords— robotics in school, project-based learning, constructionism

I. INTRODUCTION

Robotics is an excellent tool for teaching science and technology [1, 2], so current approaches in educational robotics mostly focus on these domains [3]. Yet, robotics is also excellent to teach any other concept because children easily connect robots to their personal interests [4]. When educational robotics activities focus on STEM (science, technology, engineering and mathematics) or robotics itself, they naturally attract more children who are already interested in these subjects; e.g., robotics conferences such as GCER who offer a research perspective to robotics directly address children interested in STEM. Competitions (e.g. Botball, FIRST or Robocup Junior) offer a structure for problem solving in group settings by encouraging focused hands-on problem solving, team work, and innovation [5]; however, not all children are interested in STEM or motivated by competition or tasks that require a specific kind of thinking. Alimisis [6] argues that benefits of educational robotics are important for all children: robotics projects and courses should include the whole class and not only children talented in science and technology. So, what happens when we introduce robotics in the classroom to students with various interests?

Rusk and colleagues [7] offer four strategies as entry points into robotics: exhibitions rather than competitions, themes instead of challenges, art in combination with engineering, and storytelling. Furthermore, constructionism underlines the hands-on aspect and essentially states that by being externalized or given form, children's ideas become tangible and shareable, which in turn helps them to be formed and transformed [8]. Following these principles, Resnick [9] suggests that children need four things to flourish: To work on a project that is related to their life, work and share with peers, develop a passion that makes them more persistent in case of failure, and play as a means of enjoying. Resnick and Silverman [10] also draw attention to the importance of supporting different styles of playing, designing, and thinking. Finally, Garzotto [11] argues that developing technology in an educational context creates a more holistic view (product focus) underlining a number of benefits: collaboration and discussion skills, project/goal oriented attitudes, and capability of reflection and critical thinking (as well as reflecting on technology) for children.

We developed Crazy Robots to address children with various interests and talents, and introduce them to robotics from the product developer's perspective. In the following sections, we will explain the approach in detail, present our case study with five middle school classes, and share our findings and lessons learned.

II. CRAZY ROBOTS

Crazy Robots is a top-down approach to educational robotics from the product developer's perspective, i.e. first comes context and relationships, then details. Curiosity, creativity, persistence and teamwork are in focus. In three consecutive workshops children work through three incisive phases of product development: "ideation", "prototyping", and "evaluation". The approach follows the goal to introduce children with various talents to robotics from different perspectives and gives them the possibility to focus on an area of interest while solving real-life problems in collaboration with others.

There are three educational targets to achieve this goal:

1. Empowering children to address problems that influence their lives by helping them become robot experts who solve real-life problems based on their interests and talents;

2. providing a structure for this open creative process;

3. teaching the product perspective which starts from the top with context and relationships, and then moves downward into details; the product perspective includes all aspects of robotics, so that children focus on what interests them most, e.g., appearance design or sensors, or defining the tasks of the robot, its behavior or customer segment and sales strategy.

We have developed two concepts around these targets: (1) the 5-step plan [12] and (2) the project assignment with our educational robotics platform named Mattie robot. Furthermore, we have built these concepts into three consecutive workshops: In the first workshop "ideation", each student designs her or his own robot with the help of the 5-step plan and builds a non-tech model out of modelling clay. In the second workshop "prototype", students receive a project assignment to build a robot for children. They work in five teams on different parts or concepts of the Mattie robot to realize their idea (by also using the 5-step plan as a helping structure for their ideas). Finally, students assess their robot from technical and user perspectives in the third and last workshop "evaluation" and present the robot concept as well as their evaluation results.

A. 5-Step Plan

The 5-step plan (Fig. 1) is designed for children in primary and secondary school; it is based on design methods that empower children [13] by giving them a child-appropriate structure for their creative process. The plan can be integrated into different teaching or research contexts, and adapted to different age groups or even to adults who are not familiar with robotics.

Fig. 1. The 5-step plan - an overview for teachers and researchers

The 5-step plan starts with a pre-phase where the researchers introduce themselves as robot experts and ask the children for their help. As a starting point, children are introduced to technology as "human-made objects, tools, artefacts that help us". The definition of robots draws on the definition of technology. Autonomy distinguishes robots from other technology and results recurrently in unexpected or "strange" behavior. Children are shown pictures of different robotic applications from industrial to service robotics, including personal robots, exoskeletons and prostheses, primed to the notion that robots are "something that we build to make our lives easier" and guided towards the concept of autonomous behavior.

In the main phase, children are explained that real robots are highly complex, autonomously acting, programmable machines which are designed by a team of experts from different disciplines (designers, human-robot-interaction experts, programmers, engineers, etc.), and built after months (even years) of work. The researchers briefly introduce three incisive stages which are common in many different design processes:

1. Ideation: Gathering ideas, drawing sketches and storyboards, building models to share and discuss ideas

2. Prototyping: Building one or two best ideas into prototypes, choosing one idea, ameliorating the prototype

3. Evaluation: Function testing of the prototype and evaluation in user studies and surveys

The 5-step plan is offered as a tool in the "ideation" phase to design a robot from scratch as well as in the following stages of "prototyping" and "evaluation" to refine the idea. Children are guided step by step through five important topics they need to cover if they are to design a robot. Each step is explained in detail to the children with examples. In the last step, robot parts, pictures of mechanic and electronic parts are shown. At the end of each step there is a short discussion where children contribute their ideas and ask questions. The five steps are following:

- Step 1 – Robot Task ("assignment")

- Step 2 – Robot Interaction

- Step 3 – Robot Morphology ("looks and materials")

- Step 4 – Robot Behavior

- Step 5 – Robot Parts

After this brief theory children immediately start building a non-tech prototype with modelling clay which they can take home to show family and peers. In the post-phase, once through all five steps, we use iterations as common in user-centered design. More details can be found in [12].

B. Project Assignment with the Mattie Robot

Fig. 2. The Mattie Robot: Left our simple design suggestion for demonstration purposes. Right the design of a 2nd grade school class

The project assignment incorporates all three previously mentioned phases of product development with more emphasis on "prototyping" and "evaluation". The whole class receives the assignment to build a robot for children. The class decides

for which children the robot is and what it should do. Because of time constraints, we offer the Mattie robot (Fig. 2), a platform where common robot functionalities like navigation or interaction are pre-defined. The limitation of the robot's abilities forces children to think out of the box, improvise and be creative. And at the end, there is a finished prototype, an important "quick-win" for motivation.

The Mattie robot is built of simple everyday materials that children (or their parents) have access to: a round wooden platform as chassis and an almost cylindrical shaped plastic hull (bucket cut on both ends) which is closed on the top by a carton lid (Fig. 2). It is designed for classroom workshops in middle schools for children aged 11 to 13 to introduce them (and their teachers) to robotics and allow them to focus on aspects they find most interesting: engineering, research, design, human-robot interaction or marketing. Besides the top-down perspective, the Mattie robot has the characteristic of a "white-box" robot showing the inner workings to demonstrate that "real" technology is accessible, an important aspect in educational technology as pointed out by various researchers, e.g. [14]. The chassis has two motors with wheels controlled by an Arduino board and a motor driver, as well as a ball caster. There is an infrared receiver for remote control and two light sensors for the robot to follow light. In a second version, the robot has also one ultrasound sensor in the front to stop when approaching an obstacle and a Bluetooth receiver for remote control with an Android mobile phone. Besides locomotion, user interaction is possible via buttons that can be painted on the robot using conductive paint or be attached with tin foil. A capacitive touch sensor registers if a button is touched, and an MP3-Player on a second Arduino plays the previously recorded sound files. The design of locomotion and interaction is kept very simple to allow children the replication at home. More details on the Mattie robot can be found in [15].

For the project assignment students are split into five groups of three to five students. Each group works either on a specific part of the robot or other tasks related, described in more detail in section III. B. Then, all of the parts are combined to a functioning simple robot which can be remote controlled, follows light and reacts to touching via audio. In the evaluation phase, different teams work on different perspectives (technical or user), described in more detail in section III. C. Finally, the students present their sales idea or robot concept, the robot and its functions and the evaluation results.

In the next section we will introduce our case study with five middle school classes, describe how we incorporated the concepts "5-step plan" and "project assignment" into three consecutive workshops and provide more details on each.

III. CASE STUDY

Five middle school classes (age range 11 to 14) in Vienna and surroundings have participated in our case study, successfully completing three workshops: three 2nd classes and one 3rd class with their handicrafts teachers (groups of 12 to 15), and one 3rd class with two physics teachers (25 students) and two tutors (8th graders from the same school to assist and learn). In total, 70 students participated in the project. Two researchers conducted the workshops. The first and third

workshops were held in the classroom or handicrafts room (two class hours, approx. 100 minutes in total), while as for the second workshop the students visited the Vision for Robotics Group at the Vienna University of Technology to see real experts at work with real robots and attend a workshop (two hours) in a lecture or seminar room (depending on group size).

Each workshop had a theory session which preceded the practical work. In the first workshop, the classes were introduced to the 5-step plan and worked on non-tech models of their own. In the second workshop, the class split into four or five groups and worked on a common goal from different perspectives (engineering, research & development, human-robot interaction, design and optionally sales & marketing). In the third and last workshop, the class integrated the robot parts, demonstrated the robot and its functions, evaluated the robot from technical and user perspectives and presented the results. Students, teachers and other stakeholders had also the possibility to visit the project homepage in German (http://schraegeroboter.wordpress.com) for information about the project, details about workshop materials, comments and questions.

A. 1st Workshop – Ideation

We started our theory session with the 5-step plan, including definitions of technology and robots as well as the description of the three distinctive product development phases of "ideation", "prototyping" and "evaluation" (PowerPoint presentation with discussion), and then distributed a two-page 5-step plan template (Fig. 3) before the break. The transition from filling the template to building the non-tech prototype went smoothly. The materials provided were modelling clay in two colors for each child and a selection of decoration materials (stones, feathers, plush wire and foam craft shapes) for all to choose from.

Fig. 3. Two page template for 5-step plan from 11-year-old girl describing her robot rat Spike (notice the change from dog to rat which was easier to build)

At the end of the workshop, we did not have time for a post-phase with presentations; we coded age and gender of the child on every template page and photographed it. The children were given a voluntary assignment to send in pictures of their

models along with a 5-step description of their robot for an exhibition on the home page. Teachers had the possibility to let students present their prototypes and discuss the five steps with them in the following classes. Fig. 4 shows some non-tech prototype examples.

Fig. 4. Non-tech prototypes from two different classes

B. 2nd Workshop – Prototyping

Before we started the second workshop, the class visited the Vision for Robotics Lab at the Vienna University of Technology and were shown a demonstration of the Romeo robot from the company Aldebaran (http://projetromeo.com/) where we introduced them to the robot's different capabilities and sensors including 3D cameras and computer vision. In the workshop after the demonstration, we started the theory session by repeating definitions from the first workshop: what is technology; what is a robot; how do robot experts translate their ideas into a product (i.e. the three incisive stages "ideation", "prototyping", and evaluation). We also repeated the five steps and underlined that our next focus was on prototyping and getting deeper into different robot parts.

It was also an important topic of this workshop to introduce children to robot experts: "What kind of people are they? What do they know?" We explained children important areas in robotics such as mechatronics and coding but also sociology, psychology, design, or ethics. We told them about three different personality traits to consider when collaborating: thinking and feeling types [16], generalist and specialist thinkers [17], and extrovert and introvert types [16]. We also introduced them to different intelligences [18] underlining that each of them was unique with their interests and talents, and could contribute different aspects to a team. We also talked about what robotics experts all had to have in common: curiosity, creativity, persistence and the ability to collaborate.

Finally, the "CEO of Crazy Robots Company" (one researcher) charged the "Mattie robot project manager" (the other researcher) with the project assignment to build a robot for children with a budget of 300 Euros. The project manager explained the concept of the Mattie robot, and then divided the students in groups. Each group had different tasks which are described in the following:

Sales & Marketing: In this task, students define a target customer group (e.g., children at a specific age or with special needs as users and their parents, grandparents or other relatives as buyers) and the tasks of the robot along with its design and behavior. They have to coordinate their ideas with all other groups. They discuss with the design group which materials are available, with the engineering and research groups the capabilities of the existing technology and with the human-robot interaction groups the best way of interaction with the target group. They learn about the 4 Ps of marketing (product, price, place, promotion) and think of a strategy for their product.

Engineering: This is a typical task for children interested in STEM and robotics. The students connect the electronic parts using jumper wires, a breadboard and step-by-step instructions. They need to figure out how the motors need to turn for the robot to drive straight or turn left or right. We programmed the microcontroller beforehand because of time constraints; in an expanded workshop, students can also code. This is a classic technical assignment with a predetermined goal that has to be achieved.

Human-Robot Interaction (HRI): The children in this group need to define the types of sound files the robot will play and design an interface for the interaction. They need to coordinate with the sales & marketing and design groups so that their sound files and buttons match the overall concept and design of the robot. When all agree, this group records the sound files and assists the design team which creates the buttons.

Research & Development: This group is like the research & development department of a company or researchers at a research institution who develop new sensors. For this task we let students get acquainted with real sensors and teach them what to do with sensor readings – a number which represents a voltage. In a wooden box six sensors are connected to a display which shows the current sensor readings. First, students have to identify the different sensors by stressing them. Then, they help the engineering team choose the right sensors for the Mattie robot to follow light. They discuss how to use the other sensors on the robot and what additional sensors can be developed. For groups who finish quickly there is an optional task: the students connect a tilt sensor with an LED and test it as a possible anti-theft solution.

Design: The task of this group is the design of the robot, especially the body or hull – the transparent bucket, cut on top and bottom – with decoration materials. Before the group can start crafting, they need to decide with the other groups what the robot is for and for whom. The design needs to fit the robot concept and the customer (user) group. The designers also help the HRI group to finalize their buttons on the robot with conductive paint or tin foil.

C. 3rd Workshop – Evaluation

In the third workshop, all of the five classes first had tasks to complete from the second workshop, e.g. finishing buttons or design. Therefore, the theory part was kept very short, again repeating definitions and shortly explaining what evaluation is. Then, some students were given the unfinished tasks from the second workshop. The rest of the class was divided into two teams: technical evaluation and product (or user) evaluation.

The technical group evaluated the chassis, e.g. average speed of robot, maximum distance of infrared receiver, reliability of the ultrasound sensor for detecting objects, or average deviation on a straight line. The user group was again divided into user study experts and marketing experts. While the user study experts designed the study and prepared

questionnaires and interview guidelines, the marketing experts designed a product poster. When design and buttons were finished, the whole robot was put together and the user study conducted either with class mates or students recruited from other classes. Then, the presentations followed: Product presentation, robot demonstration and presentation of evaluation results. Fig. 5 shows the garbage robot hull of one class and their marketing poster of the final product. Finally, we concluded the workshops with a feedback round.
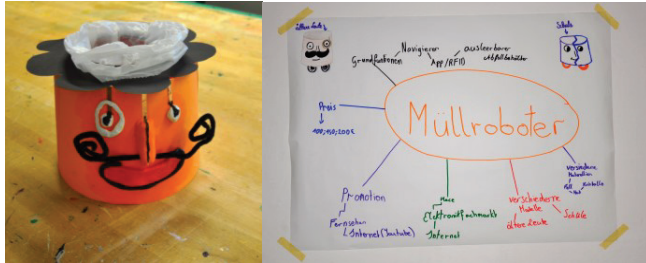
Fig. 5. Garbage robot of 3rd graders, e.g. stating garbage facts when touched (left) and marketing poster with 4 Ps (right), either for the classroom or for older people at home

D. Analysis

We used five instruments for analysis: (1) documentation (templates and questionnaires); (2) feedback from teachers; (3) feedback from students; (4) physical artefacts; and (5) observations. There was static filming for audio purposes, photography of all documents and some prototypes, also group feedback and individual email feedback from teachers. Feedback from students was collected in a questionnaire after the second workshop and in the final feedback round. In our analysis, we looked into each robot idea, either from each student collected on the 5-step plan templates, or from each class as demonstration and product presentation and also observed the repetition of definitions and concepts in every subsequent workshop to see if students had learned these. We compared these findings to our participant-observations as well as student and teacher feedbacks. In our qualitative analysis we examined three educational targets:

1. Empowering children to address problems that influence their lives

2. Providing a structure for this open creative process

3. Teaching the product perspective

IV. FINDINGS AND LESSONS LEARNED

Crazy Robots and the 5-step plan follow the goal to introduce children with various interests to robotics from different perspectives. In this paper, we present our findings and lessons learned from an educational robotics perspective.

A. Empowering children

We wanted to understand if children with different interests (not only the ones interested in robotics or STEM fields) were empowered by the 5-step plan as product designers to think about real robots for real-world problems. Our findings suggest that they were. Each student and each class had one robot idea to solve a problem from their lives, ranging from robots for parents with babies to transporter or cooking robots. Many robots (75%) referred to actual problems out of the children's lives, e.g. being alone at home after school and needing help with cooking or homework, having entertainment or a playing partner, waking up, or transporting from A to B.

Although the first workshop was very structured, the second and third workshops had many elements in parallel depending on the interests of the students, and thus were chaotic. This was demanding on the adults present but very much appreciated by the students ("it was great to do what we want and have to talk to the other teams"). For some children, the differences between the Mattie robot and the Romeo robot were unacceptable (although we explained to them that all the talk and movement of the robot was pre-programmed); they rather thought that they could work on Romeo or build more advanced robots. Next time, we will try to make clearer how much robot experts have studied and worked on robotics before building Romeo and do the demonstration after the workshop to limit disappointments.

B. Structure for creative processes

We provided three distinctive structures for the children: (1) the product development stages "ideation", "prototyping", and "evaluation"; (2) the 5-step plan to build a robot from scratch; and (3) different teams working on a common goal. Teachers were very positive about all three structures and expressed their wish to continue the project on an annual basis. They underlined the importance of teamwork and their amazement about the capabilities of their students. The students did not have much experience or no experience at all in teamwork. They were not always happy about all team members, but very proud of their achievements in the end. Repetitions were also successful. At the beginning of the third workshop, the class was able to answer what technology was and define the difference between a robot and other machines. The students also remembered the product development stages "ideation" and "prototyping", and the different steps to consider when conceptualizing a robot.

C. Product Perspective

The different groups gave the students the possibility to see different aspects of robotics. Sometimes, they changed teams in the third workshop to see other aspects. Sometimes, they deepened their knowledge in the one field that interested them most, e.g. marketing or engineering. We had positive experiences in the classes that had a Sales & Marketing team. This team was able to coordinate the other teams to reach a common goal, i.e. robot concept, more quickly. In future, we will organize the three workshops a little bit differently, so that the class arrives at a common concept more easily and quickly. It was also not easy for the students to first plan (agree with the other teams), then start working on their tasks. The limitations of the technology and materials also frustrated from time to time. The top-down approach at the beginning of the second workshop (conceptualizing the robot) was frustrating to all classes, yet, in the end all could accomplish this task to their satisfaction, which then empowered them. One comment of a girl in this respect was: "Finally, we managed to do something almost on our own, without the teacher helping us that much."

Also, in each class there were one or two disappointed children because the workshop content did not match their expectations, especially children who expected a more STEM-focused workshop. This can be addressed by better briefing teachers beforehand. Nevertheless, the majority of the children thrived on the open concept to work on something that was meaningful to them and their lives, and also expressed this in their feedback. The children who intuitively preferred the top-down approach were more interested in robot design or behavior than in building or programming details.

Unfortunately, we could not delve into more details in the different groups. Students wanted more materials and time. It would be nice to refer them to other workshops where they can deepen their knowledge in the areas that interest them most and help them more to pursue these goals in their spare time on their own or with peers.

V. Conclusions & Outlook

We have presented Crazy Robots, an introduction to robotics from the product developer's perspective, addressing children with various interests and talents. We applied our concepts "5-step plan" and "Mattie robot project assignment" in three consecutive workshops for middle school students in five schools. Our findings suggest that this top-down approach empowers students to work on technical solutions for their everyday problems (although the limitations of technology frustrate them); it provides enough structure for their open creative process (which is very valued by the teachers); and it gives them a nice overview on different robotic areas that go beyond STEM fields. Teachers also feel comfortable with this approach and confident enough to introduce their classes to robotics in this way. We have learned that follow-up workshops after the introduction are needed to refer interested students to and that we need to find a better way than a homepage to connect the students and teachers to us and each other. We think that we have come very close to the goal of picking the whole classes curiosity for robotics. A 13-year old girl summed it up better than we could: "I don't want to do anything with robotics when I'm older, but I'd like to do more robotics workshops." Our next step is to adapt the concept to older students in 5th grade where they will have one project day to work on the Mattie robot.

Acknowledgment

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4. Competition Related Aspects

Chairperson David Obdrzalek

International Robotics Competitions as Excellent Training Grounds for Technical Education and Student Exchanges

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Abstract—**International competitions in robotics provide an excellent framework for technical education and for facilitating the exchange of students across universities. Considering the evolution of technical content in school training, and the development of ICT and the internet, robotics appears to feature exceptional properties here. Smart robots are capable of cognition, the faculty to generate pertinent information; and cognitics is the field where automated cognition is explored. Moreover, cognitive aspects gain also to be clarified in academic and educational issues, as MCS theory of cognition critically contributes to support, as well in scientific, technical, as didactic terms. Considering the evolution of school education in general, as well as professional training, international robotics competitions provide a good arena for practicing numerous concepts of growing importance, such as teamwork, hands-on, peer tutoring, or connection between conceptual and real worlds for example. The paper concludes with a case study relating to our good experience about the topic in title, gained in the context of Robocup@Home international initiative. Results can be transfered.**

Keywords—robotics; education; cognition; cognitics; student exchanges; competitions; robocup@home.

I. INTRODUCTION

Humans have surely gained their privileged ecological niche in the living world thanks to their faculty of cognition, and in particular, because of their unmatched ability to learn.

Reflecting on education has therefore a particular interest here. This paper considers education from a broad perspective, with a glance on a panorama of age ranging from youth to academic stages.

When robotics appeared, in the 20th century, it was first an artist's concept [1]; then it became a technical discipline. What was mostly considered at the time, was the possibility of somehow replicating human kinematic and dynamic abilities, motions, with machine-based, mechanical power .

This context, along with some degree of automation, has allowed for the design of robots and automated systems, or the reconfiguration of flexible structures, which are still nowadays appropriate application fields for giving kids and students the opportunity to create new technical structures and to acquire hands-on experience.

Today, another phase of evolution is entered as the possibility opens for humans to design and create artificial cognitive systems (ACS).

But what are these ACS? In order to answer the question, and furthermore to create such artificial cognitive systems with some degree of success, it is obviously appropriate to clarify what is cognition, as well as to quantitatively assess the essential cognitive properties of the field. This goal is addressed with some success in [2].

Now a nice twist is that what had been attempted in order to develop novel technical systems in automated cognition turns out to give precious insights onto what is cognition for humans as well, including on learning processes and education.

Thus it appears that there is a convergence between respective evolutions, in recent best teaching practices and in automated cognition.

The paper will develop the ideas just briefly sketched in this introduction. It is organized in 4 main sections. Section II presents the interest of classical robotics as a field for exploring technology. Section III focusses on core aspects of cognition, both for natural context, typically in humans, and also for automated implementation. Some of the best practices in student education are summarized in Section IV. And finally Section V presents a case study, relative to contributions made in terms of student education, especially in the context of Robocup@Home robotic competitions.

II. INTEREST OF ROBOTICS AS A FIELD FOR EXPLORING TECHNOLOGY

Referring both to technical education, as announced in the general title of the paper, Section 2 and 4 may seem to overlap a little; in fact here in Section 2 we address issues relating more to technology, while in Section 4, attention will be given in priority to aspects relating to general education .

The Section is organized in three parts, considering first, the evolution of technical coontent in school training; then the advent of computers and internet; and last the exceptional properties of robotics.

A. Evolution of technical content in school training

The situation is of course very different depending on the age of learners. In early times, everyone is concerned, with basic competences, while in later years, specialization allows for research level activities.

For the young years, some school curricula, such as Rudolf Steiner's ones have considered practical, concretization activities in a broad variety, including the implementation of a garden and visits to industrial facilities. But this remains an exception.

Without being as developed in this regard, classical schools, at least in the Western world (unfortunately I do not know much about others), have nevertheless also proposed to pupils some practical, creative, concretization activities - drawing, wood and metal processing, textile activities.

For more elaborate technical activities, it is only in some relatively rare cases that after-school activities have allowed pupils to acquire competences, sometimes in close synergy with the conventional school system, thanks to some enthusiastic and volunteering teaching staff members, as well as visionary managers supporting long term public interest (e.g. [3]).

In old times, radio ham and meccano activities, electronics and some chemical engineering have been seen.

Currently, robots, 3D printers, maker resources, Arduino printed boards and integrated circuits are gaining momentum (e.g. [4]).

At college level, laboratory experiments and concrete projects have always been considered, in technical disciplines.

Currently the trend is towards more complex systems, often involving multi-disciplinary approaches, and the coaching of self organizing teams. International initiatives gain momentum (e.g. in Europe Leonardo and Erasmus programs) and mixed levels education initiatives, such as, much more than in the past, kids in university contexts.

B. Advent of computers and of the internet

Within a few years, the necessary infrastructure for computing and communication has become pervasive, as smartphones make it evident.

There are very contrasting aspects though. On one hand, as Steve Jobs in particular had been fighting for, the user interface has evolved towards an extreme simplicity: on the other hand, the necessary resources involved, for the designers and engineers who develop new hardware and applications, have become more complex than ever.

A gap is therefore getting broader between these two communities, and even in more advanced countries, the need has appeared to actively bring to the attention of youngsters the particulars of this techniques, their interest and to provide pathways for them to finally contribute.

C. Exceptional properties of robotics

Robotics brings exceptional advantages, as a test-bed for introducing smart machine-based systems, and for conveniently increasing awareness of technology in youngsters.

This is in particular due to three kinds of peculiarities, which deserve mention here.

The first kind relates to the richness of techniques and notions that contribute: motion in space, trajectories, sensors, closed-loop control, real-world, real-time constraints, cognition, mechanical structures, communication, energy management, etc.

The second property is the natural teamwork usually made necessary to satisfy the corresponding numerous and diverse requirements: in practice many humans must join in a coherent group, sharing some common culture (in MCS sense), in order to yield the depth and breadth of expertise globally required.

And the third one relates to the capability of robots to ground cognition in the real, physical world, by perception, and similarly to concretely enforce their decisions (an outcome of cognition) onto the real word, i.e. to act and thus immediately ensure the pertinent physical changes (re. Fig. 1).
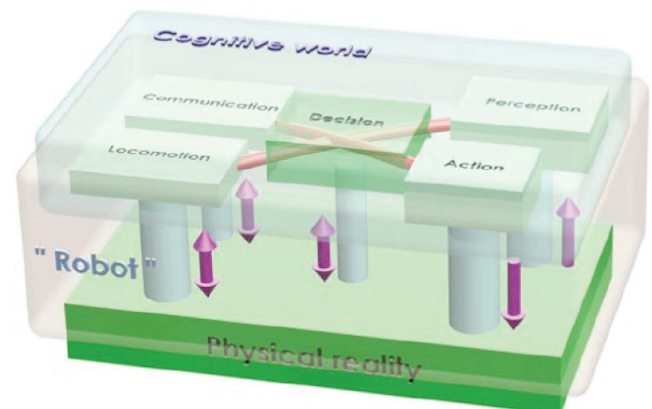

Fig. 1 Robots include cognitive capabilities. In the case of robots, the latter are directly connected to real world; with thus required abstractions, concretizations, and energy transfers, in full autonomy.

These properties can be considered already in basic modes, appropriate for the education of very young kids, less than 10 year old, and can also stretch out to most challenging levels, where research is the only chance for progress.

Education can be understood here in the classical sense, with regular courses, labs or projects as part of a curriculum, but much has been done, and is still expanding in various after-school contexts, in particular competitions. For example some of the most prominent activities of this type in Switzerland include the participation to international competitions (FIRST Lego League, Eurobot, Robocup-at-Home, etc,).

The origins of such systems can be traced back to the 50's , with the invention of "analog" turtles (e.g. [5]). The advantages of such systems have just grown, as evolution has brought more complexity and power, in particular in material,

programming, and cognitive terms. The current trend is even towards emotional aspects of human-robot communication [6].

III. COGNITION AND COGNITICS

Reference has been done above to cognition and artificial cognition systems (ACS). Let us give here an overview of how cognition is defined in MCS ontology [2]. This constitutes a critical scientific basis for the technical and methodological deployment of cognition, and is particularly central both in robotics and in human education (including didactics), which needs to be disseminated broadly.

A. Cognition in general and in natural context, typical of humans

Cognition is essentially the faculty, ensured by specific internal structures and operation flows, to process information with high performance levels, for example, in terms of complexity, abstraction, learning, or expertise (cf. Fig.2 and 3); to deliver pertinent information, i.e. to take the right decisions.
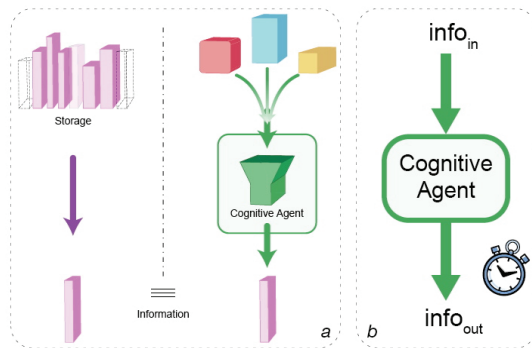

Fig.2 In MCS ontology, cognition is the faculty to deliver pertinent information; typically, generated in real time (a); cognitive properties can be quantitatively estimated by reference to the classical notions of information and time (b).

Fig.3, Metric system for cognitive properties in MCS theory of cognition [2]. The first equation is essentially Shannon's one, for assessing information quantity in a message of p probability..

Among positive aspects, notice the very simple hinges joining classical notions and MCS model.

On the negative side, beware that the unusual and sometimes disturbing properties of information are inherited by most cognitive properties: time-dependence ("volatility",

messages lose all information content upon reception), subjectivity (the same message may convey different quantities of information to different receivers), and critical dependence on the necessary, underlying, specific, associated model ("domain", "context").

B. Cognition for automated implementations, cognitics

For applications where ACS are considered, rather than humans, the general ontology as briefly introduced above can be used in exactly the same terms.

Nevertheless when cooperation is envisioned, between humans and ACS, the major difficulty comes from the difference of respective experiences, humans having typically a life sharing very little with the operational scope of ACS.

IV. STUDENT EDUCATION

As already announced above, Sections 2 and 4 may seem somehow to overlap. But in fact, while above the technical aspects were at the forefront, attention is given here in priority to aspects relating to education in general.

The Section consists in three paragraphs, addressing first the evolution of general education; then professional training and dual system approach; and finally seven concepts of growing significance will be reviewed.

A. Evolution of education in general

Education has been quite different through ages.

For a long time, few people were really learning in a sense somewhat similar to today, and they were to a large extent curious and autodidact.

Education was typically done in families, and for professional training, there were family traditions.

The public school system, in Western countries, can be traced back to the 17th century.

As already mentioned from the technical perspective, where this has started earlier, it is also true from a general education perspective that the trend is towards more open, interdisciplinary initiatives (e.g. festival of robotics for the public, open-door days, visit of parent's workplace, etc.).

Here also international student exchanges and international competitions bring their high-valued contributions: increased awareness of cultural differences and complementarities, corresponding benefits; similar effects at team level; with apparently the strong intensifier ("boosting") effect of competition-related stress and emotions.

B. Professional training and dual system

For technical domains, apprenticeship was typically the good solution in terms of professional training, for ages.

Yet in recent times, the school approaches have become so prevalent that many people feel today that this move has been excessive when it has become exclusive.

There are some countries though, where evolution has not been so strong. A dual system is in effect, whereby the week is

schematically broken in two parts, one spent in school environment, and the other one in practical, professional context.

C. Concepts of growing importance

In recent years some concepts have gained in momentum for best practices in education. Seven of them are listed below, not to mention project management, goal orientation, the management of uncertainties, or also serious games. All of them are very present in the context of international robotics competitions and international exchange programs, from the point of view of general education and even more so, from the one of technical education.

1) Teamwork.

Importance is more recognized nowadays, in education, in the acquisition of "soft skills", the ability for students to cooperate in teams.

2) Hands-on.

Conceptual approaches are inherently limited by the minute power of models to truly represent reality. By contrast, hands on approaches bring the student directly in front of the real world.

3) Emotions.

Increased attention is given to the possibility of robots to live with humans (e.g. [6] - Pepper). The communication of status and intentions in a group is ensured by emotions in humans, according to classical views.

4) Peer tutoring.

Peer tutoring is an interesting ingredient in the education system (e.g. [7, 8]). Typically, it brings two types of advantages. On one hand when given a teaching role, learners often are able to view the learning difficulties of their peers with more empathy and insight . On the other hand it allows them to deepen the knowledge they may initially have of the domain they teach.

5) Social abilities.

As already stated, the acquisition of "soft skills", and in particular social abilities, is increasingly perceived as an important part of what education should provide, even when technical subjects are in primary focus.

6) Individual initiatives and customization.

Standardization seems less necessary than in the past, smart systems allowing to adapt offers more easily to individual variations in customer demand.

7) Connection between conceptual and real worlds.

As evidenced by MCS theory of cognition, models are drastically simpler than corresponding reality, and therefore it is important to validate them in concrete, experimental set-ups.

V. CASE STUDY : CONTRIBUTIONS TO ROBOCUP@HOME INITIATIVE

Our Lab for Robotics and Automation (LaRA) has been directly involved in at least 10 robotics competitions, since 1998, most of them occurring at the international level. We focus in this case study on Robocup@Home, a competition organized at world level, in which some of our students have been engaged, in a multinational team including Swiss students as well as foreign interns joining our exchange program.

The study is organized in six parts., the first one presenting the Robocup@Home (R@H) initiative, the second international aspects, the third one refers to a key component that was developed as an R&D contribution. Internships and student exchange considerations appear in part 4,; part 5 illustrates the validation of concepts that the competitions allow, and finally part 6 presents extensions that could be made as a by-product of this participation to R@H initiative.

1) Robocup@Home

RoboCup is an international initiative devoted to advancing the state of the art in artificial intelligence and robotics. The aims of the project and potential research directions are numerous. The ultimate, long-range goal is to build a team of robot soccer players that can beat a human World Cup champion team [9].

For the Robocup competition in Bremen, Germany, it was proposed to introduce a new league, aiming at fostering research in domestic robotics, i.e. for a goal of more social orientation than soccer [10], especially in a trend where human populations tend to age, thereby requiring more help as time goes.

Particulars of this competition include the goal for robots to cooperate in "natural" manner with humans, in practical context of realistic complexity. In addition to being socially of most relevant nature, it is at the same time scientifically and technically very challenging.

We have joined this initiative from the beginning, and for the first 5 yearly editions (re e.g. Fig 4).

Fig. 4 Our RH-Y robot presents itself during R@H competition in Graz, Austria (picture taken from an HESSO.HEIG-VD video done during official competition); a referee can also be seen on the picture.

2) International aspects

R@H is obviously international by several tokens. Statistics on participation show up to 45 countries, from the 5 continents, participating to the event [11].

During our participation, we have visited Germany, the USA, China, Austria and Singapore.

Gathering teams coming from such a large geographic basis allows for involving top level experts. It also brings visibility of team activities to partners at world level.

3) Piaget as an original environment for development, programming, and actual control, in the real-world.

Piaget is an original environment for development, programming, and actual control, in the real-world, of systems, typically autonomous and cooperating robots, at various scale, from sub-system elements (e.g. ACS), to possibly integrated, robot groups (e.g. [12] and Fig. 5).

It is the place here, less for a scientific and technical description of Piaget, but more for giving the rationale and modus operandi that led to its creation, in coherence with the topic of the paper, as summarized in title.

At the beginning of our participation in international robotics competitions, back in 1998, the traditional curriculum for micro-technology allowed for an adequate number of hours for teaching courses, lab experiments and individual projects; in the case of th lab, half of the time could be devoted to the necessary variety of basic experiments, and the other half, could be allocated to a novel education approach, involving a team-based, longer term micro-project, with collaborative coaching (e.g.[13]). Students had the choice for engaging in an international competition either for a small satellite, or for an autonomous robot. The latter topic was chosen, and our teams started participating to international robotics competition at European level (Eurobot [14]).

After numerous years of reasonably successful activities, in classical teaching, R&D, as well as technical transfer, relating to robotics, the participation in international competitions was perceived with confidence. The latter appeared as a convenient mean for complementary education, as well as for benchmarking our training capabilities and for possibly learning from others some best practices we might have ignored yet.

Indeed as somewhat a surprise, the participation to international robotics competitions forced us to move beyond classical education framework, towards, additional, novel contributions in research and innovation.

In addition to the expected components our team could classically acquire, build and integrate, with the goal of fulfilling rulebook requirements and thereby gaining points in competitions, it appeared that a major piece was to be designed: an effective and efficient environment for development, programming, and actual control, in the real-world, of robots and smart systems. We progressively made it, and gave it the name of Piaget, the well-known scientist of child psychology and constructivism.

Later on, in phase with the Bologna agreement about university curriculum re-organization in Europe, our missions also evolved. Lab time was reduced, and our university moved Eurobot-type of robotic competition activities to after-school, hobby frameworks; and our lab moved to Robocup@Home participation, better in line with the new requirements: applied R&D and international relations.

In Robocup framework, the initial idea of the initiators was to let robotics and AI join. From our point of view, in the same way as robots typically include batteries and wheels, cameras and microphones, arms and grippers, techniques for kinematics and real-time control, robots also include AI; in this sense, there is nothing to join. In fact our lab had already shown for many years an interest in AI, and made contributions, though AI was not central at the education level of that time.
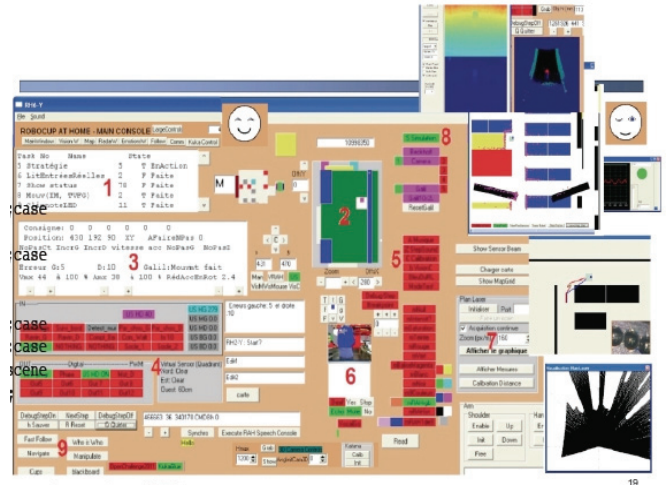

Fig. 5 Our RH-Y robot presents itself during R@H competition in Graz, Austria (picture taken from an HESSO.HEIG-VD video done during official competition); a referee can also be seen on the picture.
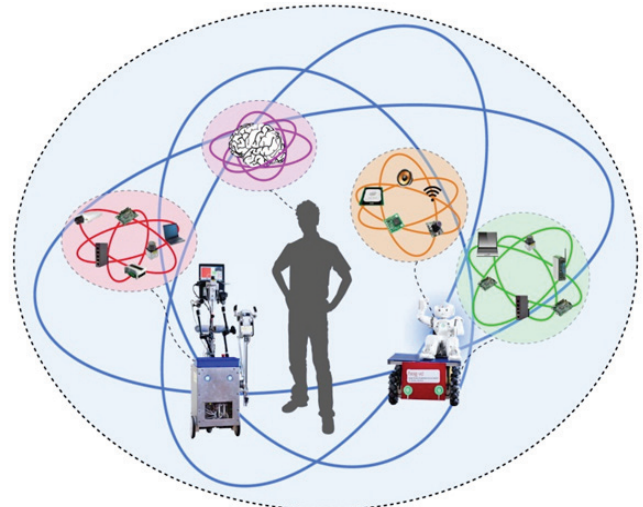

Fig. 6 Our Piaget environment allows for developing and controlling applications in real-world, not only for a single robot but also for complex systems, notably including a group de robots, and even mixed groups including humans. At and across multiple levels (sub-systems, individuals, group), there are similar subtle coordination balances to manage; stable, robust, effective and efficient cooperation.

Any way, the attention brought to AI was interesting, and in the new environment, further research in this direction was optimal. In fact, long ago, and repeatedly, at the moment of addressing the state of the art for AI, in robots or on itself, our surprise had been again and again to realize that the field was still quite terra incognita. How could we progress without a capability to identify? To quantify? To compare? Our approach

had been to define terms properly, and to propose a metric system (e.g. [2] - Cognitics).

The R@H league appeared as an excellent area where our proposals and solutions could be benchmarked, and we might learn form peers.

Two figures illustrate some aspects of Piaget. Fig. 5 presents the cockpit-like, main window and some ancillary displays of Piaget. They relate to numerous resources in terms of sensors, platforms, arms, I/O access, vision techniques, communication, strategies, agents, applications, etc. ; as well as configuration, programming, and real-time control capabilities.

Fig. 6 illustrates the fact that Piaget can help develop, program, and control in real-time and in integrated way not only subsystems in a single robot, but also robots of various kinds, as well as groups integrating them; and even humans, with the supported communication means in cooperating frameworks.

4) Internships and student exchanges

The context of international robotic competitions has allowed the fruitful teamwork of numerous students in our lab (re. Table 1 and Fig. 7).

- Canada (Mc Gill Univ. Montréal)
- Korea (Konkuk University, Seoul)
- France (ESME - Sudria, and Supélec, Paris; Univ. of Strasbourg)
- India (Ind. Inst. Techn, Kanpur, Kharagpur, Mumbai & New Dehli ; National Inst. Of Techn., Karnataka)
- Lebanon (Lebanese University, Tripoli)
- Japan (Chuo Univ. Tokyo)
- Thailand (Assumption Univ., Bangkok)

Table 1. More than thirty international internships have been made at LaRA, at bachelor, master and Ph. D levels, with students coming from 12 academic institutions, located in 7 foreign countries, most of them with involvement in activities relating to robot competitions
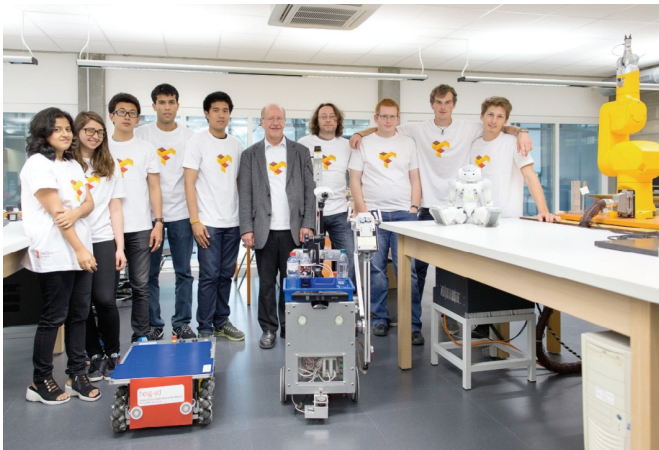

Fig.7 LaRA's team in summer 2014, including, from left to right, interns form India, Lebanon, Thailand, as well as 3 bachelor students of HEIG-VD ; the second one is now in Japon (Tokyo) in a partner lab of robotics

5) Validation of concepts in competition

The experience gained in international competitions has brought many benefits, in particular also according to the desirable aspects of technical and general education listed above (re. §IV.c).

In scientific and technical terms, the general conclusion is that our approach is good according to the scales established in R@H rulebooks, in principle reflecting the best relevance in domestic tasks and the target reached in terms of progress expected, year after year (refering to the general, final scores, our team has always been ranked in the first half, with our best result being the 4th place ; anyway, the ranking relative to other teams has never been a critical criterion for us, even though psychologically it may well be more comfortable to report being ranked in the first place rather than the last one !).

We could in particular confirm that the proposed metric system for cognition is significant and useful ; and that our Piaget environment can deliver as expected. In one test in official R@H competition in Singapore, for example, our humanoid (a NAO robot re programmed with integration with Piaget) could interact with a human, « Daniel », in the living room, as a mediator, then communicate with OP-Y, our omnidirectional platform for requiring a reliable locomotion at home, in particular toward the kitchen, where RH-Y, another of our robots (both of them are supervised, i.e. controlled at the strategic level, in Piaget) could be called in order to, autonomously as well, bring and deliver a can of beer and snacks to Daniel, back in the living room (e.g. Fig. 8).

Even though the benchmarks may be affected by various « noise » factors (e.g. speed of changes between tests, number of tests registered, referee's preparation and subjectivity, behavior and performance of other teams, etc. ; as well as countless random factors, as always, for complex real-world systems, robots and infrastructure), our conclusion is that international student teams such as ours can very quickly catch up to our previous solutions and very well contribute to further progress.

Fig. 8, Our group of robots, RG-Y, including here RH-Y, in background, and OP-Y in foreground, the latter ensuring robust navigation for a humanoid (re. Nao, of Aldebaran Robotics), also integrated, as a mediator, between human and machines, in our applications (re. text) (picture from an HEIG-VD video made during official, international Robocup@Home competition)

After five years of full participation to R@H competitions, including contributing to support and technical committees, and considering the international nature of our own team, the

incremental benefits of being physically in the official competition fields seemed to level off. And the idea to carry over to industrial contexts our solutions, and in particular Piaget, has made its way.

Nevertheless, it remains interesting for us, especially for technical education and student exchanges, to do research and to progress according to the most recent rulebooks of R@H (re. Fig. 7 and 9). Reading and publishing papers, presentations and videos, in Conferences and on the internet, allow for much of the full potential benefits ; for additional ones, the cost in terms of necessary logistics and administration procedures for participation on the official competition grounds might not be fully justified.
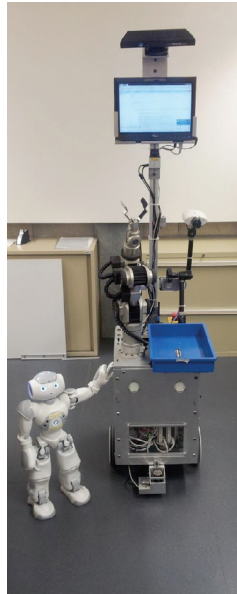

Fig.9 Our RH-Y robot, with its partner Nao. Together, they aim to fulfill the requirements for a R@H 2014 test: to receive clients in a " restaurant ", to guide them to a table, to take orders, and to bring them drinks and food accordingly (picture HEIG-VD, in LaRA lab, C38, in July 2014).

6) Integrated tutorials for cognitive metrics and more

Initially designed for international competitions in robotics, our Piaget environment has had a lot of success. Thousands of incremental developments and updates have been made, in great parts contributed by students and interns, on our collaborative "subversion" server.

Therefore the evolution of Piaget has also been driven in three additional directions, beside competition applications: tutorials, support for "regular" lab experiments, and research issues.

For example our Piaget environment includes an interactive form, "CogniMeasure", dedicated first to support the quantitative assessment of information and other cognitive entities, such as knowledge, expertise, learning and intelligence; and second to practice the application of the metric system to a representative cognitive task or agent (re. Fig. 10). The figure features in particular a serious game: the cognitive task consists in clicking with the mouse in the center of 5 targets; major cognitive properties are monitored and quantitatively assessed on the fly, including knowledge, experience, expertise, and if done several times, learning and

intelligence index. These properties are not shown in the figure but displayed in the right part of the (full) form.
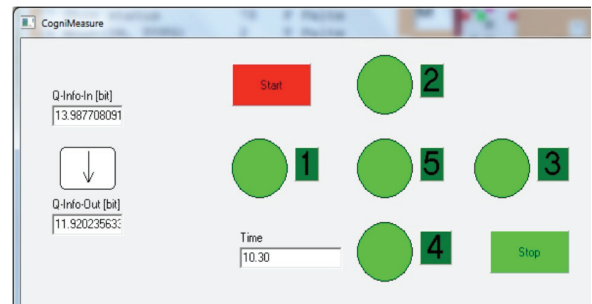

Fig.10 Part of "CogniMeasure", an interactive form provided in Piaget environment. The left area displays a cognitive agent, with current input and output information quantities; the rest of the Fig. features a serious game (re. text) .

VI. CONCLUSION

International competitions in robotics provide an excellent framework for technical education and for facilitating the exchange of students across universities.

Considering the evolution of technical content in school training, and the development of ICT and the internet, robotics appears to feature exceptional properties here.

Smart robots are capable of cognition, the faculty to generate pertinent information; and cognitics is the field where automated cognition is explored. Moreover, cognitive aspects gain also to be clarified in academic and educational issues, as MCS theory of cognition critically contributes to support.

Considering the evolution of school education in general, as well as professional training, international robotics competitions provide a good arena for practicing numerous concepts of growing importance, such as teamwork, hands-on, peer tutoring, or connection between conceptual and real worlds for example.

The paper concludes with a case study relating to our good experience about the topic in title, gained in the context of Robocup@Home international initiative.

Results can be transferred in various modes, including education, training, publications, code and possible market based agreements.

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Practical Mechatronics:
Training for Mobile Robot Competition

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Abstract—The paper presents a series of steps in educational process of mastering mechatronics. The material is meant to be used during relevant workshops and forms basic systematization of educational methods and tools the authors use in their everyday practice. Proposed approaches proved to be working and bring good educational results in a long-term time span. The paper is aimed at popularization of technical education, sharing best practices in the field and forms a platform for dialogue with the rest of the community.

Keywords—Mechatronics, robotics, education, practical training, mobile robot competition.

I. INTRODUCTION

Technical knowledge is one of the main considerations for humanity. Quality of engineering staff defines quality of our life today and tomorrow.

Nowadays we see dramatic changes in educational systems around the world. These changes are accompanied by a distinct falling interest for engineering professions as they are neglected by many prospective students in favor of humanities.

Pioneers try to reform educational systems of their countries. Less active try to put selection barriers to get the best students out there. Authors see motivation to become an engineer to be a very important impact factor for young people deciding their future and try to propose one of the working methods for its rational cultivation.

This paper is the result of work towards popularization of technical and exact sciences. The authors try to attract attention of the young ones and motivate them to expand their knowledge and abilities through practice of technical creativity.

The following description of the workshop gives an opportunity to touch the vast engineering world with the help of robotics. A robot is seen as a universal educational tool to make first steps in any known technical field. The authors tried to pack their everyday practical teaching knowledge into a form of a time-limited masterclass. Of course such form leads to known simplification of the teaching process and content and should be considered as an introduction to a long-term mechatronics and robotics course.

II. THE WORKSHOP

Building robots is fun! This section gives brief description of the workshop's content. It could be used during the work-
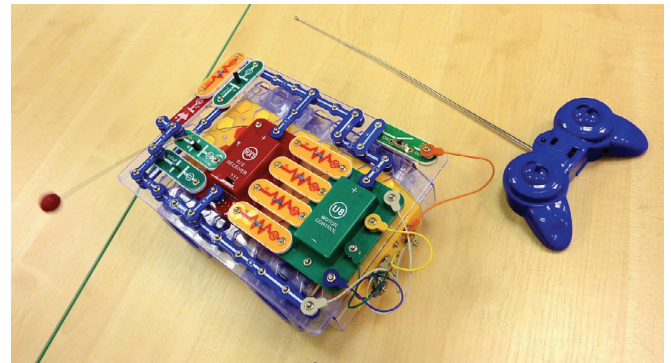

Fig. 1. Electronics construction kit "Leader"

shop itself as a compact manual or one could even use it to organize another similar popularization activity for the benefit of the younger generation.

The workshop is connected to the long-term robotics education course organized and developed by the authors. This course stands upon educational and fabrication environment - both together are often called the Lab. The fabrication part of it is addressed in the following text as the digital fabrication laboratory.

The main participants expected for the described workshop are schoolchildren but the nature of the object (which is a robot) gives a lot of potential to deepen knowledge even for much older participants. Moreover in the Lab the authors try to stimulate different age groups to work on similar tasks at the same time. This "mixing" stimulates self-education and motivation.

A. Step 1: learn about electronics

1) Theoretical part: Since his first activities in the Lab a child must solve a practical task - implement, create something and get the bottom line. Otherwise he would not be interested to continue and he will not come again. In order to inspire the child from the very first class, there are many different construction kits out there.

The electronics construction kit named "Znatok" [1] was designed in Russia 18 years ago, which allows one to seamlessly implement a lot of interesting devices. It is popular
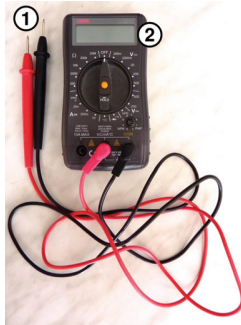
Fig. 2. Various forms of a conductor

Fig. 3. Multimeter tool

in family education. Often a child is engaged with it by himself. He is gradually gaining understanding of electrical and electronic circuits, power supplies, active device's control, etc.

A child implementing devices in a "Znatok" kit through experiment and prearranged schemes masters the basic electronic components. It has an excellent manual and learning help book, which most of the individual users neglect in their experiments. In rare cases, parents would introduce the book to their children and comment on the course of action. Teachers in supplementary technical education could benefit from this tool with extensive methodological information for the initial stage of any electronics training.

Basic electronic components of "Znatok" can be extended with a robotic kit "Leader" (see Fig.1). This is a step from building circuits to building electro-mechanical machines and devices. In addition to already known electronic components it introduces a number of more sophisticated devices like: mobile robot chassis, motor driver and radio control.

Great potential of both construction kits can be revealed within a practical robotics training course. The first training step at the lab is fully based on such kits. Some parts of the "Znatok" and "Leader" prove to be useful even on later and much more advanced steps.

2) Practical part: The main concern for the first step are conductors and the source of electric current.

One of the practical difficulties for children learning about conductors is pictured in Fig.2. It shows two main forms of conductors in an electronics construction kit used: 1 - is metal conductor incorporated in plastic casing, 2 - is a piece of flexible conductor wire. Although the conductors are taken from the same box children initially do not understand that they are interchangeable.

While building electronic circuits (like in Fig.1 from a book students do not realize that the hard wire can be replaced by a flexible one.
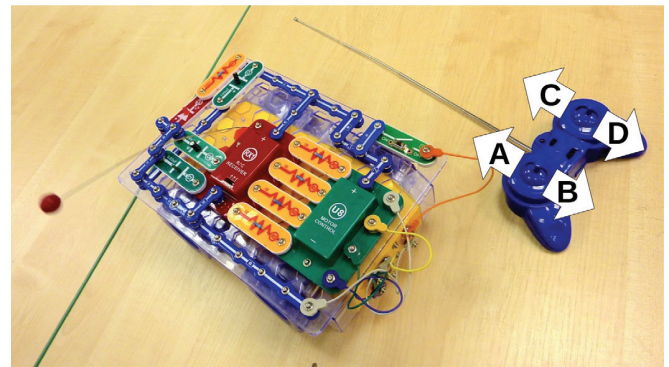

Fig. 4. Understanding the radio control in the "Leader" kit

TABLE I.   TRANSMITTER - RECEIVER CORRESPONDANCE

Transmitter joystick direction	A	B	C	D
Receiver pin	?	?	?	?

The difference between a conductor and a battery is easily explained to a child using a multimeter (like in Fig.3). Though this approach leads to a persistent wish to measure voltage in a circuit breaker, a button, a resistance and other passive components.

The solution was then found by children themselves, when they were asked to come up with tools to distinguish a wire from a source. It was quickly realized that a conductor is needed for testing a power supply, and students came up with examples of circuits with light bulbs and electric motors.

In this step it is also important to form the idea of digital calculation/computing [2]. "0" and "1". The first explanation can be based on some very basic circuits with a battery, a lamp or a switch. In electronics these math abstracts become "physical": logic "0" - voltage is less than two volts, logic "1" - voltage is greater than four volts.

Now it is time to pass on to the robot constructor kit "Leader" (see Fig.4). It has a radio control with 2 joysticks acting in 4 possible directions: A, B, C and D. Radio control has a receiver on board of a robot.

For better understanding of radio control and to consolidate all the previous learning actions a student is asked to fill-in "?" in the Table I. The main components of interest: a radio transmitter and a receiver. While using joysticks on the transmitter it is needed to find a corresponding signal on the receiver pin and put it in the table.

3) Step results: The workshop's participant knows how to use a voltmeter, has basic knowledge in digital calculation, built a circuit to control the "Leader" robot and undertands what happens on the low level with the radio control transmitter and receiver while they operate.

B. Step 2: learn about digital fabrication

This section refers to building a mechanical construction kit in "do-it-yourself" style with the help of a laser cutter machine.
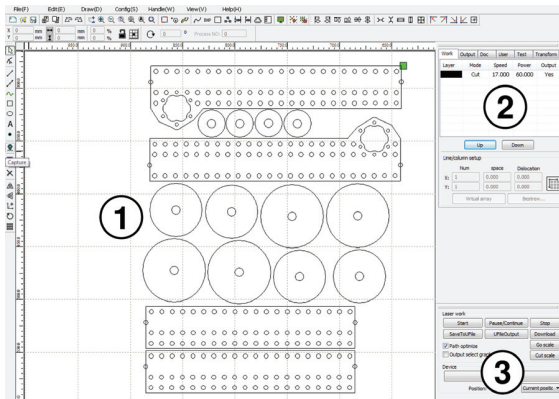
Fig. 5.   Laser cutter software controls

1) Theoretical part: Digitally fabricated objects are created with a variety of computer-aided design (CAD) software tools, using both 2D vector drawing, and 3D modeling. That is why digital fabrication is a type of a manufacturing process where a machine being used is controlled by a computer. As described by Neil Gershenfeld [3] we are today at the dawn of a new era, which could bring personal fabrication in every home on the planet as easy and silently as personal computing emerged not so long ago. He calls it "the third digital revolution" [4].

Today's serious engineer's skills include digital fabrication experience and thus such expertise should be considered during any technical training. There are five main machines forming a typical digital fabrication lab (in order of usage popularity): a laser cutter, a big milling machine, a desktop precise milling machine, a 3D printer and a vinyl cutter. For the purpose of teaching and hands-on experience some additional equipment is presented in the Lab: a "string" heater, a soldering iron, a drill, and small tools.

A laser cutter is the most important part of the Lab. It is heavily used while teaching how to build better robots and benefit from computer-aided design techniques. Practice shows that students' interest to this tool remains to be high even after the formal training is over. It is used to make mechanical parts for robotic and mechatronic projects.

2) Practical part: To introduce participants to digital fabrication they are presented with a set of previously prepared files (Fig.5) to be "printed" on a laser cutter machine. Material used is acrylic glass. In this case the files represent parts of a self-made mechanical digitally fabricated (DF) construction kit. The result of this cutting step are kit parts and raw parts which require further hand bending on a heater "string".

Correct actions and compliance with the manufacturing technology are achieved by supplying the files with technological route charts. Participants using them reproduce the process of manufacturing, yielding a set of components for further assembly (Fig.6 and 7).

When familiar with digital fabrication equipment like a laser cutter children usually show interest to how it operates, perceive it as an aid in their work, while using it in their projects they feel themselves older and even as grown-ups.

3) Step results: The workshop's participant knows how to use a laser cutter, made a set of digitally fabricated acrylic
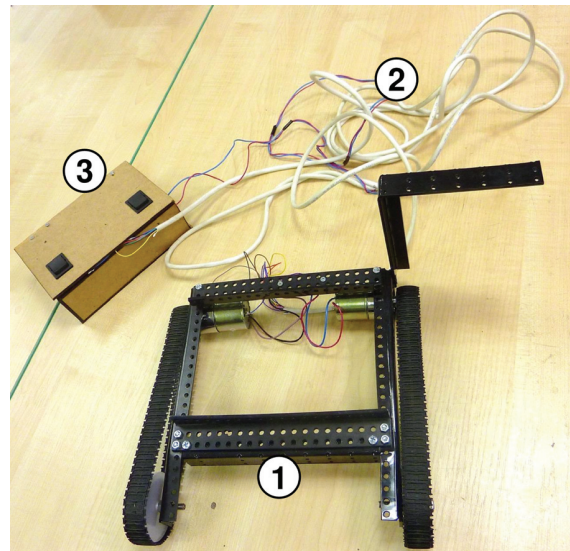

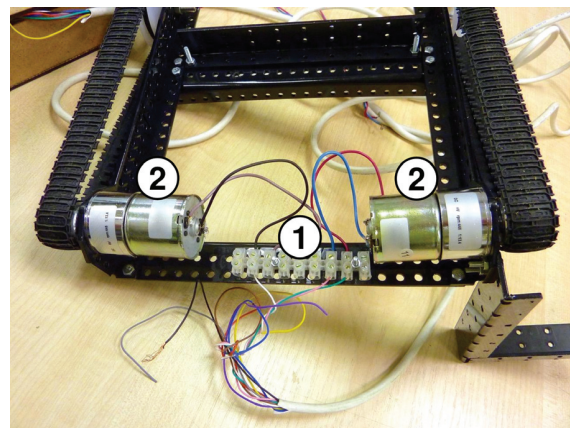Fig. 6.   A robot chasis variation of the DF construction kit

Fig. 7.   The self-made robot chasis details

parts, bended some of the raw parts on a heater "string", assembled a robot chassis and knows how to use technological route charts.

C. Step 3: learn about combination and creativity

1) Theoretical part: Technical products in our time can be simple and complex. Simple products are originating in small businesses where activity of an individual engineer is distinct in the result. Complex products are the result of collaboration and hard work of many people and usually for a long time.

A lot of gadgets used by many people every day are complex systems and can't be reproduced from scratch by an individual inventor in a reasonable time. Cell phones, operating systems and even space rockets to name a few such product types which are complex in their nature. Development of such a product is interactive and is based on using and relying on previously developed parts. These parts could even be 3rd-party. This way parts can be improved separately.

Programming field could be taken for a very natural example of code reuse. Speaking of code complexity for
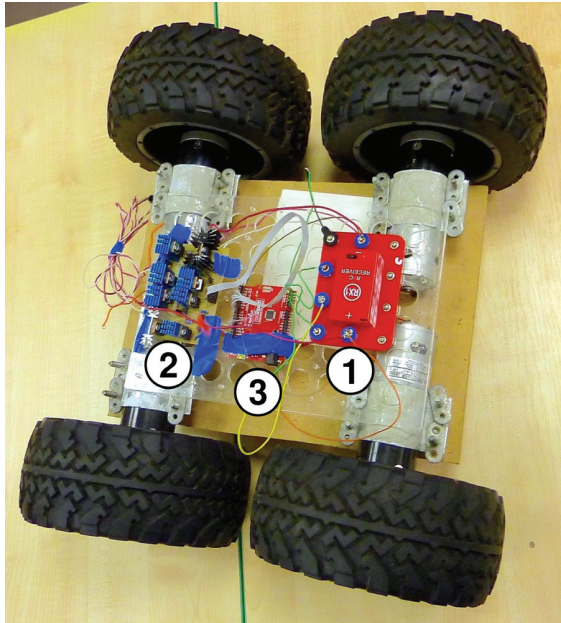
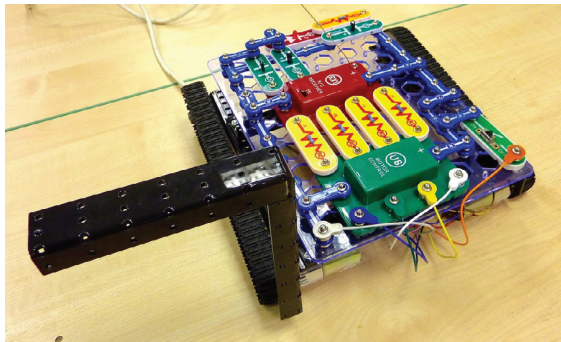Fig. 8.   A robot chasis with control parts of different origin

Fig. 9.   A hybrid chassis (electronics kit and mechanical DF kit combined)

today's desktop software applications Alan Kay [5] estimates the biggest live and managed code base to be 350.000.000 lines of code. Showing this achievement Dr. Kay also speaks of drawbacks for such an approach giving an example of a longtime justified-text bug in one of the most famous text processors of our time - now more than 25 years old and still there because of inability of the company's engineers to find the bug in the enormously big code base.

Concluding this idea - to be competitive it is important to use previous experience, when building new apparatus or product a wise choice of already existent parts and technologies is important for the product to be competitive on the market. Complementing those parts with new parts and structure potentially brings better solutions in lesser time.

Thus it is very important to communicate this reuse principle to students. Practicing it in their projects they will understand better its positive and negative sides.

2) Practical part: Forming understanding of the reuse principle and creativity starts with using parts of the previously mastered kits. Combining parts leads to new options and finally
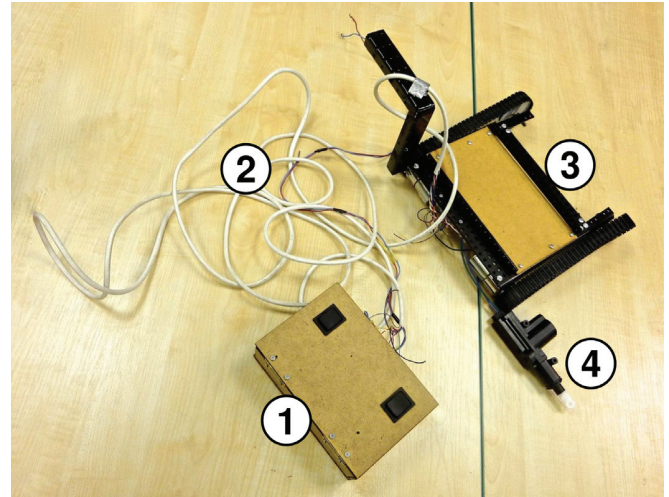

Fig. 10.   Mobile robot with wire connected control box

to better mechatronic and robotic devices made by students themselves.

First example of such an approach to robot development is shown in Fig.8. A custom mobile robot chassis is combined with a radio control receiver from the "Leader" robot kit (number 1). Motors are controlled with a custom driver (number 2). Driver is controlled by an Arduino board [6], freely available on the market. All together these parts form a unique mobile robot, able to be operated via the standard radio control but extending original actions with much more versatile robot behavior and power.

Workshop's participants are asked to combine "Leader" robot kit parts with the DF kit chassis to form a customized self-made version of a mobile robot (Fig.9).

3) Step results: The workshop's participant knows the reuse development principle and has built a complex mobile robot as a combination of self-fabricated mechanics (from provided DF construction kit files) and electronics from the "Leader" robot kit.

D. Step 4: learn about manual control

1) Theoretical part: Creating robot mechanics with basic, teacher prepared parts sooner or later move into a new phase - the creation of a self-made device. A transitional, simple yet definite step is needed for a student to succeed and become confident in his abilities to create new devices based on his own ideas. If the step is too difficult and the result of it is a failure motivation of the student is negatively affected likely leading to further end of robotic and technical practice.

In mobile robotics field it is natural to test mechanics with a special remote control box. Some robotic competitions [7] even exploit this possibility and propose special rules' editions for schoolchildren. According to these rules young engineers have to build a wire controlled mobile robot, such as in Fig.10.

In this case successfully implemented robot mechanics gives all the chances to win a competition. Later, when knowledge is enough same rules are proposed but asking the robot to be fully autonomous. This brings a new level of
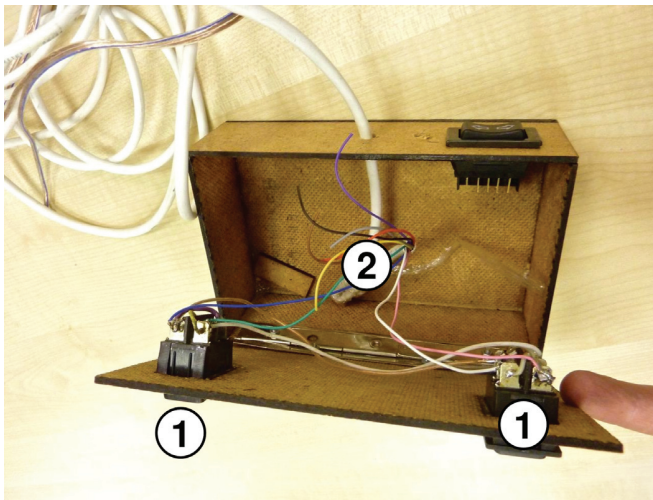
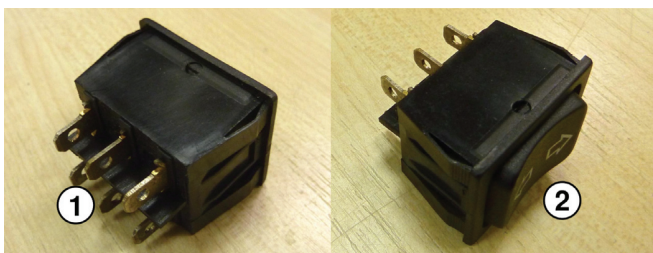Fig. 11.   Template design for a self-made manual control box

Fig. 12.   Basic button for motor control

knowledge systematization for a student and interest to go on with the proposed practical course.

2) Practical part: Building a custom wire remote control.

The remote is a box composed of laser cut parts that are glued to each other (Fig.11). The body of the box is nothing special or new but the control panel can be designed by the young engineer himself. Two control buttons (Fig.12) are used as a starting point for the development process - one for each of the two motors on a mobile robot's chassis. Besides drawing the panel design the developer has to make an electrical circuit drawing to correctly connect the power source to the motors, being able to switch each motor's rotation direction.

Development begins with building of the control circuitry. The basic principles of such control can be tested using the previously mastered "Znatok" electronics kit. General task for the circuit design is formulated as to be able to start a single motor bi-directionally. Then generalize it to the case of two motors.

Each of the two buttons used in the final circuit has two sets of contacts, each has 3 contacts activated by a spring hold button (fully pressed to activate communication between 2 contacts at a time but without external pressure it returns to the off position).

After checking the function of the circuit a control panel is designed with the control buttons in their places. The panel is then cut on the laser cutter machine.
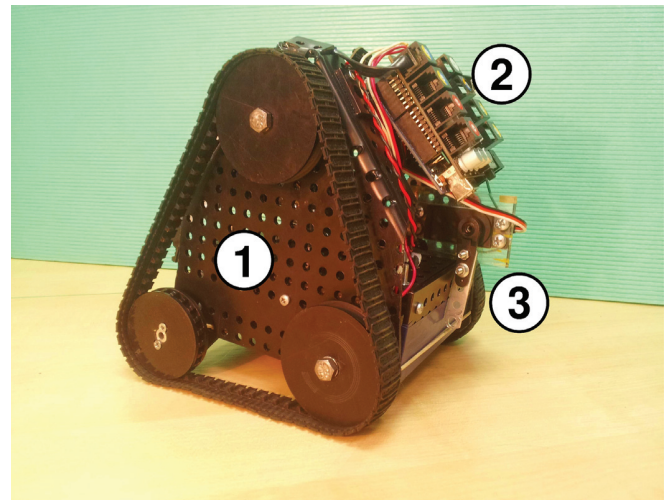

Fig. 13.   Customized self-made mobile robot for competitions

3) Step results: The workshop's participant developed a control circuit for bi-directional motor rotation, designed a control panel and assembled the remote control box with parts cut on laser cutter machine.

Fig.13 shows a robot customized by one of the students from the template DF mechanics kit. It shows how versatile the idea of a kit can get in a digital fabrication environment compared to usual mechanical kits on the market. Having the source file of the kit design a student can start his own edition of the kit (fork it), rather than try to cope with restrictions of already manufactured mechanical parts.

E. Step 5: learn about interactive control

1) Theoretical part: The Arduino platform allows one to quickly create complex electronics and programming projects. It became a de-facto standard for many hobbyists. For more professional projects it serves as good prototype base. Most teams in a well established robotic competitions use it in their robots. In our case it is a good step further into programming experience and study.

Programming potential of the Arduino platform allows building a fully autonomous mobile robot (requires deep knowledge in electronics, sensors, actuators, etc.) on a single board. Later on this rather constrained prototype solution could be reimplemented with a custom electronics solution, bringing realized basic ideas to a new level of sophistication.

Seeing the perspective, again, it is important to make an intermediate stop and learn Arduino in its simplest application, but which is connected to what was already mastered previously in the course. Combining a common Arduino with the robot's manual control designed on the previous stage one can think of an interactive mobile robot control.

An interesting approach to a possible way of interactive control of a robot's movement is proposed by the Introb project [8]. The operator has to wave his hands to make the robot move (Fig.14).

For full implementation of this idea the young engineer has to understand what an optical pair sensor is and how to

Fig. 14. Interactive robot control by hand gestures

measure trigger times with a microcontroller. If desired, the project can be easily transformed into a research simulator - it is easy to add additional sensors, change their type and study possible human gestures. More complex projects could even include changing robot behaviors and tracking possible operator reactions.

2) Practical part: Mastering of programming by the example of collecting information from sensors on the wave of a hand.

To successfully control the robot movement in the most simple case it is required to be able to count time between consecutive interruption of the two light beams. This requires a simple short program using the C programming language and the Arduino platform.

For a greater effect one can design and build his own mechanical body for the hand waving interface using DF constructor kit's source files as a staring point.

To simplify the work the robot part if taken as is from earlier stages of the workshop, it is then supplemented with a control Arduino board with a transparent radio communication. This part is preprogrammed.

In this case, a participant has to program only the side of the hand waving interface. Using code template files he can concentrate on programming techniques and study.

3) Step results: The workshop's participant developed a simple program using the C programming language and the Arduino platform. Depending on time and interest additional activity is possible in digital fabrication field, electronics and programming mastering [9] [10].

III. CONCLUSION

The paper gives a brief introduction to a practical course on building mobile robots. The material is meant to be used during relevant workshops and forms basic systematization of educational methods and tools the authors use in their everyday practice. Proposed approaches proved to be working and bringing good educational results in a long-term time span [11].

The proposed workshop is actually a long-term course concentrated for presentation to children with no previous experience with robotics. As the nature of the original educational course includes many age groups involved in a continuous engineering education process [12] there are also parts which could be interesting to experienced young engineers.

As the workshop is given in the presented form for the first time its results analysis could be a topic for the next paper to be published. Such information as the fault rate of the equipment used during the workshop and typical irreversible damage to certain parts children tend to make could form the basis for improvement and detailed recommendation on implementation of the workshop.

Future work will be concentrated on further detalization and expansion of the presented methods and material. The authors see this work as a general platform to find better educational practices in a dialogue with the rest of the community interested in the presented material.

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Model-Based Design of a Winning Competition Car at the Freescale Cup

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Abstract— **The paper shows how students used the modeling and simulation capabilities of the Matlab/Simulink to improve the control design of their winning FEIminetors car for the worldwide known Freescale Cup competition. Creating and simulating the model gives a) better understanding of the processes and b) almost bug-less transfer of the code to the embedded processor and c) first estimation of controller parameters.**

I. INTRODUCTION

The Freescale Cup, is a global competition where student teams build, program and race an intelligent autonomous model car around a track. The fastest car to complete the track without going off the track wins the race. Total number of 75 students, from 25 teams representing their respective universities from 11 European countries raced their cars on the 2014 Freescale Cup track at Fraunhofer IIS in Erlangen, Germany. The 180 sq/m racetrack consisted of speed bumps, intersections, hills and chicane curves.

Fig. 1. FEI-minetors team at the Freescale Cup Competition with their car.

Winners of the Freescale Cup EMEA competition, the FEI-minetors team from the Slovak University of Technology in Bratislava were not a newcomers in this competition. During the initial testing and programming of the car, they recognized the need for better understanding of various parameters and car properties. To be faster than any other car, they require to understand not only the basic physics beyond the car and the properties of the proposed controller, but they also need to know how certain parameter influences another, which were the most important factors etc.

As the students of the STU in Bratislava are using the Matlab/Simulink during the academic courses, it was a natural choice to use this tool also for modelling the car for the Freescale Cup. As an illustration, we will show two important models we created for the competition.

II. ELECTRONIC DIFFERENTIAL

The car contains two DC motors in the Ackermann steering geometry chassis, so it was necessary to implement so called electronic differential to safely drive all the curves in high speeds. Its function is to modify the speed of inner and outer wheels according the steering angle. For better understanding of its function and for easier implementation of the function in the embedded microcontroller, model of the steering geometry was created. It includes lot of parameters, starting from geometry (dimensions of the wheels, radius, length of the axis), including motor properties (speed, torque) and also some others.

```
% wheel driving radius
R = wheel_base/tand(angle);

% peripheral speed
omegav = v(i1)/R;

% wheel speed
vR = omegav*(R-(track/2));
vL = omegav*(R+(track/2));

t_ratio_r = 1-(v(i1)/vR);
t_ratio_l = 1-(v(i1)/vL);

% calculate differential values
t_diff_r = t/2 * t_ratio_r *
(exp(c*v(i1)));
t_diff_l = t/2 * t_ratio_l *
(exp(c*v(i1)));

% calculate each wheel torque
tR = t/2 + t_diff_r * k;
tL = t/2 + t_diff_l * k;
```

Part of the code for calculation of the torques.

Resulted differential was simulated and later implemented in the C programming language. See the Fig 2. for the 3D chart of the Speed/Torque and Steering Angle for both left and right wheels. Later the model was modified based on real tests and empiric knowledge.

Fig. 2. Ackerman drive model and 3D chart of the electronic differential. Two planes represents the respective speeds of the rear left and right wheels.

III. CONTROLLER DESIGN

For modelling, simulations and testing much more complicated model was created (see Fig. 5). In Simulink, it was quite easy to start with modelling subsystems (car geometry, DC motor, controller, etc.) and then integrate them into the one complex layered model. We started with the standard text-book model of the DC motor with some measured and some more empiric parameters (see Fig. 3).

Fig. 3. Model of one of the DC motors.

Later we added also model of the car chassis including its weight, dimensions, etc. – see Fig. 4. From the beginning, it shows that considering model non-linearities is crutial for good correspondence of the model with reality. In each step, the parameters were adjusted to obtain real results.

Fig. 4. Model of the car for the controller design purpose.

After the subsystems testing and comparing with real system, all was combined into the one complex model (see Fig. 5). The main controller of the system was tested and parameters were modified many times based on results of the simulations. Especially the current spikes were observed and the final design of the power stage electronics takes this into the account. Later, based on the real measurements and observations, further modifications of the model was included. Finally, the controller code was almost without changes transferred to the microcontroller. In the future, we plan to use the Matlab embedded coder for the Freescale Freedom Board platform, which we are just testing.

Later we studied the influence of non-linearities in the system and controllers behaviours without and with non-linear parts in the model were compared.

Fig. 5. Study of the noise influence on the proper controller operation.

Fig. 6. The car during the final race. (Photo: Andrej Lenčucha)

IV. Conclusion

The paper shows how students used the modeling and simulation capabilities of the Matlab/Simulink to improve the control design of their winning FEIminetors car for the worldwide known Freescale Cup competition. Creating and simulating the model gives a) better understanding of the processes and b) almost bug-less transfer of the code to the embedded processor and c) first estimation of controller parameters.

5. Conceptual Aspects and Cognition

Chairperson Hugo Ferreira

Towards a Robotics Concept Inventory

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Abstract—**Robotics evolved as a central issue in teaching for scientific and engineering disciplines. However, the community lacks tools allowing quantitative standardized assessment of student learning, in order to subsequently improve teaching. A common concept inventory can play the role of such a tool. We know concept inventories for a number of subjects, for example in the field of Signals and systems [1]. Concept inventories typically consist of a standardized multiple-choice exam that allows assessment of students' understanding of the most central concepts of a subject. Typically, students are tested before and after having participated in the course. The relative performance gives a numerical value that allows measuring teaching and learning success and possibly also highlights specific problems of the teaching or learning approach. With this paper we want to initialize the process of identifying a list of central concepts in the field of robotics.**

Keywords——Robotics Education, Concept Inventory, Teaching Assessment, Learning Assessment

I. INTRODUCTION

There are innumerable pedagogical approaches in teaching in general and also in teaching robotics [2, 3, 4, 5, 6, 7,8]. But, do we know the best approaches to give a robotics course? Is our favorite teaching method really the best for our students? Should we apply a more interactive style of teaching? Do we lose too much time with our problem-based approach? Do we need more than one teaching approach due to the diversity of our students? A concept inventory may help to answer this kind of questions. The goal of this paper is to initiate the design of a concept inventory for robotics. A concept inventory goes beyond known classroom tests. It is intended as an instrument for large-scale tests of educational approaches. Linedell et al. [11] defined a concept inventory as "A multiple choice instrument designed to evaluate whether a person has an accurate and working knowledge of a concept or concepts".

What makes teaching robotics particularly challenging for us is its trans-disciplinary nature. On the other hand, robotics is challenging for our students due to the fact that concepts from different disciplines have to be well understood. So, robotics requires mechatronic as well as electrical engineering, computer science, artificial intelligence and mathematical concepts. As a consequence this could mean to base a robotics concept inventory on an aggregation of existing concept inventories, e.g. for forces, mechanics, mechanics, electrical engineering and mathematics. But,

would this be a good solution? From our perspective, this is certainly not the case. In particular, there is a risk that the bridging competencies required for understanding robotics will not be included in this kind of aggregated concept inventory – we might even think about some kind of cross-concepts reflecting the complexity of the robotic system students have to deal with.

Development of a concept inventory and the related test instrument typically is a multi-step undertaking. For the design of a robotics concept inventory we are still at the very early stage of determining the relevant concepts or concept domain, preparing the test specification and constructing a pool of items. Eventually there will be a phase of iterative revision, field tests and assessment of reliability and validity. Definition of the concept domain often is based on researchers understanding and studies and literature on students understanding of the phenomena that are relevant to the domain. This paper provides a coarse orientation to foster a discussion among researchers on concepts that are relevant for a robotics concept inventory.

The remaining paper is organized as follows: After this introduction, we will shortly revisit the Signal and Systems Concept Inventory (SSCI), in order to explain the underlying approach. Then we will derive a number of categories for our robotics concept inventory and – in a second step – a list of concepts, which we consider to be central for robotics. We will end this paper with a short conclusion and an outlook towards future work.

II. CONCEPT INVENTORIES REVISITED

In this section we will have a look into one of the most often referred to concept inventories. Signals and Systems lectures typically are the first steps of students into the field of robotics, signal processing or transmission. We therefore have a look into respective research. Work on the signals and systems concept inventory (SSCI) started in the year 2000 and has initially been published by Wage et al. in her article 'The Signals and Systems Concept Inventory' in 2005 [1].

Work started with collecting core concepts of the respective field and designing the test. In a second phase, tests have been used in an alpha-test phase by a number of universities. This resulted in revision of the test questions, but also provided a basic calibration of numerical results. The signals and systems concept inventory actually consists of a continuous time (CT) and a discrete time (DT) inventory.

| #	Category	Concept(s)
1	Math	Time/frequency: select the plot of the sinusoid with the highest frequency
2	Math	Time-reversal: given a plot of $p[n]$, recognize the plot of $p[-n]$
3	Math	Time-shift: given a plot of $p[n]$, recognize the plot of $p[n-1]$
4	Math	Basic signals: recognize a plot of $u[n]-u[n-2]$
5	Math	Periodicity of DT sinusoids: given a plot of $\cos(\omega_0 n)$, recognize plot of $\cos((\omega_0 + 2\pi)n)$
6	LTI	Time invariance: given an input/output pair for an LTI system, recognize the output when the input is a shifted version of the original input
7	Sampling	Mechanics: given a plot of the samples of $x(t) = \sin(2\pi(3)t)$, determine the sampling period T that was used to obtain them
8	Sampling	Nyquist: given plots of 4 sinusoids, determine which one could be sampled at a rate of 5 Hz without aliasing
9	Trans/Filt	Filtering of a sinusoid: given an LTI system defined by a plot of its freq. response (magnitude and phase), determine the output when the input is a sinusoid
10	Trans	Time/frequency: given plots of a windowed sinusoid and its transform, recognize the transform of a higher-frequency windowed sinusoid given its time plot
11	Conv	Convolution: given plots of the input and the impulse response, recognize the output of an LTI system
12	Trans	Transform properties: given a plot of $P(e^{j\omega})$, find the plot of $R(e^{j\omega})$ when $r[n] = p[n] * p[n]$
13	Trans	Transform properties: given a plot of $P(e^{j\omega})$, find the plot of $R(e^{j\omega})$ when $r[n] = 2p[n]$
14	Conv	Commutative property of convolution: recognize that reversing the roles of the input and the impulse response does not change the output of LTI system
15	Trans	Fourier series: given a plot of a periodic signal, select the equation that best represents it
16	Math	Difference equations: recognize the form of the solution to an LCCDE with sinusoidal forcing
17	Trans	Transform properties and LTI systems: given a system with freq. response $H(e^{j\omega}) = e^{-j\omega\alpha}$ and a plot of the system output $y[n]$, find the plot of the corresponding input $x[n]$
18	Trans	Poles/zeros: given a set of PZ plots, find those corresponding to stable, causal systems
19	Trans	Poles/zeros: given a set of PZ plots, find those corresponding to real impulse responses
20	Trans	Poles/zeros: given a set of PZ plots, find the one corresponding to decaying exponential impulse response
21	Trans	Poles/zeros: given a set of PZ plots, find the one corresponding to a particular frequency response magnitude plot
22	Trans	Fourier transform: given a plot of $x[n]$, determine the DC value of its Fourier transform
23	LTI/Conv	Convolution/LTI properties: given the impulse responses of two systems, determine the causality of their cascade and parallel connections
24	LTI	Linearity/Time Invariance: given 3 input/output pairs, infer whether a system could be linear and/or time-invariant
25	Trans/Filt	Filtering of windowed sinusoids: given plots of a windowed sinusoid, its Fourier transform magnitude, and the frequency response magnitude of a filter, select the plot corresponding to the output

Fig. 1. Table of DT-SSCI (from [1]).

Each part consists of 25 multiple-choice questions. Please see figure 1 for the DT-SSCI.

Questions are designed to elicit if students actually understood the underlying concept. The concept inventory typically covers a number of categories, related to one or multiple underlying concepts. In the DT-SSCI we have among others the questions related to mathematics (Math), Linearity and time-invariance (LTI) and sampling (Sampling). Figure 2 shows as example question 1 of the CT-SSCI.

Fig. 2. First Question of CT-SSCI (from [1]).

Question 1

Figure 2(a) shows four signals $x_a(t)$ through $x_d(t)$, all on the same time and amplitude scale. Which signal has the highest frequency?
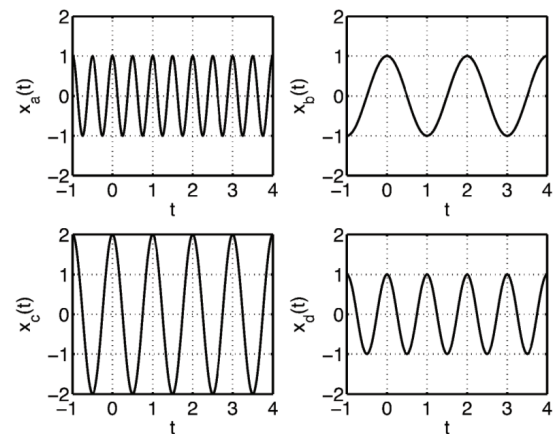
(a) Signals $x_a(t)$ through $x_d(t)$ for Question 1.

A number of about 25 items showed to be suitable to cover the content of a typical lecture and to be suitable for an individual test. Often, different items may help to test the understanding of the same concept. However, a larger number of test items may possibly help to elicit misconceptions of relevant concepts in more detail. Typically students undergo CI tests only twice, at the beginning of the lecture and at the end. Therefore, changes in the test-setup typically are not required. Furthermore, with a strict decoupling of grading and the CI tests, there is no incentive for students to specifically prepare for a CI test.

Questions are not discussed in class. Distribution of tests and specifically the correct answers typically is strictly restricted to researchers. Unlike examination test, CI tests undergo a lengthy design, test, and calibration phase for sake of comparability of results and can not be easily changed if test questions should become widely available and used for other purposes, like e.g. test-driven learning.

Typically, the same test is carried out at the beginning (pre test) of the respective course or learning module and at the end (post test). Students typically have about 60 minutes to answer the test questions without additional material or aids.

Tests are graded on a scale between 0 (worst) and 100 (best). From pre- and post-learning test results for every student an individual gain is calculated by the following formula:

$$gain = \frac{post - pre}{100 - pre}$$

The learning gain is thus calculated by relating the difference of results from post and pre tests to the unknown part of concepts at the time of the pre test. This normalization allows for a comparable assessment of learning progress of students at different levels, e.g. at undergraduate or graduate level.

Figure 3 shows an aggregated representation the results of the CT and DT SSCI tests for different course types. On the x-axis the results of the pretest is shown, whilst the difference of post- and pretest is allocated to the y-axis. The filled triangle to the right shows the test results for a traditionally taught digital signal-processing (DSP) course at graduate level. Pretest results have been about 60 points and posttest results about 85 such that a gain of about 0.63 was reached. The dashed lines indicate the gain ranges. A gain between 0 and 0.3 is considered low, a medium gain is in the range of 0.3 to 0.7 and any result above 0.7 is considered as a high learning gain. Please observe for the undergraduate level, that the interactively taught signals and systems classes (unfilled circles and squares) typically show a higher gain than the traditionally taught classes (filled circles and squares).
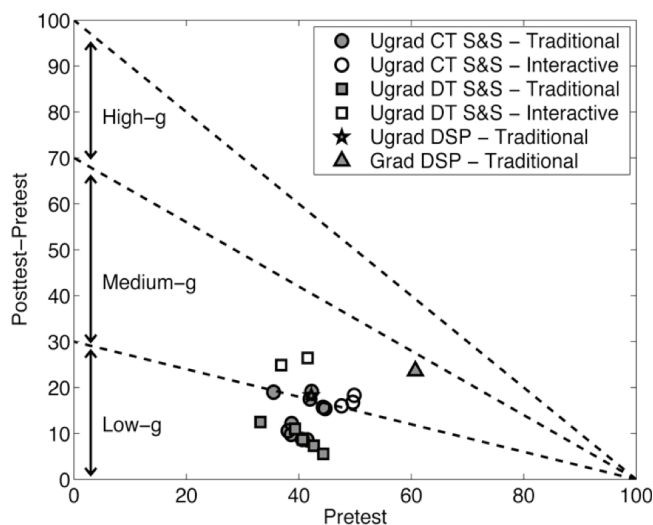

Fig. 3. Averaged gains of different course types (from [1]).

Further more, the test reveals many more details if results are processed further. A number of statistics measures can be applied, for example correlation of correct or wrong answers to different test items. Further more, specific wrong answers may indicate specific misconceptions among student understanding.

A detailed discussion of the SSCI and the results presented in figure 3 can be found at [1]. There also are more resources and publications available on concept inventories, e.g. [9] and [10].

III. THE ROBOTICS CONCEPT INVENTORY FOUNDATION

A number of specific properties affect the design of a concept inventory for the field of robotics. Robotics is widely inter-disciplinary, integrating a large number of technical and scientific domains and the related underlying concepts. Furthermore, robotics itself is fragmented into many sub-domains, for example into stationary and mobile robotics, just to mention two.

However, we believe concept inventories are a very helpful tool to further improve robotics education in a systematic way and thus propose the following starting point for the development of a robotics concept inventory. We start with an overview of concept categories, we consider central for robotics education. Readers are invited to contribute to the discussion with possibly additional concepts that should be considered.

Not all of the concepts being finally considered as relevant for the field of robotics may be relevant for all courses. However, in order to have a universal concept inventory it needs to span all potential concepts. By means of using a relative gain as quantitative measure of success, the CI will remain a valid tool even if not all of the concepts are considered in the respective lecture. If two or more sufficiently distinct sub-domains can be identified, a separation into a respective number of specialized concept inventories, similar to continuous and discrete time for signals and systems can be considered.

A. Categories of the Robotics Concept Inventory

Analysis of textbooks, curricula and course syllabi (e.g. [12, 13, 14, 15]) reveals the following list of general concept categories for robotics education:

- Math / Numerical methods
- Mechanics
- Control Theory
- Stability
- Kinematics
- Dynamics
- Sensing
- Perception
- Planning
- Navigation
- Decision-making
- Uncertainty

The 'math' and 'numerical methods' category covers all concepts related to the mathematical foundation and its application to realising robotics applications. Robot mathematics is specifically related to linear algebra as well as differential equations. Representation of multi-parameter properties, e.g. position and pose of an object in space, by means of vectors is a crucial concept. Furthermore, there should be an understanding of aggregating relations and mappings into systems of equations and matrixes and tensors. Numerical Methods are required to efficiently solve complex calculations and algorithms. In addition to real-time

constraints, in the field of robotics complexity may also be considered in view of available resources and energy to carry out certain mathematical calculations.

The 'mechanics' category covers all aspects of Newtonian mechanics. Students should have a clear concept of forces and torques, and the notion of systems. They should understand how displacement, speed and acceleration relate to each other and they need to be aware of the basic mechanical elements (mass, spring and damper), both in a linear and rotational configuration. This would lay the base to judge the basic physical behaviour of the mechatronic system of a Robot. This category may be extended to the concepts of typical robotic actuators that generate force or torque for locomotion, to articulate robot elements or grasp objects.

Robots can be considered as mechanical actuators. Therefore, the basic concepts of 'control theory' need to be part of a robotics CI. One aspect would be the principle of close loop control to change system properties in a favourable way.

'Stability' can be addressed in a number of contexts. In covers mechanical stability that keeps a robot from falling, control theoretic stability that keeps systems from un-intended oscillation and the stability notion of decision making, to consequently follow a plan.

'Kinematic' concepts are required for intentional behaviors of complex mechatronic systems, like robot arms and for motion planning of mobile robots. Kinematics has some links with mathematics, specifically systems of linear equations and trigonometry. It also addresses questions like degrees of freedom, kinematic chains and concepts that lead to conventions like the Denavit-Hartenberg model.

'Dynamics' specifically covers the field of rigid body dynamics and dynamic behavior. It introduces force and momentum into the analysis, design and control of robots. This category can be considered as basically linked with mechanics and math. However, even only for organisational reasons, it deserves a distinct category

'Sensing' of physical parameters includes signal estimation and filtering. It also includes considerations on statistics. These are crucial concepts in the field of robotics. One of the main misconceptions about sensing in robotics is taking measurements for face value and not questioning information content and reliability of the readings. The motivation and concept of Kalman-filtering may serve as an example for importance and the difficulties related to this category.

'Perception' can be seen as the level above sensing that turns sensor data into a model relevant for planning and decision-making. It requires identification of points and objects of interest as well as their high-level inter-relation. This category may also include aspects of computer vision, possibly sharing with the sensing category, however, it is expected, that computer vision would be a domain that can be separated for being applicable to other fields as well. A key concept of perception could be to identify preferably orthogonal properties of objects.

'Planning' includes a number of basic concepts that should be understood to derive complex activities. Path planning is

among the well-known planning tasks in mobile robotics, trajectory planning is the respective task for industrial robotics.

#	Category	Concepts
1	Math	Transformation between different coordinate systems: select the transformation matrix that transfers a point from one coordinate system to another
2	Math	Time shift: given a plot of p[n], select the plot of p[n+1]
3	Math / Numerical methods	Difference equations: Given a sequence of equidistant distance measurements, select the values for speed and acceleration
4	Numerical Methods	Linearization: Given a curve, select a suitable stepwise linear representation
5	Mechanics	Spring-mass-damper system: give a specific configuration, select the steady-state configuration
6	Mechanics	Robot control: select a suitable configuration of a differential drive wheeled robot that would follow a specific trajectory
7	Control Theory	Control parameters: Identify the a most suitable control response for a specific task
8	Stability	Static stability: Given a set of rigid bodies on different slopes, select the (un) stable one
9	Kinematics	Trajectory: given a differential drive robot with both wheels rotating at different speed with a fixed ratio, select the trajectory the robot takes
10	Kinematics	Building space: Given a specific robot arm configuration, select the sketch of the space the robot can reach with its tool
11	Dynamics	Motor momentum: given four robot configurations, select the one that requires the lowest motor momentum for a given task
12	Sensing	Drift: Assume a measuring system that adds a fixed, ever increasing value to the measured value, determine the time after which the measurement will be unreliable.
13	Perception	Object properties: Given a four different objects, determine the number of properties to identify the objects
14	Planning	Path planning: given a specific environmental configuration (obstacles and path), derive a suitable cost function that describes the situation
...		

Fig. 4. Tentative table of robotics CI

'Decision-making' is an important aspect for autonomous robots. It is related to the field of artificial intelligence, however in the context of a robotics concept inventory it may only cover the very basic ones. Possibly, decision-making concepts are candidates for a separate AI concept inventory.

'Uncertainty' in the field of robotics is one of the most crucial categories, as could be observed in many teaching situations. It is related to sensing and perception, however it may need to be considered as a separate category for its fundamental importance. In the field of mobile robotics a large degree of uncertainty is introduced, may this be uncertainty about sensor data or the effect of actions, e.g. due to unintended slip of robot wheels on the ground. Even, in the field of industrial robotics with high repetition precision students need to be aware of the possibility of a missing work piece and appropriate actions for example.

B. Robotic CI Details

Based on our underlying considerations, sketched in the previous section, we now present a non-exhaustive list of concepts we consider relevant for the field of robotics (figure 4). The list is intended as a trigger for a broader discussion within the robotics education community and should by no means be considered as finalised. However, the authors intend to start acquiring experience based on the preliminary set presented here.

The concepts and related questions, except for question 6 (figure 5) are not detailed further to avoid spreading the questions for test-driven preparations among students, which may affect long-term viability of the test results. However, the underlying concepts should be immediately obvious to robotics educators and should not affect the discussion.
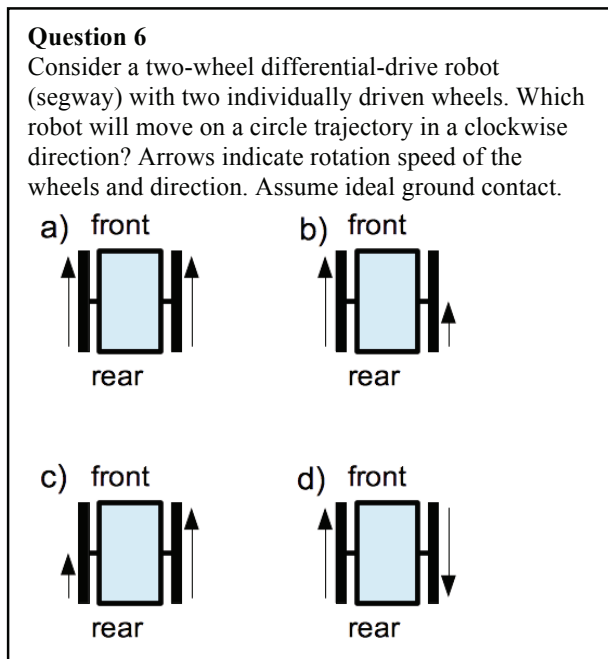
Question 6
Consider a two-wheel differential-drive robot (segway) with two individually driven wheels. Which robot will move on a circle trajectory in a clockwise direction? Arrows indicate rotation speed of the wheels and direction. Assume ideal ground contact.

Fig. 5. Question 6 of tentative robotics CI

The test items are intended to gradually evolve, based on the discussion among and contribution by robotics educators. It is expected, that following the discussion, a small number of robotics concept inventories to cover different sub-domains of robotics will evolve. However, to start with improving robotics teaching, a single CI to cover the most crucial aspects may be sufficient.

IV. CONCLUSIONS

In this paper we presented a first robotics concept inventory skeleton to assess teaching and learning quality. We started by defining a number of categories for our concept inventory. Then out of these categories, we crystallized a comprehensive list of concepts.

We will use this robotics concept inventory to assess the teaching quality in our courses and to improve the concept inventory itself.

The in our paper generated concept inventory is far from being finished. Readers are explicitly invited to comment and to contribute on still missing concepts.

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Mattie Robot - A white-box approach for introducing children with different interests to robotics

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Abstract—**"Selective exposure" in educational robotics renders activities playful and keeps children motivated; however, it also influences children's images of real robots and their expectations of technology development. We designed the Mattie robot as an educational robot for children aged 11 to 13 using everyday materials and easily accessible electronics (white-box approach). Children are introduced to five different areas of robotics based on their interests and actively participate in the integration of these domains to construct a robot. Mattie robot has been employed in a pilot project in seven junior high school classes with over a hundred students. Feedback is very positive: students like it; teachers would appreciate yearly workshops with the robot.**

I. Introduction

When teaching robotics in a classroom, educators have to consider different interests and levels of students: not everyone is fascinated by STEM subjects. However, robotics is broad enough [1] to attract all students if it is also presented from other perspectives like design or social sciences. Additionally, many introductory robotics activities use black box approaches, where the more complex parts are hidden from the children, so they focus on specific tasks, e.g. locomotion or navigation. This technique - "selective exposure" - renders activities playful and keeps children motivated, prominent example LEGO Mindstorms [2]; however, it has its shortcomings in education (oversimplification and concealing of inner workings) as pointed out by Resnick and Silverman [3].

Why not expose the more complex parts in order to show children that "real" technology is usable? We have developed Mattie robot to address two areas: (1) attract children to robotics who are not interested in STEM and present robotics as a broad interdisciplinary field; and (2) demonstrate that "real" technology is accessible.

II. Mattie Robot

The robot is designed to be used in classroom workshops for children at ages 11-13. The students are split into four to five groups of three to five students. Each group works on a specific part of the robot, described in more detail below. In the end, all of the parts are combined to a functioning simple robot, which can be remote controlled, follows light and talks on user interaction. We address different interests by having five different tasks and perspectives to robotics. This way, we are able to include the children who are not interested in the technical aspects of robotics.

Mattie robot is also designed to demonstrate that "real" technology is accessible. We use commercial microcontrollers and sensors, provide the students with information on these parts and where to acquire them. The inner workings of the robot are all observable to pique the children's curiosity. This approach is in contrast to the general development of technology, where most of the complex parts stay hidden.

We have employed Mattie robot in a pilot project with seven junior high school classes (over 100 students). The whole workshop concept is described in [4]. Each class has two workshops with two hours each. In the first workshop, the class works on the robot from four or five different perspectives (engineering, research & development, human-robot interaction, design and optionally sales & marketing). In the second workshop, the class integrates the robot parts, demonstrates the robot and its functions, evaluates the robot from technical and user perspectives and presents the results.

A. Engineering

The chassis is built from a wooden plate. For locomotion we use two motors with wheels controlled by an Arduino board and a motor driver, as well as a ball caster. The task for the students is to connect the electronic parts using jumper wires, a breadboard and step-by-step instructions. In the end the robot can be remote controlled and has the ability to follow light. We programmed the microcontroller beforehand because of time constraints. In an expanded workshop, students can also work on this. This is a classic technical assignment with a predetermined goal that has to be achieved. It is aimed at those children, who need these boundaries and definitions of a task.

Overall the students quoted that they enjoyed driving around with the robot the most. They also liked connecting the components. Although we had mixed classes, not a single girl chose this task. As Buechley pointed out, girls rather pick up interest in engineering and computer science from a creative direction [5]. We also think that friends tend to stick together, so some girls may have followed their friends to another group.

B. Research & Development

In this task children learn about various sensors. In a wooden box six sensors are connected to a display which shows the current sensor readings. Students have to identify the different sensors by stressing them and think of possibilities how to use these sensors on a future robot prototype.

The students get acquainted with real sensors and learn what to do with sensor readings - a number which represents a voltage. The cognitive performance is to interpret this number and process it. The students in this group are researchers who

develop new things. After learning about sensors, they help the engineering team choose the right sensors for the Mattie robot to follow light. They discuss how to use the other sensors on the robot and what additional sensors can be developed.

Although this is a rather theoretical assignment, without an immediate sense of achievement, the overall response was positive. After reviewing, we added an additional task, because the first groups finished this assignment quickly. We decided on a more practical task: the students have to connect a tilt sensor with a LED and test it as a possible anti-theft solution.

C. Design

The task of this group is the design of the robot. To do so, the children get the cylindrical case of the robot and simple materials like clay, felt and paint. Before the group can start tinkering, they need to decide with the other groups what the robot is for and for whom they shall design it. They also have to define the role of the robot (friend, butler, teacher or pet). We use role as a paraphrase for the more complex concept of behaviour. The design should match this role.

It was very difficult for the children not to start right away with the tinkering. They had to plan things out first. It took them some time to coordinate with the HRI and S&M groups to decide on what the robot should do and which role it could represent. The limitations of the material forced them to be more creative. These limitations disappointed some children and the overwhelming task at the beginning frustrated them. At the end they could accomplish the task satisfactorily which empowered them. One comment of a girl: "Finally, we managed to do something almost on our own, without the teacher helping us that much."

D. Human-Robot Interaction

In this task the children create a speech output for the robot. In order to do so, they design an interface and record sound files. All these things have to match the design and role of the robot. The interface consists of different buttons, which the children draw on the top of the robot using conductive paint. In Figure 1 these buttons can be seen. The buttons can also be made from other conductive material like tin foil. A capacitive touch sensor registers if a button is touched, and the robot plays the previously recorded sound files.

This team had the same starting problems as the design team. Eventually, they agreed on the robot's role and then decided on what it should say. The children liked recording the sound files. Many wanted their robot to play music which was not possible, so some came up with a creative solution: they recorded while their phones played their favourite music.

E. Sales & Marketing

This group is optional for interested children and classes with more than 20 students. The students define a target customer group and the tasks of the robot along with its design and behaviour. They have to coordinate their ideas with the design and human-robot interaction groups. They learn about the 4 Ps of marketing (product, price, place, promotion) and think of a strategy for their product.

We have positive experiences in the classes that had a S&M team. This team was able to coordinate the other teams to reach a common goal, so it was easier to get a concept for the robot.
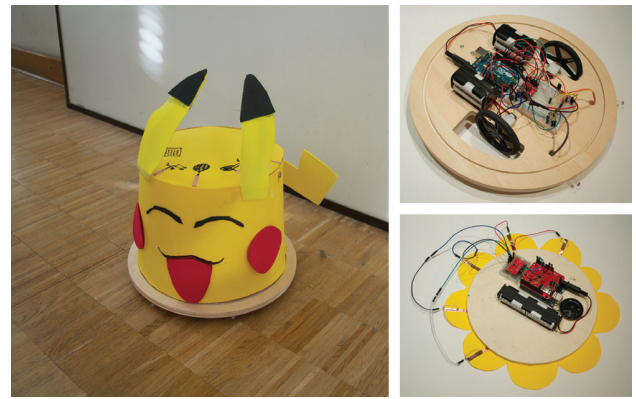

Fig. 1. A finished robot on the left, chassis and speech output on the right

III. Conclusion

The Mattie robot is used in classroom workshops to introduce children to robotics. It addresses the different interests of children by having them work on different parts and combining them in the end to a functioning robot. This way, they learn that robotics is more than STEM, and the importance of teamwork. The used technology is made visible to overcome the students' reluctance and pique their interest. It is simple enough, thus manageable by children with sufficient instructions.

Currently we are evaluating the results of the first workshops. The feedback of students, teachers and parents is mostly positive. Teachers report that they would be comfortable, doing the workshops on their own because the technical parts are simple and the provided documentation is sufficient. They told us about parents who wrote them about their children returning home inspired to explore robotics. Even students from other classes approached the teachers and asked to participate.

However, there are aspects that can be ameliorated, e.g. the briefing of the students before the workshop defines their expectations of the workshop. In future, we will work on similar improvements and are planning to adapt the concept for other age groups.

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Mattie Robot - A white-box approach for introducing children with different interests to robotics

Matthias Hirschmanner, Lara Lammer and Markus Vincze

Goals

- Attract children with different interests to robotics, especially those who are not interested in STEM
- Expose the inner workings and different parts in order to pique the children's interest.
- To use the robot in classroom workshops with children at ages 11-13

Robotics as a broad interdisciplinary field

When teaching robotics in a classroom, educators have to consider different interests and levels of students: not everyone is fascinated by STEM subjects. However, robotics is broad enough to attract all students if it is also presented from other perspectives like design or social sciences. We designed Mattie Robot to address different interests of children by having five different tasks and perspectives to robotics. The students are split into four to five groups of three to five students. Each group works on a specific part of the robot - engineering, research & development, design, human robot interaction, sales & marketing. In the end, all of the parts are combined to a functioning simple robot, which can be remote controlled, follows light and talks on user interaction.

White-box approach

Many introductory robotics activities use black box approaches, where the more complex parts are hidden from the children, so they focus on specific tasks, e.g. locomotion or navigation. This technique - "selective exposure" - renders activities playful and keeps children motivated. However, it has also its shortcomings in education. We demonstrate that "real" technology is accessible for children by using commercial microcontrollers and sensors, and exposing them. We provide the students with informations on these parts and where to acquire them. This way we try to pique their interest and overcome the reluctance to use electronic components.

Workshop Concept

Mattie robot has been employed in a pilot project with seven junior high school classes. Each class has two workshops with two hours each. In the first workshop, the class works on the robot from four or five different perspectives. In the second workshop, the class integrates the robot parts, demonstrates the robot and its functions, evaluates the robot from technical and user perspectives and presents the results. The students are split into four to five groups:

Engineering - This group has to connect the electronic parts of the chassis using jumper wires, a breadboard and step-by-step instructions.

Research & Development - In this task students learn about various sensors. They have to identify the sensors by stressing them and come up with uses for them.

Design - The task of this group is the design of the robot. To do so, the children get the cylindrical case of the robot and simple materials like clay, felt and paint.

Human Robot Interaction - The students in this group create a speech output for the robot. They design an interface and record sound files. The interface consists of different buttons, which are drawn on the top of the robot using conductive paint.

Sales & Marketing (optional) - The students define a target customer group and the tasks of the robot along with its design and behaviour.
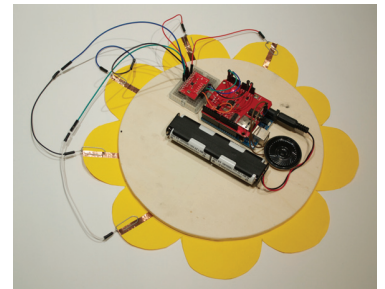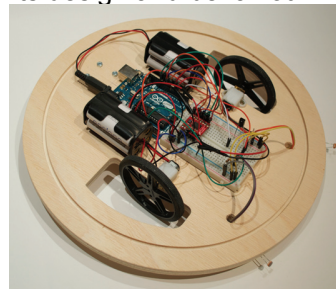
Cognition, to define alternative worlds and possible futures, visions, thus triggering anti-causal actions

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Abstract. **At the current moment of developing more capable robots, cognition appears as a crucial faculty to harness, i.e. to implement on machines; this is the field of cognitics. As a mirror effect, what is learnt about cognition for the purpose of machines also affects the way we may recognize its role for ourselves as humans. This is of paramount importance in education and academic contexts. Cognition is not bound to address only models of physical reality, even though it remains necessarily implemented on real-world, physical infrastructure. Thus cognition has the extraordinary capability to define alternative conceptual worlds, assumptions, and possible futures. A special attention should be given here to "visions", those immaterial constructs, models, capable to inspire and trigger the autonomous action of cognitive systems, typically humans today. Thus the model item that is proposed here for effective results both in technical and in human sciences is the one of anti-causality. This is in full contrast to usual models in physical world, yet provides a very natural foundation for establishing freedom, viewed independently from the reality immediately perceived.**

Keywords—robotics; cognition; cognitics; education; academic role.

I. INTRODUCTION

Cognition per se did not receive yet the scientific and technical attention it should, in view of the importance it has proved in the evolution of mankind, from the early times a million years ago to the recent boost of our highly developed societies in terms of information processing and communication. After all, it is well cognition that appears as the key factor for the privileged ecological niche humans have crafted for themselves in the known universe.

In order to contribute to an improved situation, five theses relating to cognition have been published recently [1], and the current paper extends the second of them, as shown in title.

Cognition is mostly ensured in humans by neural resources located in the brain. This relates to the implementation material however, the "hardware" in reference to computer infrastructures. Some famous Ancient Greece philosophers though, in particular, thousands of years ago, went further to refer not only to those physical structures but also to the immaterial processes they support. In that sense, their early reflections in the domain of psychology were close indeed to cognition, as we advocate it here, yet it did not address it

directly. On the contrary, psychology was a part of philosophy, which at that time was rather universal in scope.

In AI, the problem has maybe been reciprocal, whereby it is one of the purely immaterial cognitive entities, intelligence, that has been set in the focal point, and thereby the complementary role of physical reality, as well as the necessary bridges between physical ("real") and cognitive worlds have been too neglected. Turning their back to the unavoidable particulars of the physical reality, the most extreme advocates of AI are searching for an even more "general" AI than it is commonly the case.

Looking at the scientific literature, it appears that classically neither in philosophy nor in AI, cognition has been precisely defined, or measured in its own specific, essential, quantitative terms. There may have been some proposals (e.g. at least the MCS theory of cognition [2] but none of these is widely recognized yet. MCS has been made for the purpose of carry cognition over to machine-based infrastructures, in particular, robots; thus to implement automated cognition, a scientific and technical field named as "cognitics").

Quantitative considerations made possible by the MCS theory of cognition have already shown that cognition critically requires a focus on selected elements of reality, implies modeling. Now the thesis presented in this paper states that in fact, this constraint means also freedom; it requires the selection of future goals, which may allow for the necessary modeling process and, by anti-causal effects, for the cognitive elaboration of necessary planning steps and preparative actions.

Cognition relates to the "Robotics and Education" theme in two ways: on the machine side, for better robots, and on the human side, for better education.

The paper is organized as follows. Section 2 shows that cognition typically involves models relating to physical reality; but not only that. Notably, as shown in Section 3, cognition has the extraordinary capability to define alternative conceptual worlds, assumptions, possible futures. Section 4 refers to a particular kind of future related models, those corresponding to well-defined, elaborate future goals, "visions". Section 5, finally before conclusion, advocates for cognition a model very different of what is common in the physical world, anti-causality, i.e. the property of causes to have effects before their intended occurrence, which is but a very minor aspect of the dimension-free, limitless, capabilities of cognition.

II. COGNITION TO ADDRESS MODELS OF PHYSICAL REALITY; *AND MUCH MORE*

The real world tends to impose itself and it is infinitely complex. Yet for practically any goals, experience shows that specific, very crude, partial representations, i.e. by definition, models, suffice to support cognition, and thereby, to let living and machine-based, operational systems successfully act and manage those goals.

Cognition however is *not* bound to address only models *of physical reality*.

In fact modeling is already a process where, by essence, reality is not completely and necessarily "truly" represented. In fact with MCS metrics it is now shown that quantitatively, the completeness degree of any model tends to zero. Priority is given, in the modeling process, to "goodness", to the property to help reaching the specific, corresponding goals the model has been made for.

Thus modeling generates arbitrary, "ideal", cognitive worlds in infinite number and variety. In the current reasoning, incompleteness and errors with respect to reality are the causes for this variety, and pragmatism most usually justifies them.

III. EXTRAORDINARY CAPABILITY TO DEFINE ALTERNATIVE CONCEPTUAL WORLDS, ASSUMPTIONS, POSSIBLE FUTURES

In the cognitive world, which is a world made of models, the limitations of physical world do not apply. Nice examples include cartoons, and dreams, where, among other phenomena, gravity, or time direction do not follow the same laws as nature.

A notable benefit of modeling, and more generally, cognition, is to make possible the basic trial and error paradigm in the search for solutions, possibly without the limits inherent to real world, and possibly without the virtual costs that negative outcomes would yield.

Therefore cognition has the extraordinary capability to define alternative conceptual worlds, assumptions, possible futures.

IV. "VISIONS", CAPABLE TO INSPIRE AND TRIGGER THE AUTONOMOUS ACTION OF COGNITIVE AGENT

Among the conceptual worlds that cognition allows, as alternatives to current reality, a particular class is formed by potential, future worlds. For humans, dreams and nightmares fall into this category.

In general, "visions" refer to such models, sketching more elaborate views of assumptions and potentially future worlds.

This becomes extremely interesting in cognitive worlds, especially as the additional property of direction-free time dimension prevails.

Thus, cognition can generate visions, which in turn can inspire and trigger the autonomous actions of cognitive agents, leading to anti-causal processes as developed in next session (re. enclosed poster, with credit to Pierre-François Gauthey).

V. ANTI-CAUSALITY , FREEDOM AND POSSIBILITY TO STEER WORLD CHANGES

The real world seem to teach us the irreversibility of time, a reliable model by which the past is forever over, and the future always yet to come; past and present causes have future consequences. Time denotes permanence and proceeds on a positively oriented direction. In its extreme state, this model ensures determinism and, in particular for humans, appears to deny any possibility of freedom.

Yet as Parmenides states it "what is, is". Reality is there, and all is said. Any possible dimension, such as time, is just a possible attribute of conceptual models.

And anyway in cognition, physical limits do not apply. A more appropriate model to adopt there is the one where time can be freely visited, in direct or reversed direction, just at will.

Thus freedom is easily defined in cognitive worlds: an arbitrary goal can immediately be set in any convenient future (e.g. RiE 2015 in May), then stepping backward from there, the appropriate actions can be planned so as to make it finally happen; in the real world. This is anti-causality. The goal set in a future point in time causes prior, including present, and, as time passes, possibly already past actions, most often successfully steering the appropriate world changes.

In his theories, Kant has somewhat similarly linked freedom to a transcendental rational source rather than to the perceived reality [e.g. 3]. In our words, it is just an alternate set of models that should be considered, depending on current goals, contexts and applications.

VI. CONCLUSION

Cognition appears as a crucial faculty to harness, i.e. to implement on machines; robots. As a mirror effect, this also affects the way we may recognize its role for humans, which is of paramount importance in education and academic contexts. Cognition is not bound to address only models of physical reality, and has the capability to define alternative conceptual worlds, assumptions, and possible futures. A special attention is given here to "visions", capable to inspire and trigger the autonomous action of cognitive systems, by anti-causality, a very natural foundation for establishing freedom, viewed independently from the reality immediately perceived.

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RìE 2015

J.-D. Dessimoz, HESSO.HEIG-VD, RiE 2015, 6th International Conference on Robotics in Education, 21-22 May 2015, Yverdon-les-Bains, Switzerland
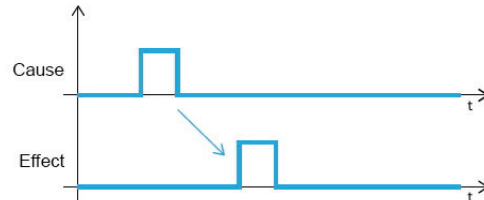
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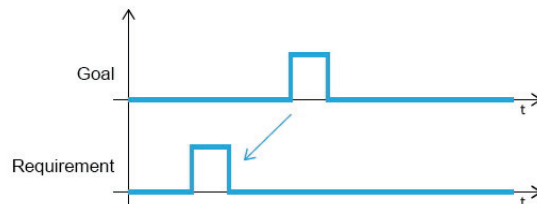

Left, «reality».
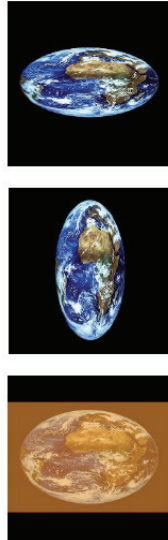
Right, examples of variations freely allowed for consideration in the cognitive world.

Causality model, appropriate for physical world: causes cannot have consequences in the past; effects can only happen in the future

Anti-causality model, appropriate for cognition: causes do have consequences in prior (negative time) moments; such effects of decisions allow for making the desired future happen.

- **Cognition is *not* bound to address only models *of physical reality***

- **Extraordinary capability to define alternative conceptual worlds, assumptions, possible futures;**

- **in particular "visions", capable to inspire and trigger the autonomous actions of cognitive agents, humans and robots.**

- **Along with anti-causality, this is a foundation for freedom**: an arbitrary goal can immediately be set in any convenient future (e.g. RiE 2015 in May), then stepping backward from there, the appropriate actions can be planned so as to make it finally happen; in the real world. (Re also Kant: freedom, from a transcendental rational source rather than from the perceived reality)

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- see also the accompanying paper published in the proceedings of this Conference for more details and references.

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6. Other, Selected Topics

Chairperson Michele Moro

Technology intervention in neurorehabilitation - A practical approach to teaching

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Abstract—the aging population and an increase in the demand for post injury therapy has generated particular interest in technology based solutions for neurorehabilitation. This paper presents a practice based approach for teaching design of technology for post-injury training of motor-functions. The content of the course and its implementation using designed 2-DOF planar robot are discussed here.

Keywords: neurorehabilitation; rehabilitation; mechatronics; design; robotics

I. INTRODUCTION

Neurorehabilitation is becoming an important area of research. Due in part to an ageing population, an increasing number of people are affected by neurological injuries (e.g. stroke, multiple sclerosis, Parkinson disease) resulting in sensorimotor disabilities. For instance, stroke (also referred to as a cerebrovascular accident) is the leading cause of disability for adults in the developed countries. It is estimated that the stroke affected population will increase further by 30% between 2000 and 2025 [1].

The high demand for physical therapy after neurological injuries has generated particular interest in using technology assisted systems for rehabilitation with the objectives to decrease the therapist's workload and facilitate training with minimal supervision at an affordable cost. Different types of technology-based solutions have been proposed in recent decades and have shown promising results [2]–[5]. However teaching/training students interested in technology based approach to neurorehabilitation remains a difficult challenge as designing an effective rehabilitation system demands input from multiple fields, including human centered mechatronics (the synthesis of mechanical, electronics, and computer science design) and medicine [6]. Furthermore, time constraints make it difficult to incorporate all the factors in a semester of graduate studies.

From a practical perspective, one possible approach for introducing a technology based neurorehabilitation course for graduate students is by adopting currently available rehabilitation systems. Robots such as MIT-Manus can serve as a basic platform and guide for students to investigate and implement different components of an effective rehabilitation regime [7]. However, most current systems are very expensive and they are generally not affordable for use in an educational environment.

At Nanyang Technology University (NTU) we have developed a low cost, portable actuated system for training horizontal arm movements, hereafter named H-MAN (figures 1 and 2). Its simple design is particularly suitable for rehabilitation in decentralized environments, such as patient's home or in small clinics. In this paper we present how the H-MAN can be used as an effective tool for teaching technology interventions for neurorehabilitation. The following section of the paper provides an overview of the H-MAN device followed by a detailed description of the course.
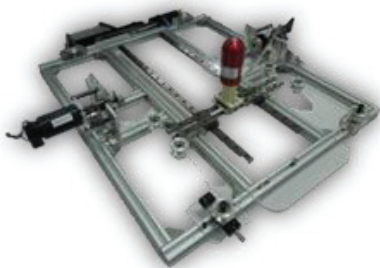

Figure 1: A planar two degrees of freedom end effector robot, H-MAN.
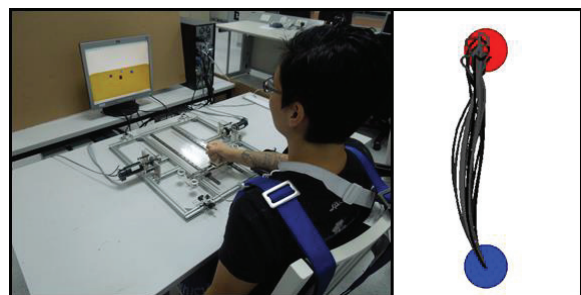

Figure 2: (Left) a participant using H-MAN for training reaching tasks. (Right) Position data collected from HMAN as the subject moves from start to final position.

II.   H-MAN - OVERVIEW

H-MAN is a compact, portable planar robot designed for the rehabilitation/training of arm planar movements (see figures 1 and 2). It can provide forces of up to 30 N at the end-effector (handle) in any specified direction on a planar surface to assist or resist the motion of the user and can be easily built using off the shelf components. The reader is referred to [8] for a detailed description of H-MAN hardware.

Here we discuss H-MAN from a software perspective. For teaching purposes, the H-MAN software interface is divided into three independent units: 1) the workstation, 2) the real-time controller, and 3) the display unit. Each one of them can be further divided into independently programmed sub-units (figure 3). This modular approach is particularly desirable for teaching/learning about the different components of rehabilitation devices without worrying about the whole setup. This also allows groups of students (with different backgrounds) to work in parallel on different components of rehabilitation. The functionality of each unit (sub-unit) is discussed in the following paragraphs.

The user interface is a graphical environment to facilitate participant interaction with H-MAN. It is used for selecting appropriate therapy or assessment routine relevant to each patient. It can also be used to provide feedback regarding performance improvement from previous and current sessions. For H-MAN, the framework for the user interface is programmed on the workstation (PC) using MATLAB's graphical user interface (GUI-Guide tool). The interface serves as the front end for the H-MAN system.

An algorithm is responsible for adapting the H-MAN controller in accordance with the performance of the user. For this purpose it uses the information from the user interface and performance of the participants during the previous trial(s). Various algorithms can be implemented based on the therapy requirements and or preference such as those used in other robotic therapy platforms [9], [10]. The workstation passes this information to the real-time control unit to update the control policy.

The real time controller is responsible for controlling the behavior of H-MAN in real time during a trial. Currently the controller is implemented on Quanser QPIDe (Quanser Inc.). As with the adaptation algorithm, the implemented real time controller can be altered depending on the requirements. For example, it can be a simple proportional-integral-derivative controller (PID) or a relatively complex assist-as-needed controller [11], [12]. In any case, the parameters of the controller can be adjusted after each trial via the adaptation algorithm. This approach is adopted to limit the amount of real time processing. This post-trial adaptation also affords the possibility to keep the controller simple, and hence allows for possibility of controller implementation using a microcontroller.

Quanser QPIDe, the real-time controller platform, communicates via transmission control protocol (TCP) with the display unit running on a PC/Mobile device/Tablet. The visual interface can be any therapy-relevant game and can be designed in any programming language and/or gaming engine. Currently the commercially available gaming engine *Unity* is used for interfacing. That said, due to the generality and widespread adoption of TCP, any graphical interface can be used.

The feedback block shown in figure 3 can manifest as many varieties of information. For example, proprioceptive feedback provided by the real-time controller in the form of a force field, or tactile feedback using external vibrators to provide haptic cues for guidance. Similarly, the display unit can be used to give visual and auditory feedback, both during and after each trial.

III.   NEUROREHABILITATION TECHNOLOGY COURSE

The proposed neurorehabilitation technology course is designed to be an elective course (13 weeks, 2 hours of lectures plus 1 hour of tutorial sessions) for final year undergraduate and master's students at Nanyang Technology University, Singapore. The course will be offered to students with a background in Electronics, Mechatronics and Computer Engineering. During the course students will learn (through practice) how technology can be used to improve the quality and quantity of rehabilitation.

Course participants will initially attend 4-5 weeks of lectures to develop a basic understanding of neurorehabilitation, including a broad overview of the literature to date on rehabilitation and assessment using robotics, conventional approaches to rehabilitation, different feedback methods, game design for inducing motivation, etc. Students will also learn how to use H-MAN during this time (table 1).

Following the lecture sessions, students will carry out practical work for the remaining weeks. Each group (4 or 5 students per group) will work on designing a complete working rehabilitation system using the H-MAN platform followed by a
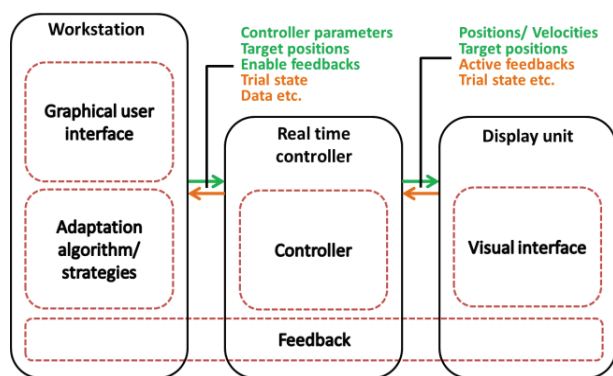

Figure 3: The H-MAN software interface is divided into three independent units, 1) the workstation, 2) the real time controller, and 3) the display unit

Quarter/Description	1st	2nd	3rd	4rth
Lectures				
H-MAN training				
Practical work				
Demonstration				

Table 1: Gantt chart giving a general overview of the course flow

final demonstration. The practical work will involve dividing work within the group based on interests and background to cover the different topics of rehabilitation; each of the main topics is briefly discussed in the following sub-sections.

A. Robotic movement control strategies

Control strategies in the rehabilitation of motor function broadly refer to how the robot and participants' limb physically interact during movement training. Multiple types of robotic strategies are used in rehabilitation, including 1) *assistive strategies*, where the participant's limb is moved in the desired manner by the robot to accomplish the task, 2) *challenge-based*, where the task is made more difficult by introducing resistive forces, 3) *haptic-simulation*, where virtual haptic fields are generated to imitate activities of daily living in a virtual environment [11]. Depending on the component of health being trained (impairment, activity and participation; defined by International Classification of Healthy and disability [13], [14]) and patient (type of injury and its severity) a version of these control strategies can be adopted.

The type of implemented control strategy can greatly affect the outcome of rehabilitation. Hence it is vital that students have a proper understanding of robotic control algorithms/strategies and their design. Students will be encouraged to implement different types of control strategies (e.g. assistive, challenge-based, haptic simulation) on H-MAN and observe their effects. Students will work on one or both the main controller and the adaptation algorithms to carry out this task.

B. Feedback strategies

Feedback strategies in rehabilitation can be broadly divided into two major types: 1) *intrinsic feedback*, which guides the subject about the task during its execution using one or combination of visual, auditory, proprioceptive, and tactile feedback components; and 2) *extrinsic feedback*, which refers to feedback to indicate the subject's performance and results [15]. Results refer to the type of skill the participant has achieved and trained for, while performance indicates the performance in the actual training exercise. Different types of approaches can be used for extrinsic feedback (e.g. computer generated verbal encouragement, charts, videos, avatars).

Choosing patient specific feedback is complex, can vary with the subject, and can greatly affect the performance of subject. Through implementation on H-Man, students will investigate which types of feedback to offer during task execution as to not distract the participants, while still guiding the subject to maintain task performance quality. Similarly, students will be encouraged to implement different methods by which task relevant results and performance parameters can be displayed.

C. Motivational Strategies

Rehabilitation professional consider motivation to be an integral component of (re)learning [16]. From a rehabilitation perspective, subjects' motivation is generally assessed on how actively they participate in the task and adhere to the rehabilitation regimen. Similarly, lack of interest during

therapy relates to participants demotivation [17]. Multiple factors contribute to motivation, including personal traits, social factors, and most importantly the task itself.

From a task perspective, it is crucial that the designed task is fun and interesting for the participant. This characteristic can be achieved by designing engaging and fun games as a part of therapy, considering that that task must not be so simple or repetitive to bore the subject, nor too difficult so as to demoralize the subject. The designed task should also adapt optimally with participant performance. Furthermore, independence in selecting feedback, time of therapy and the general control over therapy induces active participation and hence motivation [15].

Students will be encouraged to design innovative interactive games (on the display unit) for H-MAN using commercially available gaming engines, with primary focus on difficulty adaptation and ease of use. Students will also implement routines to offer varying degree of independence to the participants during therapy.

D. External Sensor Integration

External sensors refer to information that is generally not directly available from the robotic systems. In the case of H-MAN information regarding the muscle activation produced by skeletal muscles which can be measured by Electromyography (EMG). This information can be useful in multiple ways. For example, EMG can be used to trigger robot-assisted motion by, based on the activity of muscles responsible for that motion [18], [19]. Other devices, such as motion capture systems and force/torque sensors, can be used to extract relevant kinematic and kinetic information, and can be used to assess and provide feedback about the performance, and/or to improve or refine the control of the robot for maximum therapeutic effects.

Students will learn to use the EMG system, and will synchronize EMG data with that obtained by the H-MAN system, in order to extract task specific information. This information will be used in order to provide feedback to the patient regarding maladaptive compensatory movements. The objective of this work will be to enhance the quality of therapy by evaluating muscle activation patterns during task performance, and/or to develop algorithms to enhance the quality of the controller to ensure optimal participation from participants.

E. Data analysis and Statistics:

Understanding how to treat data, process inspect, clean, and transform data into meaningful information for reaching conclusions is arguably the most crucial component in any form of research, and neurorehabilitation is no exception.

During the term, students will learn how to extract and analyze information gathered using H-MAN and/or other attached instrumentations (sensors). Students will learn how to define appropriate (in) dependent variables, perform parametric and non-parametric statistical analysis, and draw appropriate conclusions based on the results. Furthermore, students will learn how to interpret the significance of these results, and their contribution to the field of neurorehabilitation.

IV. ASSESSMENT APPROACH

Instead of traditional exams, this course will be evaluated by a combination of practical work and submitted reports, both of which carry a weight of 50%. Students will submit a set of reports, consisting of: 1) *A critical review* where individual students will submit a report on another group project from a critical perspective i.e. they will highlight the issues and advantages of the approach adopted by the group; 2) *Rehabilitation components,* in which individual students will submit a detailed report on one of the sub-topics of rehabilitation discussed previously i.e. feedback, control strategies; and 3) *A project report,* in which each group will submit a detailed report on the complete project with details of work carried, and the adopted approach and reasons behind it.

Finally the practical part of the course marks will be assessed by the assessment of the developed complete systems (counting for 50% of the course mark, one mark by project's group) (table 2). Projects will be assessed in terms of the therapeutic relevance of the chosen design as well as its implementation by a panel of invited rehabilitation and engineering design experts. Non-specialist guests and the students themselves will also be able to assess the projects and their marks will be combined with the judges' at a reduced weighting. This approach of assessment is similar to the H-CARD course recently developed at Imperial College [6].

	Percentage	Submission type
Critical review	15%	Individual
Rehabilitation	15%	Individual
Project Report	20%	Group
Demonstration	50%	Group

Table 2: An overview of the course assessment

V. CONCLUSION

This paper presents an engaging project based approach for educating student's interested in technological solutions for neurorehabilitation using H-MAN. The planar robot provides a low-cost alternative to currently available expensive rehabilitation systems and its modular software design approach makes it potentially feasible to teach different components of technology intervention in neurorehabilitation in a semester course.

As future work we also aim to let students investigate, multiple different therapy regimes involving interaction between patients (patient-patient interaction) and or patient-physiotherapist interaction. The techniques can be implemented using a combination of H-MAN's, where each patient/physiotherapist uses an H-MAN linked to the others by a student defined algorithm that promotes learning. However details of this are not in the scope of the paper and will be discussed in future studies.

ACKNOWLEDGMENT

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Learning to Program Mobile Robots in the ROS Summer School Series

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Abstract—**The main objective of our ROS Summer School series is to introduce MA level students to program mobile robots with the Robot Operating System (ROS). ROS is a robot middleware that is used by many research institutions worldwide. Therefore, many state-of-the-art algorithms of mobile robotics are available in ROS and can be deployed very easily. As a basic robot platform we deploy a 1/10 RC cart that is equipped with an Arduino micro-controller to control the servo motors, and an embedded PC that runs ROS. In two weeks, participants get to learn the basics of mobile robotics hands-on. We describe our teaching concepts and our curriculum and report on the learning success of our students.**

I. INTRODUCTION

The main objective of our ROS summer school series is to introduce MA level students to program mobile robots with the Robot Operating System (ROS) [1]. As a basic robot platform we deploy a 1/10 RC cart that is equipped with an Arduino micro-controller to control the servo motors, and an embedded PC that runs ROS. Besides us being passionate about mobile robots, we believe that we enable students to deal with some key future technologies as we try and outline in the following.

Why are mobile robots important for future university graduates in Computer Science, Mechatronics, Mechanical Engineering?
Under the topic cyber-physical systems (physical entities that have a computing or network communication unit attached to it), mobile robots will be ever more important in the factories of the future. While the customization of products will become a huge issue in the future, mobile robots will have to step in and help with logistics tasks in the smart factories of tomorrow. It is sometimes called the fourth industrial revolution; the first came with the invention of the steam engine, the second came with the invention of the assembly line and the third came with the computer and the Internet. Now we are facing the fourth industrial revolution. Production is changing right now and is going to change dramatically in the near future. Besides mass production, customized products will be more and more important in the future. This has inter alia the effect that the designer of the product will be closer together with its manufacturer and it is believed, for instance, that by 2020 10–30 % of the products that the USA are importing from China today could be produced inland [2]. The new production will be supported by so-called cyber-physical systems. These

systems combine computation with physical processes. They include embedded computers and networks which monitor and control the physical processes and have a wide range of applications in assisted living, advanced automotive systems, energy conservation, environmental control, critical infrastructure control, smart structure or manufacturing [3].

Why is it still a quite hard task to program a robot?
In [7], Brian Gerkey asks the question, why it is hard to write robot software: "The biggest obstacle to broader adoption of robotics is that only experienced roboticists can develop robotics applications. To make a robot reliably and robustly do something useful, you need a deep understanding of a broad variety of topics, from state estimation to perception to path planning. While few people in the world have this expertise, many people can write software. What we need is more of those software developers involved in the business of developing robotics applications. I say 'applications' to distinguish this work from that of developing new algorithms or core building blocks. Making an analogy to traditional software development, I don't need to understand how process schedulers, or file systems, or memory managers work in order to develop useful desktop applications. And I don't need to know the details of DNS, web servers, or web sockets to develop portable web applications. Knowing more about the underpinnings of the system will always be useful, of course. But the key is that, once the building blocks are established, understood, documented, and tutorialized, the barrier has been greatly lowered: you just need to be able to write code. [...]"

With ROS the task of developing robotic applications have become much easier. Many researchers world-wide contribute their research results as Open Source ROS packages. It was never that easy to download and run highly sophisticated robot software. However, to be able to run your robot with the different packages, still quite some expert knowledge is required. Not only do one need very good programming and system skills of the surrounding OS; to be able to set up and adapt all the parameters that come with a particular ROS package, quite some deep understanding of the subject matter is needed.

This is exactly what we are targeting with the ROS Summer School series at FH Aachen University of Applied Sciences. The participants of the Summer School get a 1/10 cart robot

that is equipped with an IMU and an RGB-D camera. For controlling the servos, we make use of Arduino-based flight controllers developed for Unmanned Aerial Vehicles (UAVs). In two to three weeks of lectures and hands-on sessions, we lay the foundations for future mobile robot developers. In the morning, the theoretical background of advanced mobile robot topics is explained. This is done in a lecture style. Additionally, we invite renowned guest speakers to present their work—related to ROS. In the afternoons, we provide guided hands-on sessions where the participants need to apply the imparted knowledge practically with making certain related ROS packages run or with implementing several high-level robotic tasks. The goal in the end is to drive the cart autonomously around a track confined by wooden curbs. These will be used to detect road borders with the RGB-D camera. The last days of the competitions are reserved for a race competition where teams of participant compete against each other. A future goal is to develop the task of driving around the track into a scaled version of the Urban Challenge Scenario. During the 2014 edition of the summer school, we had about 48 participants from 10 different countries and at least three different disciplines (CS, Mechanical Engineering, and Mechatronics).

In the next section, we will outline the hardware system which we use for our summer schools. In Section III, we give an overview of the concept behind the ROS Summer School and the topics being taught, while in Section IV, we show the assessment of the summer school's participants and discuss ways to improve the curriculum for the future. We conclude with Section V.

II. HARDWARE PLATFORM

There is a large number of robots that support the Robot Operating System (see, for instance, [8]). We decided however against using one of them for several reasons. For one, for a summer school with 40–50 participants, many of the available ready-to-run platforms are beyond the price scope. Considering that about 20 platforms (about 2 students share a platform) are required, the price becomes a major cost factor. For another, to show the participants that building a robot with available hardware components themselves is also valuable. For the selected hardware it is important that ROS drivers are available. Our decision of which hardware components to choose was based on the following criteria:

- Good Ubuntu OS support
- Low power consumption
- High processing power
- Multi-core architecture
- Open Source hardware components
- Low cost
- Robustness

ROS is best run under *Ubuntu OS*. There is a lot of support already for different Linux distributions, but a stable system is the easiest entry point for a beginner with binary ROS packages that run out of the box. As most binary packages are pre-compiled for Intel architectures, using one makes life much easier. On the other hand, Intel architectures usually have a higher *power consumption* for the mobile system and higher costs. When comparing Intel with ARM architectures, the processing power vs. power consumption is still remarkably better for ARM architectures. The price for ARM hardware is as well lower compared to Intel processors. In addition, a *multi-core architecture* with a large number of cores, e.g., from the used Odroid XU system, is well-suited for the distributed, fine grained ROS framework: most of the tasks are implemented in small programs (nodes) which are distributed over the eight cores of the used CPU. The description of the components for the mobile robot should be available to the students, so the hardware schematics and the software drivers need to be *Open Source*. Well-documented drivers for sensors commonly used in mobile robot applications such as the Asus Xtion RGB-D camera are also available. The complete system is targeted for a student budget, so it should not exceed a price of around US\$ 600, so that students can build one on their own. There are of course very *low cost* robots available— mostly based on just one micro-controller like Arduino—but they do not have an interface to common hardware components such as web cams or RGB-D cameras and have too little *processing power*. These robots cannot run all the software algorithms we intend to teach during the summer school such as SLAM, visual odometry, or navigation. The hardware for the driving system needs to be as rugged and *robust* as possible and still affordable.

Instead of building our own platform with motors, electronic speed controllers, wheels and encoders, we decided to check for available *low-cost* RC cars for outdoor driving. Our hardware consists of:

- CPU, Odroid XU or Intel NUC
- Flight Controller, Crius[1] or PixHawk[2]
- RC Crawler chassis, Ridgecrest AX10[3]
- LiPo driving battery, 5800mAh
- RGB-D camera, Asus Xtion
- IR Ranger, Sharp GPD series
- Custom-designed mounting base

Figure 1 shows the assembled FH Rover based on the 1/10 RC Crawler. The RC Crawler has a quite rugged driving chassis, enough headroom and payload for carrying the CPU, the battery, the flight controller and the sensory devices. The springs can be adjusted or replaced for higher loads and the damper oil can be exchanged as well. There are carts available for a lower budget, but the ones we use are very reliable and worth the price. The used IMU is part of the flight controller design. The Crius has an on-board Invensense MPU6050 which is well documented and where a lot of source code is available to read out the raw data from the tilt and gyro sensors, for instance. The Crius is based on an Arduino design, so the implementation of the *rosserial* package can be easily shown via connecting an IR range sensor

[1]http://www.rctimer.com/
[2]www.3drobotics.com/pixhawk
[3]http://www.rccrawler.com/

to the I/O pins of the AVR2560 micro-controller. The *rosserial* package is an easy way for beginners to interface nearly any embedded system with ROS and is the right starting point for connecting additional hardware without explicit ROS drivers to a ROS-based system. As an alternative design for higher computational demands, we use an Intel NUC Core-i5 device together with the PixHawk 4 flight controller.

III. THE FH AACHEN ROS SUMMER SCHOOL CONCEPT

A. Challenges and Concepts

The basic idea is to give a general introduction to mobile robotics during the summer school. Our ROS Summer School runs for two weeks[4]; plenty of time, but still it is quite tough for teaching a comprehensive course in robotics. Robotics is a wide research field and as Gerkey, one of the main developers of ROS, pointed out in [7], a lot of experience is also required to design good robot software applications. The required qualifications range from solid mathematical understanding for dealing with noisy data, kinematics, or dynamics over good understanding of electronics or physics to distributed real-time software systems running—as in the case of ROS—under a Linux OS. Writing a robot application requires some knowledge in mechanical engineering, mechatronics, computer science and software engineering in general, computer vision and AI, in particular. The group of students attending the *ROS Summer School at FH Aachen* is quite mixed between CS and Mechatronics students, Electrical and Mechanical Engineering majors. Hence, the target group is quite diverse as are the prerequisites of the participants. Up till now, we did not have particular requirements apart from basic knowledge in programming and the Linux operating system.

Our teaching concept therefore foresees intensive workshop sessions with lectures in the morning and hands-on tutorials in the afternoon. For the afternoon sessions, we provide a number of skilled tutors who can individually help the participants with their particular problems. These range from problems with running a terminal under Linux via solving compiler and linker errors to discussing solutions to robotic problems and their implementation in ROS. We include social activities such as visits to close-by research institutions and universities that are active in the field of mobile robotics. To motivate the students beyond "ordinary" classwork, the last days of the summer school are reserved for a competition among teams of students. Our concept consists of the following five building blocks:

1) Lectures, invited talks, and hands-on sessions;
2) Lightning talks by participants;
3) Visits to research laboratories;
4) Industrial exhibitions and demos;
5) Final competition.

We briefly discuss them in the following.

[4]In the 2014 edition, we extended the duration to three weeks. While this was generally a good experience, we will switch back to two weeks for 2015.

1) Lectures, invited talks, and hands-on sessions: Lectures usually take a 2–3 hour span in the morning. The topics covered in the lecture series as well with hands-on tutorials are:

- Basics of ROS;
- Working with proximity sensors under ROS;
- Basic image processing;
- Bayes filtering, localization and mapping;
- Implementing basic reactive control algorithms.

In the first week, we lay the foundations with a general introduction to ROS. We introduce the concepts of the *rosmaster*, *nodes*, *topics* etc. and the students get to know the basics of a distributed real-time system. In the hands-on sessions, the participants write their own first nodes, exchange data and write a joystick teleoperation node for the Rover. Furthermore, they get into touch with the Rover hardware, in real as in simulations. They learn how to exchange data with the attached Arduino MC and have to read sensor signals from the MPU 6050, an integrated 6D IMU. They have to attach an IR Ranger from Sharp and use the package *rosserial* to communicate with the ranging device.

After the first week, all participants are fairly familiar with ROS and are able to learn higher concepts. Therefore, we focus on higher-level functionalities in the second week. We start with an introduction to kinematic modeling, local navigation and visual odometry, inertial navigation, and the data integration with an Extended Kalman Filter; on the practical side, we introduce the packages *tf*, *rviz*, *rqt_plot*, *robot_pose_ekf*, and the *ccny* package. Additionally, we introduce the Bayes Filter and have sessions on related ROS packages. Another focus lies on image processing. We use the RGB-D camera for basic image processing tasks such as color segmentation in 2D, and obstacle detection with 3D data. Fig. 2 shows the local obstacle map from the track that was extracted from the point cloud provided by the RGB-D camera. We have brief introductions to OpenCV and the bridge into ROS [9], [10] as well as the Point Cloud Library (PCL) [11]. We also introduce the general concepts of high-level control and prepare the students to get the carts ready for the final competition. During the preparation time for the competition, the participants have to code a simple control strategy that keeps the Rover in the middle of the road. Fig. 3 shows part of the competition track for the final competition. The detection of the road borders is done with the depth image that is projected to the ground plane to provide a 2D occupancy grid of the current camera frame.

We rounded up our lecture series by three invited talks with guest lecturers from University Nuremberg, Freiburg University and German Aerospace (DLR). They are all experts in specific fields, like e.g. Rescue Robotics, SLAM algorithms and UAVs. All of them are using ROS extensively and gave a lot of hints and advices how to start with mobile robotics and even participating in RoboCup [12].

2) Lightning talks by participants: As some participants already had some experience with ROS or robotics applications, we encouraged lightning talks by participants for
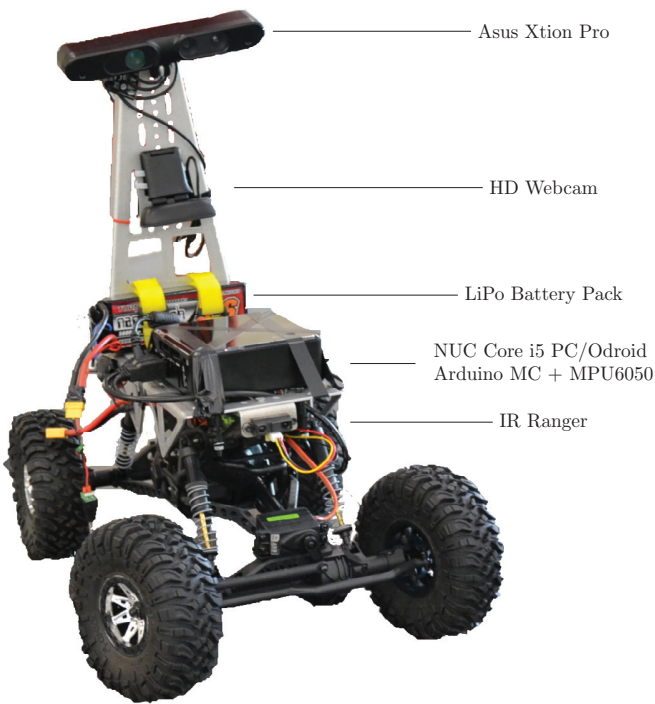
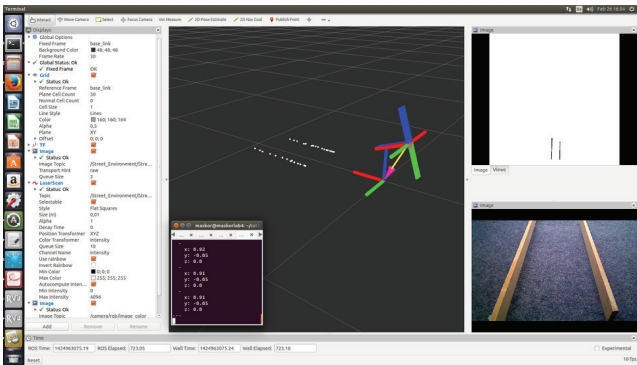Figure 1.   The FH-Rover 1/10 carts

Figure 2.   Occupancy scans from the track.

Figure 3.   Competition track.

participants. We had some interesting talks on mutli-copter control and an industrial application, where a laser cutting machine was loaded and unloaded with a simulated PR2 and a real programmable logic controller (PLC).

3) Visits to research laboratories: We organized several social activities around the ROS summer school. In the beginning we had the usual get-together and a guided city tour. At the end of the first week, we visited the Aldebaran Laboratory[5]. We were given some presentations on the Nao Robot. At the end of the second week, we visited the Biorobotics Laboratory[6]. While many of the researchers were still attending the 2014 RoboCup Championships in Brazil with their Domestic Service Robot team, we got an excellent tour through their laboratory. It was in particular insightful to show that much of the material covered in ROS Summer School was also deployed on their robots. This underlined the significance of our teaching activities.

4) Industrial exhibitions and demos: As we pointed out in the introduction, the material covered by the ROS Summer School is not only relevant for mobile robotics which is mainly

done by research units throughout the world. With the advent of cyber-physical systems in manufacturing, also an important impact for the automation industry can be expected. To guide the student in that direction, we organized a Special Session for industry partners to show where ROS would be used for their products. We had a presentation by FESTO Didactics giving a demonstration of the new Robotino 3 robot. Another partner from industry was the German distributor of Universal Robots. They showed their latest developments in compliant robot manipulators and the future impact of the taught methods w.r.t. human-machine collaboration. Here, a brief overview of industrial applications was given by mentioning *ROS Industrial*; so the learned skills can be even applied to industrial robots.

5) Final competitions: For the final competition we gave the participants some leeway regarding lectures and theory. They had three days time to develop a controller that would be able to autonomously drive the vehicle around the track. To keep everyone in the competition, we defined three competition levels with varying complexity. To make it a fun event and to make everybody be able to participate, the first stage was to teleoperate the robot around the track with a joystick. At the second stage, the robot had to perform the same task

[5]Aldebaran, Paris, France
[6]Biorobotics Laboratory, Delft Robotics Institute, Delft University of Technology, Delft, The Netherlands

Figure 4.   Impressions from the 2014 ROS Summer School.

autonomously. For the third stage, the robot had to obey a street light that was at some unknown position on the race track.

B. Financial Background and International Relations

An effort to organize a summer school for up to 50 participants with hardware, accommodation, catering etc. would not be possible without substantial financial support. Some of the costs could be covered with the participant's registration fees of € 550. Given that, for the 2014 ROS Summer School, this included travel expenses for trips to Paris and Delft, catering and drinks, this is a quite reasonable price.

In addition, the ROS Summer School is approved for the DAAD scholarship program university summer courses in Germany for 2015. This program will support the ROS Summer School for 2015 and the following two years.

The ROS Summer School can also be rated as a success w.r.t. international relations. With participants from 10 countries, it was indeed an international summer school. The Summer School yields also good international exposure for participants of our partner universities and other institutions as well as for our local participating students. In particular, they get some international experience without having to stay away for a whole semester. Additionally, they can earn credit points for the course outside our semester times. This unravels the quite crowded study plans of the students or offers the opportunity to speed up their studies. The scholarships provided by the DAAD scholarship program will support international students to participate in the ROS Summer School also in the future. The 2015 ROS Summer School event promises to be even more international, since we already have about 50 application in total, with some of the applicants coming from Pakistan, Algeria, Tunisia, Egypt and Saudi Arabia.

IV. Improving the Summer School

In total, a number of 48 students registered for the 4th ROS Summer School, which was held between July 21 and August 8, 2014. About half of the students were international students from Brazil, China, Hungary, India, Portugal, Russia, Slovenia, Taiwan, and the USA. The other half were local students from FH Aachen who enrolled for Computer Science, Mechatronics, or Mechanical Engineering. The course was evaluated through our center of university didactic. The students answered a standardized evaluation form and estimate the following features:

Indicator	Evaluation	
	μ	σ
Global Indicator	1.86	0.83
Structure and commitment of lecturer	1.88	0.84
Realization	1.75	0.67
Relevance of the lecture	2.06	0.89
Social interaction	1.62	0.86
Exercises, seminars, preparation for exams	2.03	0.91
Study success	2.04	0.84
Overall rating	1.67	0.78

Table I
Results from the evaluation form.

structure and commitment of lecturer, realization, relevance of the lecture, social interaction, exercises, seminars, preparation for exams, study success and overall rating. At the end of the evaluation form some open questions can be answered as free text, i.e. what did the student like most, how could the lecture be improved and how can be described the lecture in one sentence. Table I summarizes the students overall rating in a range from 1 to 5. While it was quite a challenge to host such a variety of different backgrounds and nationalities, overall, we got very positive feedback from the students.

Many students acknowledged the practical experience coupled with more theoretically oriented lectures. In particular, they liked being given enough time to find solutions to the given exercises with the support of our tutoring team. Although in 2014, the summer school was three weeks, some participants found it even too short. Another lesson we learned from the assessment of the participants was that we need to hand out more preparation material before the Summer School starts. For the next edition, we will make some virtual hard drives available where the participants can use the ROS simulation environment Gazebo [13] and prepare already for the summer school with our cart model in the simulation. As we mentioned above is the background of the participants quite diverse. There are students from Computer Science, Mechanical Engineering, Mechatronics with very different skills w.r.t. programming or working with Linux. In the last editions we did not have particular participation requirements for the summer school apart from the mentioned basic ones. As more and more students have used ROS before and therefore

already have some working knowledge in ROS, we need to adapt our curriculum. Therefore for the 2015 edition of the ROS summer school, we will set up two parallel tracks. One *beginner track* for participants without prior knowledge, and an *advanced track* for students with good working knowledge in ROS and robotics. The reason for this split is not to bore the more advanced students with basic stuff they already know. On the other hand in the beginner track, we could focus more on the basics of robotics and on ROS, in particular. For the advanced track, we also equip our carts with the Intel NUC to have more processing power available.

For both tracks, we will stick to the final competition. The participants will start in two groups. The task for the beginner will be according to the gathered skill. As it turned out in the 2014 ROS summer school, writing a reactive controller to drive around the track is challenging but doable during the summer school. For the advanced track participants, this task could easily be made more complicated by, say, obeying street light and street signs, do some global path planning on a more complicated track layout with crossings and stop signs. In the future, the scenario of the race could be extended towards a small-scale Urban challenge scenario with street crossings, traffic lights, and street signs. Then, also more advanced robotics tasks such as localization, path planning, object recognition (sign and object detection) can be tackled. For 2015, we will offer students the possibility to buy the FH-Rover. Then, they could also continue their work on the rovers and deepen their skills with using ROS.

V. Conclusion

In this paper, we summarized the ideas and the background of the ROS Summer School. The basic idea is to teach the basics of mobile robotics and the programming of robotics applications with the Robot Operating System as a software basis. This has the advantage that many state-of-the-art algorithms and methods are available quite out of the box. To use such algorithms the right way, however, some theoretical knowledge in mobile robotics is required. Therefore, we combine thorough theoretical lectures teaching the concepts and fundamentals of mobile robotics with hands-on tutorials where participants can try out different algorithms and have to solve fundamental problems of mobile robotics. If not more, participants get a good overview of the problems in robotics. We think that this is very important to prepare our students for some future technological challenges coming from cyber-physical system and the future in automation.

With a varied programme consisting of lectures, hands-on tutorials, invited guest lectures by robotic experts, visits to robot institutions, we offer an interesting and challenging programme for our participants. While, until now, we did not require special prerequisites apart from basic Linux and programming skills, for future editions we will provide two tracks in the programme, one for beginners in mobile robotics and one for advanced users of ROS.

At the end of each summer school there is a competition among the participants. They have to program the rover carts

so that they are able to drive around a track autonomously. For the future, we want to increase the complexity of this domain to end up with a small-scaled Urban Challenge scenario with street crossings, street signs where the robot have to stop at red traffic lights and overtake other vehicles.

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Technology and Art – Solving Interdisciplinary Problems

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Abstract—**Our pilot project, led by Lodz University of Technology together with Academy of Fine Arts, is aimed at designing and prototyping equipment that therapists may use with their patients who are children with mental disorders. We present some of the outcomes of this co-operation and highlight the conditions necessary for the success of such ventures: creativity, communication and deep thinking.**

I. Introduction

The 'Rehabilitation and Service Robotics' course, offered in the second semester of the Control Engineering and Robotics Graduate degree at Lodz University of Technology (TUL), provides an overview in the theoretical basis of modern robotics. In the past, as a practical part of this course, students would work on some (usually technical) subjects related to design of rehabilitation or medical systems (e.g., drives, sensors, control). Service robotics has become a more realistic future career scenario for master's students in Europe, contrasted to mostly research careers in the past, and therefore we have decided to engage our students in a real-world project that would introduce them to robotics as it really is – a demanding, interdisciplinary and challenging discipline.

In particular, we wanted students to participate in a real life design of Human-Robot Interaction (HRI). Our group is engaged in teaching HRI (an article about our practices for undergraduate students was presented in [1]) but up to this point we have not engaged students in projects of this scale.

Our partner institution, Strzeminski Academy of Fine Arts Lodz (Academy in short), conducts one year classes on Ergonomic design, which is taught at the master level. Since the beginning of this program, its mission has been to train designers to be able to understand the needs of people with disabilities, through various projects related to medical and rehabilitation applications.

These two classes became the basis for the interdisciplinary project engaging master's students from two universities. In this paper we describe our experience and, using it as an example, discuss topics of creativity and communication, that we believe are key to success of the students participating in such ventures.

The practical value of this project – creating tools for therapists of children with mental disabilities is important in itself, and we hope, that our example will motivate different robotics groups to "lend their brains" to help their societies, while educating students in the process.

II. Similar projects

One of the most important goals of this educational project was teaching human-machine (robot) interaction and solving a real problem.

A. Nature of Human-Robot Interaction projects

HRI projects are particularly challenging as educational projects – as it is quite difficult to separate the technological side (robot construction, software) from the soft side (ease of use, understanding, design). These parts need to be designed and developed together because any change in one (e.g. shape of robot) changes the other (e.g. how the system is perceived) and vice versa.

The universal nature of these problems motivated HRI researchers to create guidelines for HRI accepted practices, as listed in [2], which we attempted to follow in our project:

- create an interdisciplinary team of experts. Our project graduate students from the 'Control Engineering and Robotics' and 'Industrial Design' programs, as well as therapists who were involved in project, were the subject matter experts.

- create real systems and evaluate these systems using experiments with human subjects. This postulate, which contrasts to doing only a proof of concept solution is a highly important part of our project. Students from the beginning were made aware their prototypes would be used by the real people.

- use established standards and common metrics so that project could be easier to maintain and its results evaluated and compared. Students used standard technical solutions (such as Arduino, ROS, Linux built-in tools) and established prototyping and testing practices (explained in detail in [1]) in their solutions.

- use longitudinal studies. While the core part of the project (the need-finding, designing and creating first prototypes of sensory therapy tools) was done in a period of one semester (from October 2014), the study itself started earlier and will take another year to complete. Our focus as a research group, is to study

how these tools influence therapists' well being and reduce their burnout [3]. Students, willing to continue their projects as their master's thesis, are working with the most prospective designs.

- experimenting with using both physical and simulated systems – this postulate was not implemented in last semester but is considered while the specialized software will be developed.

B. Teaching HRI

A number of institutions have HRI courses on their graduate curricula. A majority of the courses teach theoretical and practical aspects of conducting research in Human-Robot Interaction. We drew on the experience of Andrea Thomaz's class CS 7633 about social intelligence topics such as: anthropomorphism and embodiment, perceiving intent, emotional intelligence, learning through lectures and readings, and Ilah Nourbakhsh's class 16867: Principles of HRI [4].

C. Teaching robotics technology through real life, important projects

A project based course 'Technology for Developing Communities' from Carnegie Mellon Robotics Institute, studies ways to use advanced technologies (sensor networks, robotics) to help developing communities. Students are given background knowledge about problems occurring in developing countries and proceed to solve real problems through participatory research (knowledge for action). This consists of understanding situation priorities and perspectives, securing funding, co-opting stakeholders and creating realistic and very much needed technical solutions. While problems are real, solutions developed during the course are theoretical preparations for further work, which some willing students can expand into real solutions beyond the classroom [5].

III. RESEARCH PROJECT DESCRIPTION

Our project "Robotized Environment for Improving Therapists Everyday Work with Children with Severe Mental Disabilities" came to life after we had presented some robots to autistic children, during *Autism Day*, an event organized by Navicula Centre.

Through participant observations and ideation sessions, we distilled ideas that could be very helpful for therapists and have an immense educational value for our students. One of the most interesting ideas was a robotisation of the already existing sensory therapy tools that therapists use. By robotisation we mean adding different robotic features, such as actuation and sensing, and making them programmable in easy-to-use fashion.

Many autistic children have problems with over and under sensibility to different stimuli which results in stimuli either being painful which results in tantrums (over sensibility) or children being aloof (under sensibility). Sensory integration therapy is a tool for accustoming patients to stimuli through presenting various sensory opportunities. For therapy to be effective, it has to have some particular features: just-right challenges (adjusted for a specific patient's level of skills),

ensuring physical safety and guiding patient's self-organisation (child can learn how to plan own behaviour) [6].

Features of effective therapy described above require high understanding of child's state and capabilities, therefore, we have proposed the tools to be programmable – so that therapist could use their knowledge in creating effective actuator-sensor loops for patient stimulation.

Therapists also wanted to have tools for multi sensory stimulation. This demanded a design that would provide access to different stimuli:that would be attractive to the child, effective in therapy and in the same time safe.

IV. EDUCATION GOALS – PROJECT BASED LEARNING

We consider student work as a serious contribution to the whole project. But also, the project should be an exciting way to expand their knowledge and learn important skills in the following areas.

Embedded systems – students worked on Intel Galileo boards (sponsored by Intel), which are small linux boards with input/output capabilities similar to the Arduino, and with additional ability to use USB or mini PCI based devices.

Internet of things – an important part of project was the requirement for the designed devices to be programmed/controlled from standard computers and tablets. Students therefore learned how to use standard protocols and make their devices part of a larger network.

For students from the Academy of Fine Arts, this interdisciplinary project was a chance to open up to the world of electronics and control engineering as well as describing their design needs to engineers. Students are very well prepared for designing form of product, they have a solid background in psychology and anthropometry, and therefore, could lead student teams at the beginning of the project. Both groups deepened their knowledge in human-machine interaction when a development proceeded into further stages.

A. Project based learning

This form seems to be ideal for realization of multidisciplinary projects with diverse group of students. Students acquire knowledge and elements of the core curriculum, but also apply what they know to solve authentic problems and produce results that matter [7]. They go through an extended process of inquiry in response to a complex question, problem, or challenge. The project started with direct contact with therapists from Navicula to discuss their needs and observe their work. Then a few alternative forms of the product were proposed – this part was mostly driven by students from Academy. Based on the presentation of these proposals clients (i.e., therapists) provided feedback and the whole group discussed results.

Students had six weeks to request the necessary electronic components and fill-up the mock-up form with sensors, actuators, and control – this stage utilized students from the Lodz University of Technology. The second presentation of prototypes was organized on the Navicula premises and involved more therapists and management of the Centre. The project is continued in the second semester by the smaller groups from
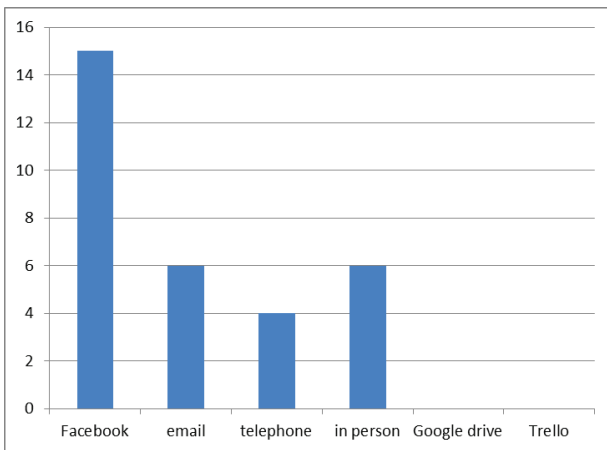
Fig. 1: Number of respondents declaring use of the different communication methods among teammates (6 possible choices were proposed in the project and included in the questionnaire, although two of them were never used)

both universities – mostly interested in their master's thesis based on this design.

B. Teams, communication, exploration

Thirty one students from two universities were involved in this project: 16 from the Academy (mostly females) and 15 from TUL (mostly males). Six teams were created on the first common meeting where students from the same school could choose mates and the subgroups were matched randomly. All contact information and necessary documentation were published on Google drive for internal usage of the project. Although, almost all possible means of communication were used, Facebook appeared to be the most popular followed by email and in person contacts as shown in fig. 1. What is interesting here is that students did not appreciate neither Google drive to further share data or exchange information nor Trello – the project management application where the special account was created. This is one of the lessons we have learned – we hoped to base the project on these tools (as they are commonly used in our everyday work), but both require some degree of knowledge and in future projects some of the time has to be committed to actually teach students how to use these tools effectively.

Even though we have received some information in regards to problems in exchanging information between students of different schools, finally the overall note for the quality of communication was above the average as shown in fig. 2.

The project's formula gave an opportunity for students to be creative. None of the faculty or therapists had a one right solution, therefore students had a large solution space to explore. However, results were average with respect to creativity (see fig. 5). While different in shape and form, devices initially had very similar functionality, they could be touched and watched, and responded by changing colour, vibrating and making sounds. None of the designs had functionalities of a typical robot, such as mobility or AI. While not necessarily bad, students' abilities were underutilised.
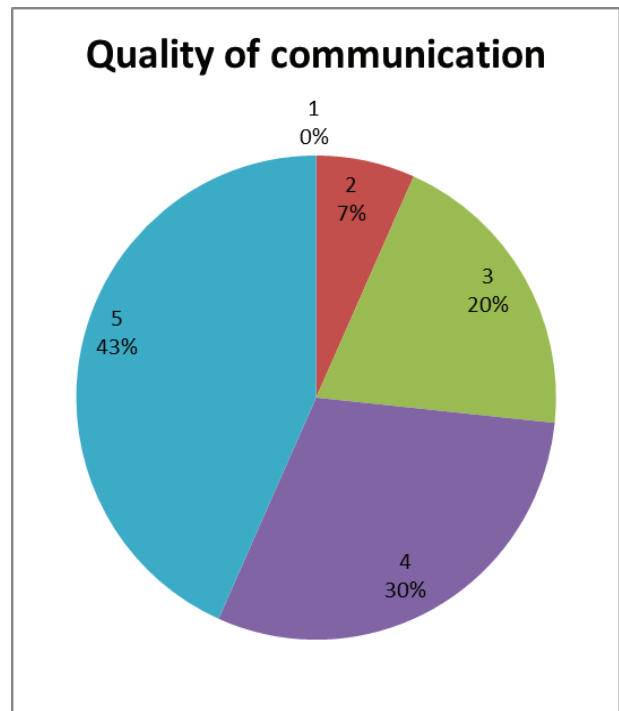

Fig. 2: Number of respondents rating the quality of communication between students of different schools (1 – no communication, 5 – excellent communication)

We believe that several factors could lead to more creative projects. One is to clearly state that all students are expected to be creative and contribute to a main task – at the beginning of this project Academy students were leaders in ideation, while TUL students took a role of 'supporting engineers'. Without interdisciplinary discussions design students came with creative ideas about form and texture but not about technology, as they did not understand what could and could not be done, and this resulted in overly simplistic solutions in that area (compared to the abilities that some of TUL students had). Because of that, students who decided to continue their work on this project have to understand the *goals* behind the devices being created and contribute actively into improving and implementing the solutions instead of only fulfilling the designers ideas.

Also worth noting is that groups that have frequently met in person made qualitatively better projects. We have decided that going forward, although more organizationally complicated, it is better for all students and faculty involved in the project to meet every week in person to report and discuss current matters. This allows for not only faster work, but feedback and discussion are much easier. Also, sometimes the faculty has the role of 'translators', as students from both schools have sometimes issues with understanding different vocabularies and the processes and procedures of their partners.

With reference to the educational outcome of the project we have asked students to what extent they have explored new areas of knowledge and how would they rate the knowledge development in the major area of their studies. They could rate these developments on a the scale from 1 to 5. As we can learn
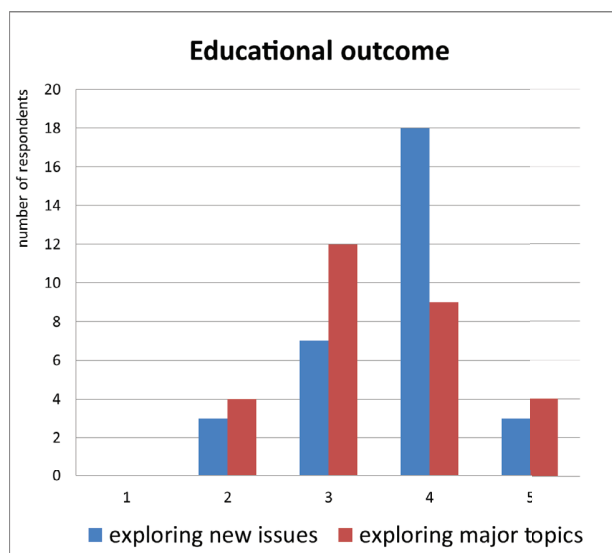
Educational outcome

Fig. 3: Results of the questionnaire given to the students to what extent the project let them explore new issues and their major subjects (scaled from 1 - didnt to 5 - excellent progress)

Should the inter-university project be a part of the normal curriculum?
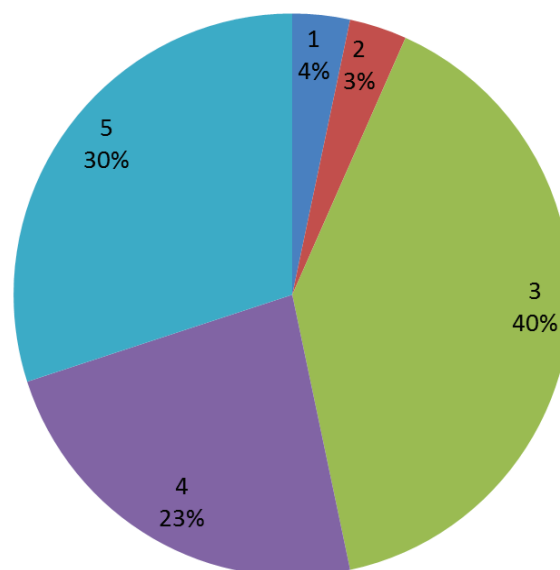

Fig. 4: Results of the questionnaire given to the students should the joint project be a part of the normal curriculum at both universities? (rated in the scale 1 – definitely NO, 5 – definitely YES)

from fig. 3, students took advantage of the interdisciplinarity of the project and focused much more on exploring new issues (not directly related to their major discipline). Moreover, most of them have seen the project as an interesting experience (worth some minor troubles they had).

Most of the students would see inter-university projects as a normal part of their curricula (see fig. 4) although only a few decided to continue this topic as a Master Thesis. Also not all of Academy students decided to continue their projects. Students, when asked about their decisions, stated such reasons as problems with communication and unclear goals. This also prompted us to force a tighter cooperation between groups.

V. RESULTS

During one semester of the joint project we have seen two presentations of the preliminary ideas and pre-prototypes showing technology demonstration. What is the most important in our opinion is satisfaction of the clients – therapists from Navicula Centre. The majority of the respondents (7 people) rated the project as correct and useful for their practice, however, the novelty of the presented ideas was rather average, as shown in fig. 5. They have also commented on all presented projects and ranked them.

Four of the top designs are being developed as prototypes ready to be tested with therapists and children. Due to different structure of curricula at Academy and TUL we cannot continue this project in the same form for the second semester. However, three students from the Lodz University of Technology continue the co-operation doing their Master Thesis and most of the students from Academy will further develop their ideas.

As a master thesis, students integrate particular designs into one system, with features of a ubiquitous robotic system, where physical mechatronic solutions are connected and integrated with AI functionalities (voice recognition, emotion

recognition) and that could be programmed and changed by therapists through different modalities (physical interfaces and programming interface based on Scratch).

Therapeutic needs of children differ considerably, as children have different levels of disability, skills, age and stimuli sensitivity. We therefore encouraged students to create diverse designs to have a range of different prototypes to test, as well as create flexible and programmable designs, that therapists could change and program themselves.

Roboticized therapeutic devices created by student groups varied both in shape, functionalities, size and form. While some of the designs could be considered more therapeutic toys other were more similar to a therapeutic playgrounds.

The 'Exploration box', shown in fig. 6, is a programmable box that can be thrown, pushed or caressed, and that responds by moving, generating sounds and voice, or vibrating. This device utilizes many robotic features including mobility and sensing (accelerometer, touch sensors. The focus of this device was on the kinesthetic type of therapy, where children are encouraged to move and play with objects, exploring their features, such as weight or texture. Therapist will be able to program how the box responds, so that it could, for example, play the child's favorite tune when a preferable action has occurred or present some available action through blinking or telling.

The current design (fig. 6) is a second iteration obtained after discussions with therapists. The group changed their design from a immobile large box that child could touch to
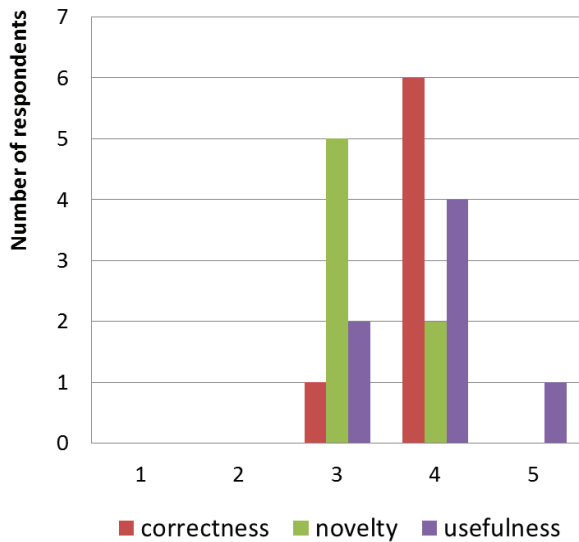
Fig. 5: Results of the questionnaire given to the therapists from Navicula Centre their notes in three categories: correctness, usefulness and novelty of the presented designs, rated in the scale 1 (low) – 5 (high)
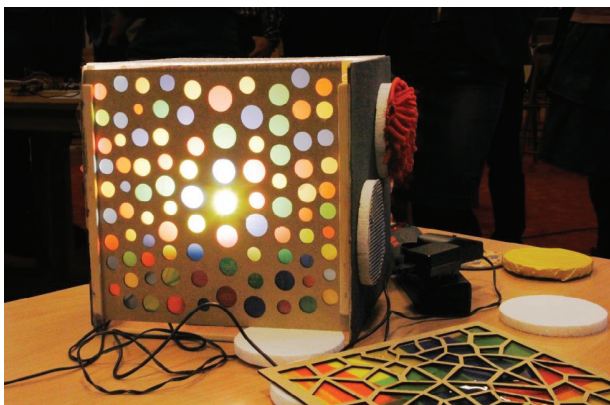

Fig. 6: Exploration box authors: Magdalena Bartczak, Olga Rogalska, Szymon Surma, Magdalena Gregorczyk, Dariusz Urbański
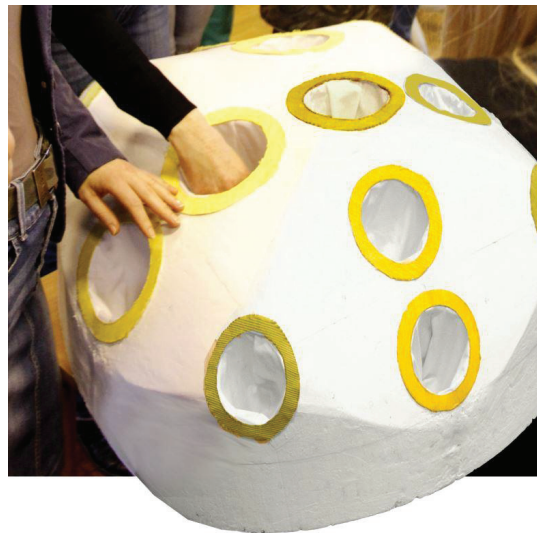

Fig. 7: Magic holes authors: Olga Maciaszczyk, Anna Wawszczak, Monika Kocot, Mateusz Pakosz, Adrian Kowalik, Tomasz Karolczak
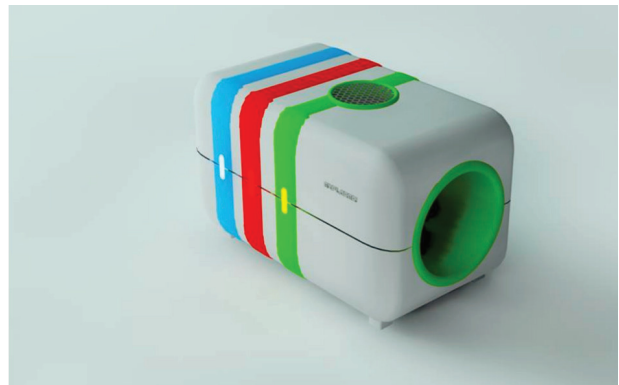

Fig. 8: Sensible Sleeve authors: Kornelia Kulik, Dominika Rajska, Krzysztof Barzdo, Mieszko Polański, Mateusz Wodziński, Maciej Jarosiński, Łukasz Matusiak

a smaller one that could be moved and played with. As a consequence, the new box has to be rugged and light. As the therapists will be able to animate the robot's movement – the group is currently set to design a pair of soles on the bottom of the robot, actuated by servos, so that it could express a range of motions.

'Magic holes' offers an object with a set of holes that have different functionalities encouraging exploration, as shown in fig. 7. Holes can warm up, vibrate, light up or make sounds reaction to hand moving inside. The design aim behind this project was to encourage exploration through holes that would light up.

The prototype was manufactured with a soft foam covered with rubber shell. This allowed for a safe exploration.

'Sensible sleeve' (see fig. 8) is similar to a sensible "car wash" for an arm where the child can sense warm/cold air, vibrations, tingling sensations. The device senses movement of a hand, tapping on the cover and the user's voice.

The design aim was to integrate different stimuli for a child, such as visual (through LED strip around the device), sound and touch through interaction with the sleeve. Since some of the children can be afraid to put their hand into the sleeve, or simultaneously stimulate both hands, the device can be used as two separate halves. As the device uses a considerable amount of power (mostly from Thermoelectric Cooler Modules) it is a corded device.

'Interactive Bricks' (see fig. 9) is a set of bricks used to control stimuli through building a tower. The height of the tower controls the strength of the stimuli. Designers proposed a game where the child can build a beehive by putting together bricks that are buzzing. This prototype could not only be used
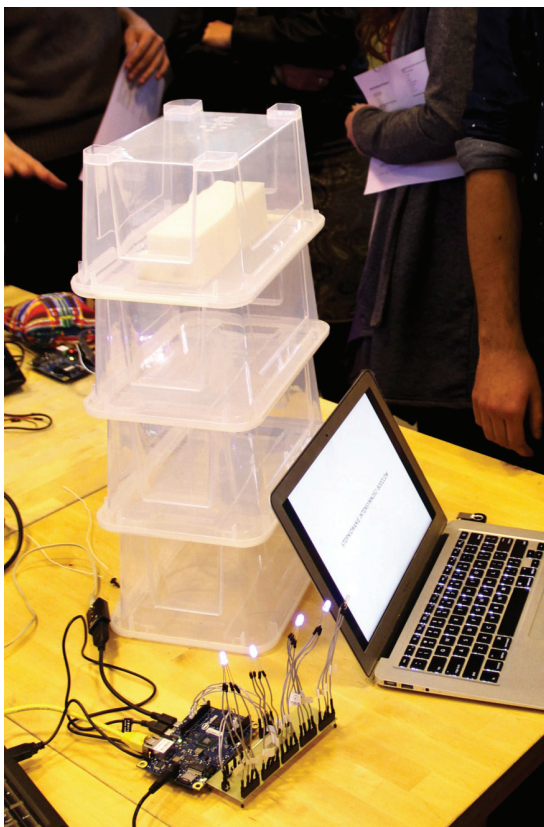
Fig. 9: Interactive Bricks – authors: Iza Mrozowska, Adrian Dutkowski, Michał Wyszyński, Konrad Kustosik, Tomasz Wasilewski

in sensory therapy (it has the ability to generate sound, and whole brick can light up) but also to learn cognitive skills.

Interactive Bricks is also a project that is challenging to make the design and electronics work together as proposed features are demanding – from one side the bricks must be light enough for the child to pick it up, robust so it could not be destroyed easily, and powerful enough to have programmable interaction, react to proximity of other bricks and change the sounds accordingly. Students are using an embedded Linux computer (Intel Galileo) inside the bricks to make it work.

All of the designs will have a common programming interface, being developed by the students now in the second semester. While initially students created their own control programs for laptops and tablets (based on Processing language), therapists expressed the need to have a bigger scope of control – thus the need for a programming interface, that would still be still easy enough to be used by non-professional programmers. We decided to use Scratch as a basis for our programming interface, as it is commonly used, has a large community and had multiple previous successes in introducing people to programing. As an alternative, especially because therapists are usually very involved in interacting with children, they will be able to use voice interfaces and physical interfaces (moving elements, drawing) to change device's behaviour. This is what students are working on during their master's thesis.

VI. Conclusion

We have presented some results at the halfway point of our interdisciplinary project aimed at supporting therapists who work with mentally disabled children. Except for the very important and concrete prototypes that were created, the student groups learned how to work in the interdisciplinary environment on a common task.

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Starting Robotics in secondary school: Assembling i-SIS an autonomous vehicle

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Abstract—The project aims to develop, balance and enhance the theoretical knowledge, skills and attitudes of students focusing on Science, Technology, Engineering and Mathematics (STEM) disciplines applied at secondary school level. The work, carried out by K-12 students, is differentiated into two blocks, coding and robotics. In the first block, programming in Scratch becomes one of the main goals, in which the students make code intuitively but supervised by the teacher, enhancing and developing the computational thinking and the digital competence. The programming tools used are Code, Scratch, Arduino and Scratch4Arduino. In the second block, an autonomous vehicle named i-SIS is assembled. Here, they will implement their knowledge to make it work. In teams, the students will apply their knowledge of mechatronics. Controlling emotions, interpersonal motivation and collaborative work will be essential for success. Moreover, the student's autonomy self-esteem and entrepreneurship are boosted.

Keywords—digital competence; starting robotics; autonomous vehicle; mechatronics; computational thinking

I. INTRODUCTION

Mobile robots and robotics are an educational tool that provides a complete solution to promote technology for secondary school students. The purpose of this project is designing, building, programming and testing robots during the first years of secondary school. The global task combines physics, mathematics, technology and computing. During the sessions, students are actively engaged with all these disciplines. Another key factor of this project is that it introduces students to technology, giving them a different point of view for learning robotics, in an attractive and fun way. It was inspired by the programming pioneers and other robotics projects made before, and it aims to avoid commercial brands using open source hardware and software. However, what makes the i-SIS project successful and motivating is its low-cost nature [1].

Over the last decade, in our country there has been no economic investment in technology in the state schools, to the point that for economic reasons, it may disappear. The cost of i-SIS is very accessible to schools due to its modest budget.

This allows our project to expand to many of these institutions easily. Moreover, i-SIS provides a great introduction to do-it-yourself robotics in secondary school, it provides open hardware in technology classes, a reusability of the materials, and it gives a framework for high school students to conduct experiments that will give them experience in addressing global engineering challenges.

i-SIS was inspired by professor Michael Resnick [2]'s quote:

I believe that the best way to help people understand the world is to provide them with opportunities to actively explore, experiment and express themselves.

This project has emerged from the intense debates of regional Artificial Intelligence and Educational Robotics (IARO) conferences held in the Institut Font del Ferro [3] which have been adapted every year since its origins in 2013. The aim of these events are to spread the technological and computational thinking [4, 5] into the local educational community of the Institut Font del Ferro of Palafolls, Barcelona.

II. METHODOLOGY

The purpose of both secondary education and digital competence is to educate people with knowledge of the world. With the project, students will acquire the tools to understand it, to inhabit it and improve it. We will apply a methodology that seeks mainstreaming, which is understood as the criterion for the selection of content and focus on interdisciplinary learning areas. An example would be the close link with communicative competence through the connection with the subject in English as a foreign language, where students are introduced to new technical vocabulary. Our methodology is based on functionality, and prioritizing strategies oriented towards the application of learning in different contexts and real situations. It also aims to encourage the students' autonomy, to promote learning strategies based on self-regulation, to make students more independent, and to take responsibility in the evaluation period.

Therefore, this methodology is not based on storing and reproducing information, but on teaching how to search, select, organize and interpret it using reason and knowledge. In this way students can make their own interpretations, to communicate these one to another, in different situations and contexts of the project.

In summary, the project model uses the computational thinking and the digital competence detailed below, and it is training-based problem solving. This is the philosophy that facilitates technology education through the practice of the process.

A. The computational thinking and the digital competence in secondary school.

The computational thinking (CT) can be achieved in many different ways. Therefore, we need to view the model of CT as a way of defining the problems of the real world by digital representation. In this way it is interesting that we can classify the thinking into two types, according to the interests of the CT. On one hand, we mention algorithmic thinking that structures a sequence of actions according to a result that leads us to solve the problem. On the other hand, the heuristic thinking is made by informal or intuitive rules that point to "mental shortcuts." This thinking is used when it is not possible to use algorithms, either because they are not available or because the application is impossible in practical terms. All this will provide students with a clear understanding of computers and their daily applications.

The digital competence applied in our project is described in 4 dimensions which allow the students to develop the abilities mentioned below:

- Instruments and applications: includes the necessary skills to understand concepts related to information and communication technologies (ICT). Also, it includes the ability to solve technical problems and use the more extended applications, such as word processor, spreadsheet editor presentations, among others.
- Information: includes skills related to searching, selecting, evaluating and organizing digital information. The student must be able to transform and adapt to a new product or develop a new idea.
- Communication and collaboration: groups the skills that are related to transmitting, exchanging ideas and working with others using the technology.
- Digital coexistence: includes skills which help students to evaluate ethics, learn how to use ICT responsibly understand the risks and opportunities of the Internet and be able to decide the limits of sharing information.

B. Applying the curriculum in secondary school: linking robotics with technology

Initiating the students in robotics in secondary school is a task that requires a correct and coherent application of all the concepts, definitions and procedures from the technology area. The teachers implied in the project were then encouraged to adapt this to of the national educational technology standards [6]:

- The basic operations and concepts where students demonstrate a sound understanding of the nature and operation of technology systems, and a proficiency in the use of technology.
- Technology productivity tools: students use technology tools to enhance learning, increase productivity, and promote creativity.
- Technology research tools: students use technology to locate, evaluate, and collect information from a variety of sources.
- Technology problem-solving and decision-making: students use technology resources for solving problems and making informed decisions. They also employ technology in the development of strategies for solving problems in the real world.

C. Students level and timing in i-SIS project

The students are between 12 and 16 years old. In order to increase project effectiveness, the group was distributed initially into two small groups: D1 and D2. In the final phase of the project, four teams were created. The work sessions are taught once a week.

D. Materials

All the materials used for carrying out the activities listed below:

- Workbenches for assembly, disassembly and handling of the vehicle.
- Projectors for presentations.
- Shelves and cabinets to store written procedures and instructions.
- Boxes to store portable machines and delicate tools.
- Panels for common tools.
- Panels for placing technical information.
- i-SIS material (See Table I and Fig.8).

TABLE I.   I-SIS MATERIAL

Material list	
Name	Units
BATTERIES CONNECTOR	1
SCREWS M3	8
MOTOR DC	2
WHEEL	2
BATTERIES HOLDER	1
UNIVERSAL WHEEL	1
WIRES DUPONT	10
MOTOR CONTROLLER L293D	1
PROTO BOARD	1
INFRARED SENSOR	2
ARDUINO BOARD	1
CHASSIS	1

E. Structure of the project

According to the work plan, the project is structured in two main blocks: robot programming and i-SIS assembling. Table II, shows the stages, the timing and the student grouping in every session described here below. Also, the last column of the table shows two abbreviations: Ti means *student individual work* and Gt means *student teamwork*.

CODE [7]: Individually, students learn to program intuitively while playing at the same time, upgrading their abilities step by step and creating the movement of the objects. Also, they improve in blocks design and the equivalent written code in Java Script (See Fig.1).

Fig. 1.   Student programming and playing with CODE.

TABLE II.   I-SIS WORKING PLAN

WP	Working plan			
	Blocks	*Sessions*	*Description*	*Grouping*
I	Robot programming	4 h	CODE	Ti
		6 h	SCRATCH	Ti
		2 h	SCRATCH 4 ARDUINO	Ti
II	i-SIS assembling	2 h	FRITZING	Gt
		4 h	UNBOXING ASSEMBLING	Gt
		2 h	ENVIRONMENT	Gt
		2 h	TESTING	Gt
		1 h	COMPETITION	Gt

SCRATCH [8] [12]: Individually, students make simple games by means of a didactical guide and then they create their own games (See Fig. 2).
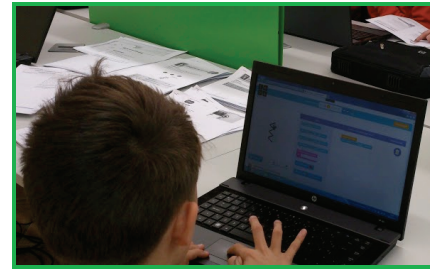

Fig. 2.   Student creating a videogame with SCRATCH.

SCRATCH 4 ARDUINO (S4A) [9]: In teams, students use the code once the robot is assembled. Initially, the primary code is given to every group and they will modify it according to their own building in order to improve the robot´s effectiveness.

FRITZING [10]:   In teams, students will design the electronic circuit. They will draw with the PC the Arduino connections in which are included the sensors and the servos. This activity will take place under the careful supervision of the teacher. (See Fig. 3)
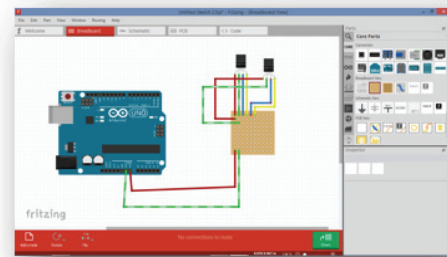

Fig. 3.   Design of the electronic circuit using the visual tool Fritzing.

UNBOXING AND ASSEMBLING: students will build their own robot, observing and comparing with a sample vehicle and interpreting the Fritzing design (See Fig. 4).
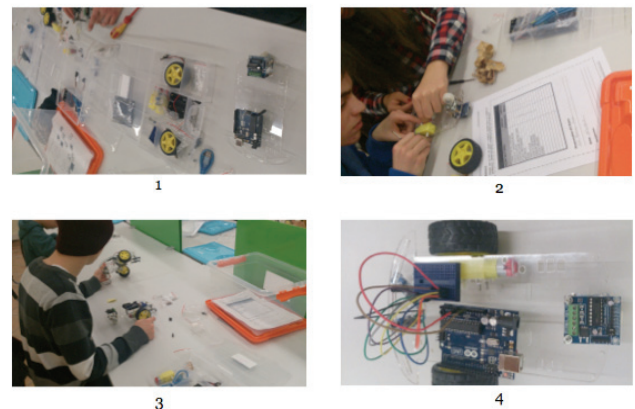

Fig. 4.   Students unboxing and assembling i-SIS.

ENVIRONMENT: students will design the path to testing i-SIS and prepare the future competition (See Fig. 5).
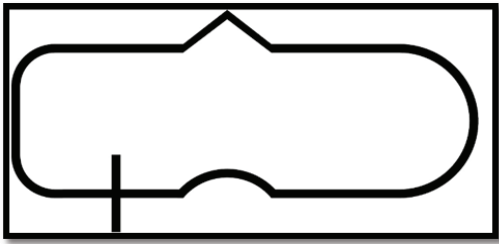
Fig. 5. Sample path for testing i-SIS.

TESTING: Once the robot is assembled with the Arduino board, students will introduce the code Scratch4Arduino so they can test i-SIS and adjust the parameters if necessary. Fig. 6 shows the materials distribution over the selected chassis between two types available in the kit.
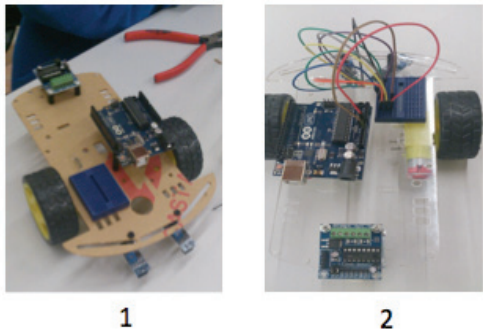

Fig. 6. i-SIS testing and assembling: there are two types of chassis in which the student assemble the materials.

COMPETITION: Students will compete between the different teams of the class.

Fig. 7 shows the whole project duration as well as the distribution of the students according to the session requirements.
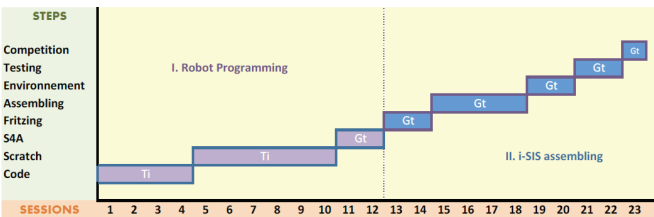

Fig. 7. i-SIS time diagram

F. Diversity in the project

The project has to be accessible to the maximum number of students in the project. The teacher has to provide specific support if the student needs it, depending of the student level and learning difficulties.

Due to the common diversity of the student's level and rate of work, we decided to evaluate the student capabilities, individually or in teams, in order to compare them and to decide how to change the grouping distribution dynamically.

III. INITIATING ROBOTICS WITH I-SIS

A. i-SIS simple mechanical concepts

Robots use a variety of mechanisms. The mechanisms of i-SIS need to be analyzed in detail by the students so they can adjust some physical parameters in the assembling process. Then, they have to deal with common definitions such as force, mass, weight, acceleration, speed and distance.

Fig. 8. Pictures of i-SIS material

B. Practicing some geometry

While students tested the robot and before the creation of the environment, they took measurements of the robot: the rotation angle introduced in the code of the wheels, the length of the planned path and the wheel diameter. Then, while they adjusted the parameters, there applied basic maths calculations

like perimeter and area of the robot wheel, expressed in equations (1) and (2) respectively.

$$Perimeter = 2 \cdot pi \cdot ratio \qquad (1)$$

$$Area = pi \cdot ratio^2 \qquad (2)$$

C. Measuring and playing

Students also made measurements about speed, distance and time reached by i-SIS. The results where recorded by each team on sheets and they compared the final results, as well as the speed average of each assembled robot.

D. Extra work for advanced students

In general, all the students reached the goal of assembling and programming the robots. However, some students needed to go further and to program basic Arduino [11] commands in the Arduino board, with the aim to give independence to i-SIS, which has the connection cable from the personal computer to the robot.

IV. EVALUATION PROCESS

The evaluation process started at the time the teacher guided the activity, put forward a challenge and the objectives. The first reactions from students are adequate indicators of the success or failure of the project. Further, the trial and error testing is an important factor in student motivation because they can observe in real time if what they are doing is giving the expected results. If they don't get the expected results, they can modify and prevent future changes in both the assembling and the code. Evaluation also requires the observation of the teacher, as well as the presentation of the student results in a clear and transparent way for the corresponding level.

Thus, the quantitative evaluation is applied individually or in groups. The score is given in percentages and the maximum reached is the 100%:

- 10% i-SIS assembling
- 5% ability to correctly distribute the pieces over the chassis.
- 5% capacity to debate, expose and make decisions.
- 5% correct calculations and testing.
- 5% correct i-SIS code.
- 5% correct design with Fritzing.
- 5% Participation in the design and building of the environment.
- 15% correct use of Scratch code.
- 10% Scratch guided exercises.
- 20% Scratch videogame creation.
- 5% correct material identification in the workbook.
- 10% good attitude.

Fig. 9 shows the summary results for student's evaluation and Fig. 10 shows a collection of i-SIS of each team. Finally, the involvement in the assigned tasks, the collaboration, and teamwork and the suggestions for improvement and/or expansion of activities is evaluated.

i-SIS total scores		%			
Evaluation items	Max %	Team 1	Team 2	Team 3	Team 4
i-SIS assembling	10	7.5	9.5	8	8.5
Correct pieces distribution	5	5	5	4	4
Debate, oral presentation	5	4	4	4	5
i-SIS code	5	4	4	4	4
Correct Fritzing design	5	5	5	4	5
Environment	5	5	5	5	5
Scratch code	15	14	12	10.5	12
Scratch guided exercises	10	7.5	7	8	9
Scratch videogame creation	20	15	17	17.5	15
Material identification	5	4	4	4	4
Good attitude	10	8	10	9	9
Total	100	79	82.5	78	80.5

Fig. 9. Teacher notes which shows the global results of students evaluation during the project.

V. VALORATION AND CONCLUSION

The experience acquired with this project was very positive and gave us some learning tools adapted from the secondary school curriculum and arising from the STEM disciplines integration. We consider that the project is very helpful, very easy to apply and quite adaptable, depending of the diversity in the classroom and the previous student knowledge. In conclusion, students learned in an active way, according to their level, technological knowledge and algorithmic thinking.
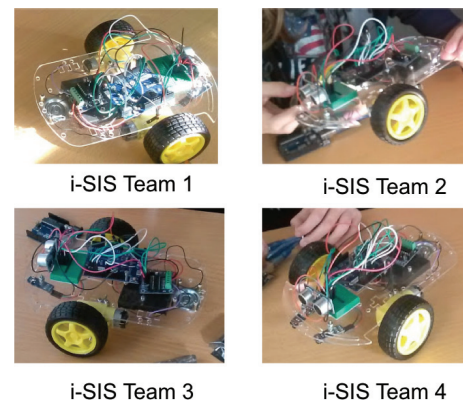

i-SIS Team 1   i-SIS Team 2

i-SIS Team 3   i-SIS Team 4

Fig. 10. Four units of i-SIS totally assembled by teams.

VI. FUTURE WORK IN I-SIS

Robotics has been advancing over the years and has been implemented into the life of the human being. It will not take long for it to become a necessity rather than a tool, and lately its presence has become essential for the optimal development of businesses and industries. The future work of this project is to integrate it into the educational initiative of the local Department of Education entitled "Mobilize Coding" [13], which is a festival held in the context of the mSchools (Mobilize schools) program, and sponsored by the International Association of mobile companies and the Barcelona Mobile World Capital Foundation. In that sense, we will implement the curriculum in which students will design and develop an application for mobile devices that

communicate via bluetooth with our autonomous vehicle i-SIS, combining robotics and mobile applications.

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Educational Robots and Mathematical Modelling

Exploring the use of Turtle type robots in High Schools

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Abstract— **Do Turtle type educational robots have a role to play in High School? In general the use of these robots is in early years and primary schools. In High Schools the use of Lego and Vex construction type robots predominate. According to the Educational Robotic Application (ERA) Principles Turtle type robots can support the development of older students. This poster reports on a pilot project exploring this principle using the Roamer® robot.   The project showed how robots can make a positive contribution to enriching a student's mathematical experience and provided important insights on how to improve the organisation of robotic activities.**

Keywords—Turtle, Logo, Roamer, Educational Robotics, Mathematical Modelling, Educational Robotic Application Principles, ERA Principles, Embodiment, Valiant Technology

I. INTRODUCTION

The first educational robot was developed in 1969 [1]. The Turtle robot was the brainchild of Seymour Papert as an extension of his program language LOGO. This was designed to enable even young children to use programming as a pedagogical method. The computers used at the time were PDP-1s. They were housed at MIT or BBN Technologies Inc.[1] and the school connected to them via teleprinters.   VDUs (Visual Display Units) did not exist [2].   The Turtle robot provided students with something they could visualize and manipulate. However, examination of the 62 Logo Papers written over a ten year period between October 1971 and October 1981, shows that the vast majority of work was done with virtual robots [3].   This also reflected many Logo publications [4], [5], [6], [7].

Catlin and Blamires postulated The Educational Robotic Application (ERA) Principles [8]. This meta-analysis of work with Turtle type robots since their inception results in a framework of ten principles against which the outcomes of efforts with educational robots can be evaluated and correlated.

In the heyday of Logo, Turtles were used in primary schools and students "graduated" to screen Turtles in high school. This was consistent with Piagetian Stage theory which in part underpinned Logo. This poster reports on work aimed at exploring the thesis that the concrete nature of Turtle robots can enrich the experience of older students.   The ERA Embodiment Principle states," *Students learn by intentional and meaningful interactions with educational robots situated in the same space and time*." This principle makes the claim that there is at least a qualitative difference in a student's experience with a physical and virtual robot.   This is a conjecture which is subject to ongoing research. The Roamer was used in this project which is programmed directly through its onboard keypad using a derivative of LOGO [9].

II. PROJECT SETTING AND OBJECTIVES

This poster reports on work aimed at exploring the thesis that the concrete nature of Turtle robots can enrich the experience of older students. Turtles focus on Teaching With Robots, and this activity aims to develop student's ability to use mathematics to solve practical problems.

The ERA Pedagogical Principle identifies 28 different ways of using robots in an educational environment. This activity includes: Mathematical Modelling, Presentation (a means for students to explain their work) and the Provocateur (inciting thinking and discussion). In this case discussions about the nature, use and morality of statistical data.   The ERA Curriculum and Assessment Principle implies that activities should not focus on the robot, but the educational value of the student. In this type of activity the robot plays an important, but only a supporting role that augments this experience.

The project took place in an after school mathematics club in Kingsdale Foundation School in South London with a Year 9 students (14 year old). The authors have noted number of characteristics of such clubs which effect the learning environment: 1) They are voluntary and take place in a more casual atmosphere than normal lessons 2) Students are tired and less attentive after the school day. Maths teacher Edward Otineo and Valiant's Dave Catlin and Kate Hudson supervised.

III. THE CHALLENGE

The students were asked to design and model a bus service for a small town[2]. They were given the town map shown in Fig 1, showing buildings, building function and occupancy/usage details. The students were made aware of some of the design issues used in the development of mass transportation systems: Service Levels, Standard Service Periods, etc. [10].   This project is very open ended with multiple possibilities for extending it in a variety of directions for example: visits by local bus companies or transport museums, data gathering in

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[1] The company who ran the project that invented LOGO and Educational robots.

[2] This reports on the activity "On the Buses" is covered by Creative Commons License BY-NC-ND. Attributions should be made to Valiant Technology Ltd.

the field like timing people getting on and off of buses and how journey times vary according to traffic conditions.
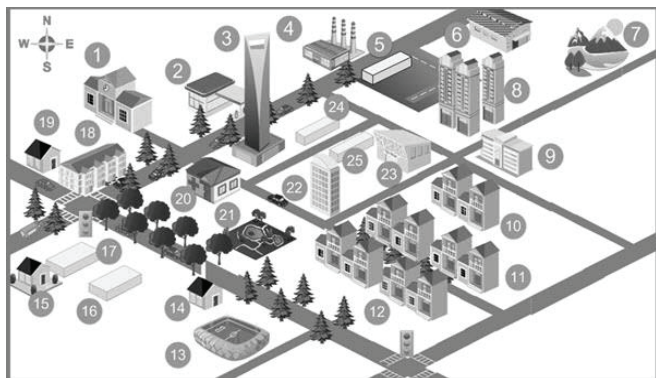

Figure 1 The town map.

IV. THE ACTIVITY SESSION

Students engaged with the design problems and thinking through the issues involved. One group became fixated on buses going to the sports stadium, whereas others realised that a normal bus service could never satisfy match-day demand for transport and it required a special service. The first group eventually realised this when they came to create the bus time tables. This was an indication of a positive contribution made by the activity. It was clear that the students had the mathematical knowledge to solve the problem, but struggled to apply that knowledge to resolve the practical problem – certainly they struggled to do so in an efficient way.

The activity provoked a wider debate about statistics and their use. An example of this was a discussion of how the State of Arizona could reliably use the reading scores of 3rd graders to predict how many prison beds they would need in the future[11]. The students considered the statistics prejudicial and unethical. A lively discussion pointed out the neutrality of statistics. The UK uses the same statistics to plan preventative interventions. A detailed account of the work done, written by the students is available online [12].

V. STUDENT LEARNING AND EXPERIENCE

What is the point of Arizona prison statistics? First it occurred in the debate. But it was also indicative of a transformation in the students perspective about statistics. Normally school statistics is about data provided by the teacher and learning a set of manipulative techniques. In this activity students began to see them as way of evaluating situations and solving problems that had wide social impact. On a practical level students did not understand how to make mathematical judgments when the data supplied was not specific enough to solve the problem. The challenge helped them appreciate they were creating a mathematical model which would be tested and revised. So they were free to make assumptions understanding that in practice such a model would be field tested and then adjustments made to the model. They also became aware that the mass transit industry used data gathered over many years to help them devise effective bus schedules, but they would still take care to build and then test their models. Specific data on the students response to the activity was not gathered. However a key indicator is that the students were inspired to attend the workshop for 5 weeks. In these types of workshops students stop attending if they have no interest in the task.

VI. THE VALUE OF THE ROAMER

The fundamental question is what did Roamer add to the project? Apart from the suggestion that using the robot to introduce the activity might have some benefit had there been no need of it so far? Mathematics teacher Edward Otineo said, "*I think that using the robots was beneficial to the pupils as it added a practical dimension to the whole project. The visual element of the behaviour of the robot helped even though it depended on the robot being programmed correctly. There was the issue of calculating distance of their chosen routes which I think was helped by the use of a robot. I also think that they were just fun to handle and programme.*"

Viewed from the holistic perspective on the activity the robot did provide a focus – the production of a mathematical model. But this activity demonstrates the ERA Practical Principle by showing how easy it is to create an interesting scenario without needing the expense of software development.

VII. CONCLUSION

One of our motivations behind this activity is exploring the use of robots in a subsidiary role. As smarter robots become less expensive we predict this type of application will become more prevalent. This pilot project helped us to understand how to improve the planned repeat activity. We presented the problem to the students top-down. This was a mistake. In a manifestation of the ERA Engagement Principle the students were eager to use the robots from the start. In retrospect we should have utilized this enthusiasm to introduce the activity via a bottom up approach. More attention should be paid to the group sizes to ensure students are kept busy. The inclusion of a physical robot did seem to impact the activity.

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Educational Robots and Mathematical Modelling

Exploring the Use of Educational Type Robots in High School

Dave Catlin (Valiant Technology Ltd) and Edward Otieno (Kingsdale Foundation School)

Introduction

Traditionally Turtle type robots have been thought of as tools for primary school education. This Project shows how to enrich the experience of older students by using the Roamer to help design and mathematically model bus routes.

Fig 1: Turtle type robots; the Valiant Turtle, Classic Roamer and Roamer.

Roamer®

Derived from the original Turtle these Roamers are primarily used in a TWR (Teaching with Robots) context. A cut-down version of LOGO software is embedded in the robot's microchip and is normally programmed through its onboard keypad.

Turtles Vs Construction Type Robots

The game below aims to develop a student's estimation skills. Children estimate distances then program Roamer to travel forward to their target. The one who scores the most wins. The teacher needs to be able to set up the robot and activity within one or two minutes of the start of the lesson.

Fig 2: Six year old pupils using Roamer to develop their estimation skills.

These kinds of activities make the use of the technology accessible to many teachers who lack technical skills.

Activities like this are prevalent in Primary schools. Is there an equivalent class of activity suitable for high schools?

Project Objectives

The project aimed to make to enrich a student's mathematical experience and help further our understanding of this type of activity in high school.

The Challenge

To design a bus route for a small town. Students were asked to:

1. Decide the bus route
2. Situate the bus stops
3. Create a bus time table
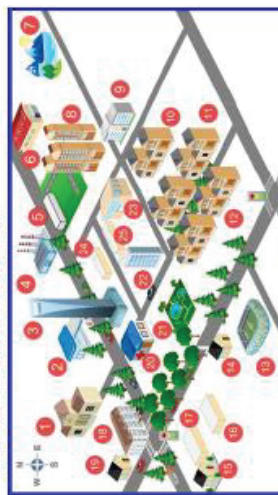4. Use Roamer to model and test their time table

Fig 3: Map of a small town showing the buildings.

Students were provided with the town map and information about the function and occupancy of each building. Initially they struggled to understand how to estimate how many people might be using the bus at any time. Eventually, they realised the purpose of the mathematical model was to create something that could be tested. They then used the data to make a best estimate. Programming the robot to test the idea showed up a number of anomalies in their design which they then improved.

Weekdays	Bus Frequency	Nº of Passengers	Weekends	Bus Frequency
5am to 7 am	20 mins	45	5am to 7am	30 mins
7am to 10m	6 mins	37	7am to 10am	20 mins
10am to 2pm	30 mins	38	10am to 8pm	12 mins
2pm to 4pm	10 mins	18	8pm to 12pm	18 mins
4pm to 8pm	6 mins	28	12pm to 5 pm	30 mins
8pm to 12pm	20 mins	10		
12pm to 5am	40 mins	6		

Table 1: Example time table created by the students.
The students did not calculate the Number of passenger travelling at the weekend because of these limitations.

(GO) You can see the students' report on the project on http://goo.gl/049dOX

Kingsdale Foundation School Maths Club

The project took place with Year 9 (14 Year olds) gifted maths students. After school clubs are more casual than formal classes and students tend to be tired at the end of the day. Attendance is voluntary. The high turnout for the 5 weeks project is a marker of student interest in the project.

Fig 4: Students develop their models. Most of the work does not directly involve using the robot.

Robot does not need to be the main focus to the activity.

They can play a valuable supportive role.

the use of educational robots is to become widespread and fulfil their potential there will be a lot of activities where the robot plays a supportive role. This project is one of several where this idea is being explored.

Fig 5: Tape was used to layout the streets then the students used Roamer to test their models.

Enrichment

After school clubs offer the opportunity to use broader, more experimental approaches to learning. Generally, a students experience of statistics is being given data by the teacher and learning how to manipulate it. The robot provided them with a different goal. Instead of stopping with the production of the bus time table they had to provide a dynamic demonstration of their ideas. Viewing this activity holistically the activity provoked passionate discussions about the nature and ethical use of statistics.

ERA Principles

The Educational Robotic Application (ERA) Principles is a framework of ten elements aimed helping the development and evaluation of educational robots and their activities.

Conclusions

The Educational Robotic Application (ERA) Principles is a framework of ten elements aimed helping the development and evaluation of educational robots.

ERA: Embodiment—The physical robot provided

ERA: Curriculum and Assessment—This activity did provide students with an augmented and practical experience of statistics beyond which they get from normal teaching approaches. The demonstration of their model provided the teacher with a way of assessing the quality of the student work.

ERA: Pedagogical Methods—There are 3 methods evident; mathematical modelling, presentation (of their work and ideas) and the provocateur (the creation of an environment that provokes the children to think and debate issues and ideas).

ERA: Engagement —The students were attracted and excited about using the robot. We can improve the activity by using this motivation to present the activity in a bottom-up fashion (we used a top-down approach).

ERA: Sustainable Learning — This is lifelong learning and includes things like problems solving and working as a team.

ERA: Practical — The ability to quickly set up the activity and modify it to suit the group makes it adaptable and practical.

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Roamer: www.roamer-educational-robot.com

Contact

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Keynote Lectures

1. Webots and ProgBot Contest
    Olivier Michel, Cyberbotics S.à r.l., Switzerland

2. Astronauts and Robots
    Claude Nicollier, astronaut, Swiss Space Center, EPFL, Switzerland

Workshops

1. Practical Mechatronics - Training for Mobile Robot Competitions
   Org. Anton Yudin, D. Sukhotskiy, M. Salmina

2. Which approaches do actually work when introducing children to robotics?
   Discussing lessons learned and failure stories
   Org. Lara Lammer, Martin Kandlhofer

3. La robotique scolaire - un potentiel au-delà de la robotique
   Org. Denis Leuba and al.

RiE 2015

6th International Conference on

Robotics in Education

Workshops

May 20-23, 2015

Yverdon-les-Bains, Switzerland

Workshop I | **Practical Mechatronics**

May 20th 2015, 9h-12h, HEIG-VD, Av. des Sports 20, Room S147

Practical Mechatronics

Training for Mobile Robot Competition

Organized by the the National Organization Committee (NOC)
for Eurobot in Russia, along with the Swiss NOC

The main aims of the workshop is to foster cooperation between education people and organizers, as well as to stimulate interest of youth for robots and technology.

The former goal is best addressed in the present, more theoretically oriented workshop, organized in RiE-2015 context. Here, possible contributions from additional experts are also welcome.

The latter goal is better addressed in the context of robot competitions and takes place at La Marive between Thursday 21 and Sunday 24 May 2015, with 2 hr sessions, several times a day.

The audience of the practical workshop is very broad and starts from 6-7 year old children. Several steps allow different age segments to potentially find a suitable task. Student segment starting at about 17-18 is less considered for testing the main workshop content, but can still find some other, interactive parts interesting (control of a robot, control of a drone…).

The workshop may benefit from a fablab environment (laser cutter, 3D-printer…) also on-site.

(re. Proposal Anton Yudin, D. Sukhotskiy, and M. Salmina, 29 April 2015, last ed. 15 May 2015)

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Workshop II

Children and robotics - Best Approaches

May 20th 2015, 13h30-17h, HEIG-VD, Av. des Sports 20, Room S147

Which approaches actually work for introducing children to robotics?

Discussing lessons learned and failure stories

Organized by Lara Lammer and Martin Kandlhofer
Schräge Roboter – das kreative Mitmachlabor Vienna University of Technology
Institute for Software Technology, Educational Robotics, Graz University of Technology

In this workshop, we will discuss workshop designs to introduce children to robotics, with a special focus on school settings.

Workshop participants will elaborate their own methods (art or STEM focused, black boxes vs. white boxes, top-down vs. bottom-up) and evaluate each presented method with a set of agreed evaluation parameters.

The outcome of the workshop will be a summary of diverse methods and techniques (especially lessons learned and failure stories) highlighting advantages and disadvantages of each as evaluated by experts.

Exemplary questions to be addressed:

- Definition of technology and robots?
- Theory first, then practice or vice versa?
- How much complexity? How much tinkering?
- Black boxes ("selective exposure") or white boxes?
- Which examples work best?
- How to handle different team personalities?
- How to handle different interests and backgrounds?
- Quick wins or not?
- Top-down approach starting with scenarios or specific problem-oriented bottom-up approaches?
- How to evaluate the impact of robotics in education?
- How to attract children who are not already interested in STEM fields?

http://workshops.acin.tuwien.ac.at/RIE2015_Evaluation_ER_Methods/index.html

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WORKSHOPS

May 20-23, 2015

Yverdon-les-Bains, Switzerland

Workshop III | **Robotique scolaire - un potentiel au-delà de la robotique**

May 20th 2015, 13h30-17h, HEIG-VD, Av. des Sports 20, Room S106

La robotique scolaire

un potentiel au-delà de la robotique

Organisé par Denis Leuba
Unité d'enseignement et de recherche
"Didactiques de l'art et de la technologie" UER A&T
Haute école pédagogique du canton de Vaud - HEP, Lausanne
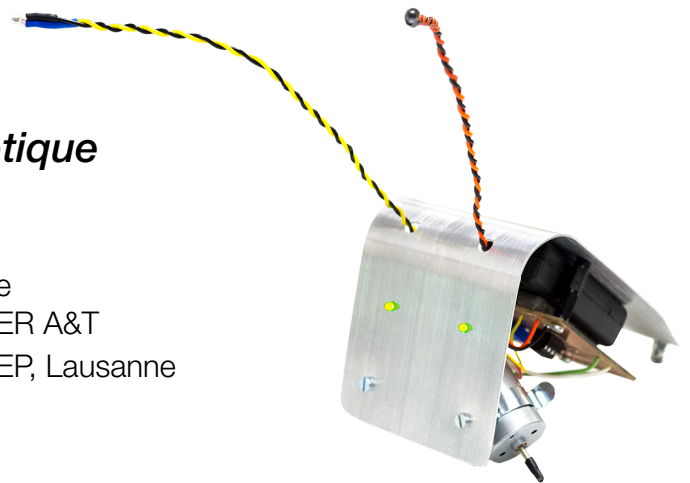
L'atelier sera lancé sur la base de quatre posters présentant une étude de cas: un petit robot original permettant la rencontre d'activités créatrices aussi diverses que le travail du métal, du bois, une introduction à l'électronique et à la commande de moteurs.

Ce projet s'est fait dans le contexte du programme suisse romand PIRACEF (Programme Intercantonal Romand de formation des enseignants en Activités Créatrices et en Economie Familiale) .

Il apparaît que la réalisation du robot peut être une magnifique opportunité de développement des capacités scolaires ou humaines hors robotique (message : la robotique scolaire a un potentiel au-delà de la robotique).

Il s'agit d'un atelier faisant la part belle aux aspects expérimentaux et scientifiques relevant de la robotique en contexte scolaire, auxquels les participants sont appelés à contribuer.

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RiE international conferences on Robotics in Education aim at providing an insight to state-of-the-art educational robotics to participants from both academic and school education. They allow to report on latest results in the fields of research and development as well as new applications, the latest products, systems and components for using robotics in schools, in universities and in informal education.

RiE international conferences have a history of previous successful editions, which witness the continuously growing interest in educational robotics in Europe and world-wide. They had counted so far 5 editions; in Bratislava (2010), Vienna (2011), Prague (2012), Lodz (2013), and Padua (2014). And Yverdon-les-Bains, in 2015, brought an additional contribution.

The 6th International RiE Conference, RiE 2015, happened in a broader context both thematically and geographically. The final round of Eurobot robotics competition was organized this year at Yverdon-les-Bains, as well as the Swiss Robotics Cup and a Robotics competition between local, primary and secondary schools, along with the « Robots:15» festival and Yverdon-les-Bains "Year of Robot" events. Indeed, many activities relating to robots in the realms of art, science, technology, and education were organized those days in Yverdon-les-Bains, which attracted a special attention from contributors. This is also well in line with "Robot-Int", the Robotics-International initiative to promote robotics for the benefit of mankind, which could make a new step of development during these events.

The RiE 2015 Conference has featured two keynote lectures, relating to real-time robot simulation and space context, which can still be watched on YouTube. Mostly though, the presentations reported in the present book have addressed more specific, scientific issues. The RiE 2015 Robotics in Education Conference mainly consisted in six technical sessions where were discussed Methods and Best Practices, Education and Mechatronic Platforms, Curriculum Aspects, Competition-related Aspects, Conceptual Aspects and Cognition, and some other selected topics.

Roboptics Editions