Development, Usability and Communities of Modular Robotic Kits for Classroom Education

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***Abstract*—Robotics is becoming a mainstream phenomenon, entering all domains of our lives. Besides the cutting edge research and development, the classroom and home education of robotics are equally becoming important. Numerous educational kits have appeared on the market recently, ranging from simple toolboxes and toys to complex, configurable R&D sets. Their value in formal teaching lies in modularity, and the applicability of the adjoin curriculum. Some kits have already attracted major crowds of users, forming strong communities. The aim of this article is to review the currently available educational robotics kits along their possible usability in formal education, focusing the analysis on system capabilities, modularity and teaching materials available. The summary of these teaching aids should ease the decisions of robotics experts and instructors when choosing their tools for teaching and demonstration.**

I. Introduction

Robotics needs to become an integral part of classroom education, since we have to prepare the next generation for the organic coexistence of robots at various levels of the society. In higher education, engineering schools have long been relying on using open interfaces to certain industrial robots, and integrated such systems for teaching, or provided funding for talented students to build their own robots. However, at undergraduate, and moreover, at K-12 level, price and complexity might be a prohibiting factor, as students need more structured form of robot courses, and building fully custom robots might be impossible for larger classes.

Robotic kits have been around for a long while, but only recently achieved such a level that they are now to be considered as a distinct sub-field of educational robotics. Their popularity increased with the recent renaissance of the STEM fields (Science, Technology, Engineering and Mathematics) in higher education [1]. When it comes to the design of a new robotics course, many factors play a role regarding the choice of the optimal hardware platform. Modularity is an absolutely key requirement, since new classes are using the kits every semester. Modularity is supposed to come hand in hand with reconfigurability and tuning of course materials and tasks, leading to an optimal system after customization. Systems with very limited options and extensions were not included in this review, since they would never be able to provide the above advantages.

When presented with a set of tasks, children are getting familiar with the basics of mechatronics, assembling, building and testing functional equipment. These goals can already be achieved by relying on building kits alone, such as LEGO or fischertechnik.

Software environment provided with the system has great importance to introduce children to robotics related software technologies, while the validated curriculum is necessary to facilitate the work of the teachers and instructors, and also to introduce best practices in the education in a structured way. Some systems only target the functions related to entry level programming, such as ROMO (http://romotive.com), iRobot (http://www.irobot.com), Codie (http://www.getcodie.com) or HEXBUG (http://www.hebug.com), therefore they are omitted. Validated tasks at software level are important, since credentialing can only be guaranteed at a national standard level with accredited teaching programs.

The article guides the reader through the most important systems presenting their main features in a tabular format, facilitating the choice of best use. The work is structured as follows: Section II discusses the most relevant publications in the topic. Section III explains the methods of research, selection and evaluation of the discussed robotic kits, while Section IV gives a detailed overview of the most relevant robotic kits identified during research. The paper is concluded with a summary of our findings and the discussion of Table I, summarizing the most important feature of these robotic kits.

II. Related work

While robotic education has grown tremendously in significance, there are surprisingly few publications assessing or comparing existing products and prototypes. A notable review was written by Ruzzente et al. about available robotic kits for tertiary education, addressing their versatility, modularity and price, highlighting kits with ROS compatibility, but providing little information about community development, software and educational materials [2]. Back in 2007, Hilal et al. published a detailed survey about the available commercial starter kits for robot building [3]. In the past decade, the robotics community experienced a rapid development of the field, and the appearance of new kits, technologies and software environments created a strong need to publish an update the list of kits. The usability of robotic kits in teaching artificial intelligence [4], there general use in the classroom [5] and their integration into the educational methodology have been discussed in the literature in general [6]. Benitti explored the potential of using robots in schools in a review paper [7], while the opportunities and challenges of this new trend were addressed by Alimisis in 2013 [8]. An overview of the possibilities for teaching STEM subjects using robots was published by Chiou [9], but none of these works gave a detailed description of individual robotic kits and their capabilities.

III. Methods

When it comes to evaluating educational materials, creating an objective metric proves to be very challenging due to the diversity of these tools in terms of intended use, efficiency, level of abstraction etc. In order to get an overview of the existing educational materials in STEM education, three main channels were investigated for gathering information:

- Investigating online and printed educational materials of the STEM fields;
- Contacting the distributor of robotic kits/educational materials directly;
- Browsing the websites of the manufacturers of various robotic kits;
- Conducting literature research on related work from conferences and journal papers.

Our main goal was to create an objective evaluation criteria focusing on *educational resources*. This paper focuses on robotic kits with a level of modularity (explained later), which are partly or completely intended for use in STEM education.

Evaluation of the collected kits was based on a subjective classification. Consequently, the diversity of the educational materials offers several evaluation criteria, which could be considered prior and during collection of data. These criteria include:

- Cost;
- Target audience;
- Modularity level;
- Quality of educational materials;
- Design (mechanical and electrical);
- Development and extension possibilities;
- Compatibility;
- Availability;
- Portability.

As it can be seen, most combinations of the above mentioned criteria would result in an evaluation that is too selective for building a hierarchy. However, as the cost and availability of these kits are the two most important properties, only those kits were included in the review, which were provided with detailed and reliable description to these criteria. The detailed list of criteria can be seen in Table I.

It is generally recognized that the quantitative assessing of the educational impact of robotic kits is almost an impossible task, since, in general, the real impact on the students' performance can only be assessed years later. The quantitative assessment of these kits is essential to motivate educators and school/university staff in investing and using educational kits. In order to give an overview on such approaches, relevant research materials were collected in Table I, for those interested in the topic.

Although most of the kits are available in global distribution, the diverse educational needs and priorities in different countries make it challenging for the manufacturers and distributors to create kits for general educational use that fits these needs. How these systems align with the educational goals of different counties or schools systems is rather a political than a scientific issue. However, during our research it was clearly seen that the popularity of robotic kits in education is significantly higher in the developed countries, where school systems have undergone an educational revolution in the past decades (typically Wester Europe and North America), while the kits are still on the edge of breaking into the market of developing countries (mostly in South Asia and Africa), which still prefer the traditional educational methods. Furthermore, most of the listed toolkits are still unaffordable for average public schools in many countries of the world, therefore for some years the true availability will be restricted due to the cost factor.

Nowadays, robotics in elementary and middle schools is used for hands-on demonstration in programming, engineering, robotics or technology courses. There certainly is a need for a curriculum that emphasizes the use of robotic kits to teach and demonstrate the laws of physics, theorems of mathematics etc. In order to address this critical point, Table I summarizes the curriculum options available for each described robotic kit in three categories: *SDK* (software development kit), *Education* (STEM fields) and *Other*.

The modularity of the discussed kits is one of the key properties, since it facilitates learning and offers large variety of construction possibilities. Due to the diversity of the commercially available kits, an objective evaluation of the level of modularity is challenging. A detailed modularity description for each kit discussed in Section IV, and a subjective rating of this property has been included in Table I and were rated as follows. Robotic kits that require assembly upon purchase, but only one type of robot can be assembled using the parts, were given the 1/5 points to the modularity level. Robotic kits with pre-built sensor mounts, changeable actuators and sensors but a limited variety of skeleton parts were rated 3/5. Kits containing elementary building parts such as gears, joints, rods and plates, which allows the construction of any custom designed and modifiable robot, were rated as 5/5.

Before the detailed discussion of the systems, some of the frequently used phrases and terms are explained below.

- *Curriculum*: Teaching instructions, theoretical explanations and evaluation guidelines, which, in our case, is usually incorporated in the robotic kits or is created by a third party.
- *Educational material*: Any type of material, such as kits, textbooks, curriculum, guidelines etc. that is intended for use in the classroom or home education.
- *STEM curriculum*: Curriculum and guidelines for teaching subjects that are focusing on the STEM fields.
- *Programming curriculum*: Curriculum and guidelines for teaching the programming the robotic kits.
- *Robotics curriculum*: Curriculum and guidelines for teaching topics related to robotics, such as robot motion, robot control, mechatronics etc.
- *STEM kit*: Building kits that are intended to be used in education related to the STEM fields, not restricted to robotics or programming education.

IV. Robotic kits

This chapter reviews all existing educational robotics kits identified based on scholar and general internet search, survey of exhibitions, and interviewing experts. An overview and comparison of the most important features of each kit is provided in Table I, while their official missions, catchphrases and bywords are also provided in this section. It is important to note that the authors do not wish to propose a relative ranking among the listed robotic kits, since their usability and overall score should be weighted by the specific environments of intended use.

Certain kits are omitted from the review, since they are more suitable from home education than classrooms. These include the Multiplo (http://multiplo.org/), which is an open-source, Arduino-based system (a successful Kickstarter project); the MOSS (http://www.modrobotics.com/moss), which is a robotic kit using intelligent cubical blocks, dedigned for younger children; and the ArTeC Blocks Robotist (http://www.artec-educational.com), a robotic kit extension of the ArTeC Blocks. Other robots, such as the Nao (Aldebaran Inc.–SoftBank Group Corp., Tokyo, Japan) [10], the YouBot (KUKA Roboter GmbH, Augsburg, Germany) [11] or the RobotsLAB BOX (RobotsLAB US Inc., San Francisco, CA) [12], gained recognition in educational use, however these are all excluded, since they cannot be employed as robotic kits due to their high cost and complexity of use. Numerous companies offer modeling accessories, sensors and actuators with limited, or no structured frameworks, or not in the form of robotic kits. These were excluded from this survey, however, mentioning some of them is relevant from the point of view of categorizing the available modular robotic systems. ServoCity (*http://www.servocity.com*) is an online store of a large variety of robot modeling parts and accessories, which also supplies the Actobotis project (*https://www.sparkfun.com/actobotics*) with components. Actobotics was created in 2013 as a ball bearing based precision system, looking into developing teaching materials for electronics education and launching an online developer community. ReRo (*http://rero.com.my*) is a small reconfigurable robotic kit intended for younger children. Further robot parts and accessories from independent manufacturers can be purchased through various distributors, such as RobotShop (*http://www.robotshop.com*), SparkFun (*http://www.sparkfun.com*) or Karlsson Robotics (*http://www.karlssonrobotics.com*).

A. LEGO Mindstorms

Fig. 1. LEGO Mindstorms EV3 basic set. (Source: LEGO)

LEGO Mindstorms (*http://mindstorms.lego.com*) is probably the most popular modular robotic kit, building on the famous bricks, with a wide range of applications. The official mission of LEGO is to *inspire and develop the builders of tomorrow*. Developers aim to use the LEGO kits in education and popularizing science, while numerous universities around the world are involved in product and educational material development. Most notable are Carnegie Mellon University and Tufts University for the structured curricula they provide for LEGO Mindstorms kits [13]. The general advantage of the kit is its compatibility with all LEGO parts that can be found in almost every household, allowing its gradual integration into education from a younger age already.

Originally introduced in 1998, the LEGO Mindstorms is a true success story. The newest, 3rd generation of the family, called the EV3, was released in 2013. Like all other Mindstorms sets, the central element of the package is the Lego Intelligent Brick, which serves as the I/O interface, communication interface and computational unit. Following LEGO's community development policy, the firmware of the Intelligent Brick has been released open source. LEGO is also offering an SDK for more user-friendly solutions, and a Hardware Development Kit (HDK) for custom component development. These are accompanied with the complete documentation of the hardware structure of the Intelligent Brick and a Bluetooth Development Kit (BDK) for improved wireless communication.

There is a rich choice of programming tools for the Mindstorms kit. Besides the official National Instruments GUI-based software, the most widely used languages include the RobotC, NBC and NXC, which are C-based environments with extensive LEGO Mindstorms libraries. The 2nd generation of the kit, the NXT has developed a remarkable ROS (Robot Operating System) development community, while the ROS-compatibility of the EV3 system is still under development.

LEGO released complete educational curricula for K5–K12 levels, and facilitates integration with the TETRIX kit (*https://www.tetrixrobotics.com*), an educational robotic kit that was joined to Mindstorms in 1998. The teaching materials include design engineering projects, building and programming instructions and several hundreds of task examples. There is also a vivid online community built around the system with thousands of active users world wide (*https://community.lego.com/t5/MINDSTORMS/bd-p/1042*).

B. Lynxmotion

Lynxmotion (*http://www.lynxmotion.com*) is one of the world's most experienced robot kit developer and manufacturer, creating products for hobby, educational and scientific purposes. Their official motto is: *Imagine it. Build it. Control it.* Their basic kit, the Servo Erector Set (SES) Construction Kit provides a very high level of modularity, offered with the official FlowBotics Studio software, using the Ruby programming language. The main mechanical

Fig. 2. Lynxmotion's Servo Erector Set. (Source: Lynxmotion)

elements of the SES are made of aluminum with fairly flexible plastic connector elements. There is a large palette of actuators, motors and manipulators. Lynxmotion also offers special aluminum tubes that can serve as connectors or legs for some of the models, equipped with sensors. Two types of central computational units are distributed: a changeable microprocessor for general use, for which the manufacturer supports programming using the FlowBotics Studio; and on the other hand, the BotBarduino unit, which is an Arduino Duemilanove compatible microprocessor, where Arduino-based programming languages are recommended. The system is also compatible with the Sony PlayStation PS2 console (*http://us.playstation.com/ps2/systems*), thus direct remote controlling can be achieved. Lynxmotion gives full support for software and hardware development. Wiring, pinmaps, properties of the microchips and their programming and firmwares are available on the manufacturer website, while the 3D models of the SES elements can also be downloaded in SolidWorks-compatible format. Several basic/educational kits are available with building instructions, however, no structured educational materials or curricula are offered.

C. Dongbu Robot

This Chinese company was founded in 1998 under the name Established Data Technology (*http://www.dongburobot.com*). Today, their products can be found in various fields of robotics, including industrial, service and educational/hobby robotics. Their most successful robotics kit is the Hovis Lite, which can be used for building humanoid and many other types of robots. The enclosed GUI-based software, the DR-Sim allows the creation of simple routines, while more complex programs can be created using the DR-Visual Logic software, which is a "drag-n-drop" C-based programming environment. On the software side, the Hovis Lite is widely compatible with conventional programming languages, such as Microsoft Robotics Developer Studio, Visual Studion and AVR Studio. The distributor DST Robot's mission is *to be a comprehensive enterprise of robots includion industrial robots and service robots*, which indicates that Hovis Lite was initially intended to be an educational branch of a professional robotics company. The modularity of the system is limited due to the small variety of injection molded plastic elements, but this limitation is compensated with a very extensive set of options for motor control. The core of the control unit (DRC unit) is an Atmel microprocessor, therefore the system development can be done on Atmel's own programming platform. Most of the sensors are integrated into the DRC, thus hardware development opportunities are quite limited. New hardware components can be purchased from other manufacturers, but they require custom programming. The company does not provide official educational materials or curriculum. In the meanwhile, their robots are widely used for developing novel educational platforms focusing on robot programming and camera image processing [14].

D. Bioloid

The South Korean Robotis (*http://www.robotis.com*) started as an industrial robotics development company, and issued its first educational kit, the Bioloid in 2005. Today they are one of world's leader educational robotics companies. Two extensive development kits are distributed on the market: the Ollo family is mechanism-oriented, with a high level of modularity, while the Bioloid family is robotics and programming oriented, being sold in 5 specific development kits. The Bioloid STEM kit is compatible with the Ollo elements, although compatibility with other kits and non-Robotis products is very limited. Their motto is very similar to the one of Lynxmotion: *Design, build and program your own walk of life*, highlighting that their main focus is on walking robots. Bioloid kits are equipped with two types of control units, depending on the family. While the Atmel processors are very popular in the market among competitors, the STEM, PREMIUM and GP kits are sold with 32-bit ARM M3 processors, opening up now possibilities in drive and control. Programming of the robots can be done using the official Roboplus software, which contains several programming modules, supporting the controller. Kits equipped with the ARM controller can be programmed using embedded C, which is a useful tool for hardware development. The manufacturer encourages the users for developing the control panels in order to extend the sensor and actuator variety, which is quite limited at the current stage. Robotis offers the STEM kit for educational purposes due to its compatibility with the Ollo family (*http://www.robotis.com/xe/ollo*). Teaching guidelines, curricula and full support is offered for those who wish to use these kits in education. 12-week curricula are offered for learning basic principles for building robots, scientific theories and basic programming, provided in three educational kits: Ollo Starter, Ollo Explorer and Ollo Inventor Expansion Set.

E. Orion Robotics

Orion robotics was founded in 2010 (*http://www.orionrobotics.com*), recently acquired by ION Motion Control. Their mission is to create robotic kits that

Fig. 3. Bioloid STEM kit. (Source: Robotis)

Fig. 4. Fischertechnik Robotics: TXT Advanced kit. Source: Fischertechnik

can easily be assembled and used. Most of the software and hardware elements and support are provided by Basic Micro Inc (*http://www.basicmicro.com*). The motto of the company is: *Control your word*. The manufacturer offers four larger families of kits, which can be used for building robotic arms or tracking, wheeled and walking robots. Due to the special mechanical design, the modularity of the kits is very limited, but still possible to combine a few of the kits. The main mechanical elements are created from aluminum, and the constructions are very massive. All of the hardware elements are Arduino-compatible. The robot uses the Da Vinci panel as its main computational unit, which is an Arduino compatible board with an Atmel processor. The programming can be done using the official Orion Robotics Studio, using the Basic-like MBasic language. Some kits can also be programmed using C-based languages.

In order to facilitate development, all firmware are available on the manufacturer website. Because of the text-based programming, this kit is not recommended for entry-level programmers. In higher education, all of the kits can serve as useful educational platforms, however, except for the example programs, no structured educational curriculum is provided.

F. Fischertechnik

Fischertechnic (*http://www.fischertechnik.de*) is a company with long history and tradition, having been the competitor of LEGO ever since its 1965 foundation. They offer a wide palette of modular building sets from developing toys for children to industrial robotics education. The company is very proud of the premium quality they deliver, all the construction sets being produced in Germany. The motto of the educational sets: *Understand technology while playing!* Most of the mechanical elements are made of plastic, but a large variety of aluminum elements can also be found in the robotic kits. The modularity level is very high, including a set of special elements, such as actuators, batteries and cables (mechanical, electrical and pneumatic). Fischertechnik also offers solar motors, micro servos, solar cells and a pneumatic set. There is a number of different controllers in distribution. The E-Tec module is ideal for basic programming tasks, while the ROBO TX is a more advanced control unit that can be used for more complex tasks, using the RS485/I2C protocol. The official programming interface is a 3D CAD-based GUI, the fischertechnik Designer, containing the models of all products, capable of simulation the relative motion of each element. The ROBO TX unit can be programmed using the ROBO Pro software, relying on the “drag-n-drop” approach. ROBO Pro is compatible with the Microsoft Robotics Developer Studio, allowing higher level software programming.

Fichertechnik creates full educational building kits and STEM kits, including building and programming instructions. STEM kits include curricula for classes in physics, green energy, optics, pneumatics, mechanics and electronics. There is an extensive community of developers of teaching materials and curricula, while the manufacturer provides full support for those who are using the products in education.

G. RoboBrothers

RoboBrothers (*http://www.robobrothers.com*) offers a limited choice of robotic kit families: the RoboCrawler, the Philo Junior and the RoboPhilo. All of these kits can be purchased RTW (Ready To Walk), assembled form, or as a kit with building and programming instructions, making it capable for educational purposes. As they also indicate in their motto, *Most Affordable Programmable Robotics*, their products are among the lowest priced robotic kits available.

The assemblies carry a low level of modularity, but the elements are compatible between the families and there is an extended PS2 controller and Microsoft Kinect compatibility. The central computational unit is an 8-bit Atmel microprocessor,a low-power processor compared to the other mentioned robotic kits. The official programming interface is the Philo Motion Creator, which is a simple GUI for creating movement patterns. Additional patterns can be downloaded from the manufacturer website, although the possibilities are limited using this software. The strength of this kit lies in the C and C++ based SDK offered, extending the possibilities in movement pattern generation. Furthermore, the basic kits can be completed with additional kits and accessories that can be useful for educators.

H. KumoTek

KumoTek is a US-based manufacturer and developer of robotic kits, sensors and educational materials, offering three major families of robotic products: humanoid robots and building kits, entertainment robots and sensors, cameras (*http://www.kumotek.com*). Their main mission is to *provide cutting edge interactive robot applications to schools, museums and government agencies*. The KT-X Gladiator Bipedal Robotical Kit and the KT-X Standard Bipedal Robotical Kit are PS2 compatible, and are intended for educational purposes, sold with building instructions.

The central computational unit is an ARM7 architecture HV7 microprocessor. There is a limited variety of sensors, which can be purchased from the manufacturer separately from the kits, useful for development purposes. There is an SDK provided for the motor boards, and there is an advanced support for SDK users. Programming of the system can be done in the official Robovie Maker 2 software, which is based on the graphical positioning of the robot joints, not usable for advanced programming task. KumoTek also develops specialized humanoid sets, the Advanced Humanoid Robots. These robots were explicitly designed for robot competitions, such as RoboCup, making them popular among educators.

I. VEX EDR

VEX Robotics is major player in educational robotics development, designing robotic kits for international robotics competitions (*http://www.vexrobotics.com/vex*). The motto of the company is: *Think. Create. Build. Amaze. VEX.* 3 major families of robotic kits are offered: the VEX IQ is a STEM-centered set of kits and educational materials for elementary and middle school students, VEX EDR is a classroom robotic platform for middle school, high school level, while the VEX PRO is recommended for teams entering competitions.

Thanks to the high level of modularity and the large variety of elements, there is an extensive building, programming and developing community. The shared knowledge and support is collected on the VEX Documentation Wiki page, accessible for anyone interested in the topics (*http://www.vexrobotics.com/wiki/VEX_Documentation*).

In the case of the VEX EDR, the central computational unit is the VEX ARM Cortex-based Microcontroller with 12 input ports, which is very useful for simultaneously receiving data from the large variety of available sensors. The firmware is open-source. The official programming software is the VEX Robotics Design System, but the programming can be achieved using compatible ROBOTC and easyC languages, where the manufacturer offers free webinars and educational materials on the Wiki page. Full educational materials, teacher's guidelines and curricula are available for all educational levels with the STEM kits. There is an active community of developers of teaching materials, accessories (sensors, actuators and controllers), curriculum developers, while VEX offers full support for the developer community.

J. Gears Educational Systems

Gears Educational Systems is a product of DEPCO LLC, which is a US company developing and marketing curricula for K-12 and post-secondary school education (*http://www.gearseds.com*). The Gears Invention and Design system is a modular, heavy-duty mechatronics prototyping kit, consisting of industrial grade components primarily for educational purposes. Their motto is: *Design, Build, Test, and Learn*.

Fig. 5. VEX EDR Classroom & Competition Super Kit. (Source: VEX)

The electronic controls of the system, the XIPMods are the products of Machine Science, using an Atmel microcontroller in the master module. Several other modules are available for communicating with the sensors, actuators and other I/O units. The choice of sensors is limited, most of them have to be purchased from another vendor. However, there is a wide choice of actuators, including pneumatic kits, while CAD solid models of the components can also be downloaded from the manufacturer's website.

The SDK is limited to the possibilities of Arduino programming, which is also the most commonly used programming interface for the Gears-IDS. Alternatively, as the system is compatible with the LEGO NXT, other C-based environments can be used. The Geard-IDS was explicitly developed for STEM educational purposes, the kits are sold with detailed curriculum and teaching instructions, examples and sample lessons for educators, all in connection with the Gears Engineering Construction and Design program *http://www.gearseds.com/gears_program*.

K. Makeblock

Makeblock is a Chinese open source startup platform (*http://www.makeblock.cc*), providing mechanical elements and electronic modules in their kits, mainly for hobby and educational purposes. Most of their products are sold as a set of aluminum mechanical and electronic parts without any specific building instructions, facilitating creativity in system design. Makeblock is now officially partnered with Arduino, participating in the Arduino Atheart program *https://www.arduino.cc/en/ArduinoAtHeart/HomePage*.

The core of the systems is an Arduino processor, therefore Arduino-based SDK is available. There is also a small,

Fig. 6. The Gears Invention & Design System. (Source: DEPCO)

but enthusiastic developer community. Sensors and actuators can be purchased separately from the kits, allowing one to buy the components and build a robot piece by piece. The programming of the robots can be done using Arduino IDE programming or the ArduBlock plug-in, which was explicitly developed for the Makeblock system. As all the kits were intended for educational purposes, full STEM-kits are available with basic curriculum. More teaching materials and support can be found at on the developer community's website (*forum.makeblock.cc*).

V. Curriculum developer communities, competitions

While in most cases the manufacturers offer some forms of educational materials and curricula with the robotic kits, the role of STEM curriculum developers and communities is essential to complete these systems.

LEGO offers extended curriculum packs with the LEGO Mindstorms EV3 Engineering Projects (*http://education.lego.com*). Still, the most widely used and best-known LEGO-based curricula are developed by Carnegie Mellon University's (CMU) Robotics Academy (*http://www.education.rec.ri.cmu.edu/content/lego/ev3*). Robotics Academy offers research-based educational tools and guidelines for teachers, which are based on the EV3 kits, and are aligning with US STEM standards (*http://www.nea.org/home/stem.html*).

NASA recently launched its Robotics in the Classroom—Introduction to Robotics program for 6–8th graders (http://robotics.nasa.gov/edu/6-8.php), offering an extensive collection of robotics education programs, based on LEGO Mindstorms and other, custom-built robotic kits.

Lately, CMU launched its curriculum development project for VEX robotic kits (*http://education.rec.ri.cmu.edu/vex*), forming 6 topics to be covered by the educational material: safety, project management, planning your project, robotic lessons, programming lessons and engineering activities.

STEMRobotics is a curriculum developer community from Portland State University (*http://stemrobotics.cs.pdx.edu*). Their educational materials are open-source, based on, but not restricted to LEGO Mindstorms sets, providing a set of structured teacher's guidelines for STEM robotics education.

Robot competitions present the best opportunities to bring national and international educators, robotic kit developers and end users together. Dozens of annual competitions and challenges are organized world wide, where the above listed robotic kits play a major role.

FIRST is undoubtedly the most successful world wide robotics competition (*http://www.usfirst.org*). In 2014, FIRST registered more than 367,000 students from more than 80 countries, launching competitions for all age groups [15]. Besides the specific LEGO League competitions, other categories have also been launched, where other robotic kits or custom-built robots could be used.

VEX Robotics Competition attracts more than 10,000 teams from countries around the world (*http://www.vexrobotics.com/vex/competition*). While this competition is based on VEX robotic kits, there are 750 tournaments organized annually, making the largest robotics competition for middle and high school students.

Robotics Education & Competition Foundation (*http://www.roboticseducation.org*) provides an online platform for helping educators increase the student interest in STEM fields. The Foundation operates the Robot Events website (*http://www.robotevents.com*), where up-to-date information can be found about the upcoming robotics challenges and competitions.

Professional organizations also play an important role in the popularization of STEM fields and robotics in education. The IEEE RAS Creation of Educational Materials in Robotics and Automation (CEMRA) proposal was accepted in September 2014, in the framework of the IROS 2014 conference TAB meeting. The two-year project includes creation and dissemination of educational materials in Human Movement Understanding and Synthesis, which already involved the 2015 IEEE RAS PEBRAS Summer School *http://www.ieee-raspebras2015.com*. Traditionally, they have not been involved in robot kit or curriculum development, yet they promote the spread of these. The IEEE RAS-TEP (Technical Education Program) is a program jointly run by Member Activities Board (MAB) and the Technical Activities Board (TAB) (*http://www.ieee-ras.org/educational-resources-outreach/summer-schools*), sponsoring and co-sponsoring three summer schools around the world every year. However, it is important to note that as of now, only college students are in the focus of the activity of RAS-TEP. Besides RAS-TEP, the IEEE-RAS Competition Committee also plays a major role in coordinating competition organizations at the IEEE RAS flagship conferences, such as ICRA and IROS. The Institute for Personal Robots in Education (IPRE) is a joint effort between Georgia Tech and Bryn Mawr College (*http://www.roboteducation.org*). IPRE applies and evaluates robots as a context for computer science education, primarily sponsored by Microsoft Research. In order to harmonize and leverage educational programs and activities on the full European scale, euRobotics AISBL created the Topic Group on Education and Training (TGET) (*http://people.mech.kuleuven.be/~bruyninc/TGET*). Activities of TGET include curriculum harmonization, creation of educational materials and organization of summer schools.

VI. Summary

There are many great robot kits, yet diverse in configurability, offering components, curriculum, pricing and so. It is not easy to chose a robotic platform if someone is willing to set up a modern education program on robotics at a younger age. While there is a variety of open control platforms for higher education, and a pool of modular kits is available for K-12, not all have the necessary software development platform or curriculum to easily enable a course development. This article reviewed the most relevant, commercially available robotic kits, investigating their hardware and software capabilities, development opportunities and curriculum developer communities. The findings of this research have been collected in Table 1, listing and addressing the most important properties of the discussed kits. The target age was determined by the complexity of the kits and the required skills for designing, building and programming the robots. The availability indicates whether the product can be purchased or is shipped globally or locally, on what conditions. The modularity level of each kit was addressed on a scale 1-5. Sensor and actuator scores were also given on a scale 1-5, based on their variety, quantity and quality in a specific kit. Software development possibilities and the existence of educational materials and communities were also addressed. Finally, the price of the most relevant families of kits were surveyed and presented.

The authors of this article wish that Table 1 will serve as a useful guideline for future STEM educators, selecting the most suitable robotic kit for visualization and hands-on presentation of their curricula.

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TABLE I

MODULAR ROBOTIC KITS FOR CLASSROOM EDUCATION AND SOME OF THEIR MOST RELEVANT PROPERTIES.

Robotic kit	Manufacturer	Target ages	Availability	Modularity level	Sensor / Actuator score	Software SDK	Curriculum SDK/Edu./Other	Developer community	Price
LEGO Mindstorms *mindstorms.lego.com*	LEGO	10–21 yrs.	Global*	5	4 / 2	Yes	Yes/Yes/ Community	Yes	$350
Lynxmotion *www.lynxmotion.com*	RobotShop Inc.	15–21 yrs.	Global**	4	2 / 3	Yes	No/No/No	Yes	$1000
Dongbu Robot *www.dongburobot.com*	DST Robot	18–21 yrs.	Global**	3	3 / 2	Yes, but limited	Yes/No/No	No	$730
Bioloid *robotis.com/xe/bioloid*	Robotis	10–21 yrs.	Global	5	4 / 3	Yes	No/Yes/STEM	Yes	$350
Orion Robotics *www.orionrobotics.com*	Ion Motion Control	15–21 yrs.	USA	1	2 / 2	Only firmware	No/No/No	No	$1000
Fischertechnik *www.fischertechnik.de*	Fischertechnik GmbH	10–21 yrs.	Global*	5	4 / 5	Yes, but limited	Yes/Yes/Consulting	Yes	$1000
RoboBrothers *www.robobrothers.com*	RobotBrothers Inc.	18–21 yrs.	USA	2	1 / 1	Yes	No/No/No	Yes	$400
KumoTek *www.kumotek.com*	KumoTek Robotics	18–21 yrs.	USA	1	3 / 3	Yes	No/No/No	Yes	$1400
VEX EDR *www.vexrobotics.com/vex*	VEX Robotics	10–21 yrs.	Global*	5	5 / 2	Only firmware	Yes/Yes/ Community	Yes	$800
Gears Educational Systems *www.gearseds.com*	DEPCO	15–21 yrs.	USA	4	2 / 4	Yes, but limited	No/Yes/No	No	$1300
MakeBlock *www.makeblock.cc*	MakeBlock	15–21 yrs.	Global*	4	4 / 3	Yes	Yes/No/Arduino	Yes	$700

* Shipping and distribution available in most but not all countries around the world

** Ships through RobotShop