# A review: Can robots reshape K-12 STEM education?

Mohammad Ehsanul Karim, Séverin Lemaignan, and Francesco Mondada
Laboratoire de Systèmes Robotiques
École Polytechnique Fédéral de Lausanne, EPFL
Email: {ehsan.karim, severin.lemaignan, francesco.mondada}@epfl.ch

***Abstract*— Can robots in classroom reshape K-12 STEM education, and foster new ways of learning? To sketch an answer, this article reviews, side-by-side, existing literature on robot-based learning activities featuring mathematics and physics (purposefully putting aside the well-studied field of "robots to teach robotics") and existing robot platforms and toolkits suited for classroom environment (in terms of cost, ease of use, orchestration load for the teacher, etc.). Our survey suggests that the use of robots in classroom has indeed moved from purely technology to education, to encompass new didactic fields. We however identified several shortcomings, in terms of robotic platforms and teaching environments, that contribute to the limited presence of robotics in existing curricula; the lack of specific teacher training being likely pivotal. Finally, we propose an educational framework merging the tangibility of robots with the advanced visibility of augmented reality.**

## I. Introduction

Robots have the potential to be the next effective add-on to traditional education. The tangibility of robots and the excitement they bring into the classroom environment is considered conducive for learning. Such claims from anecdotal studies have inspired many schools to adopt robotics into their formal or informal curricula. However, the actual contribution of robots in science, technology, engineering and mathematics (STEM) education is not obvious; the fundamental question remains unanswered: Can robots in classroom reshape education and foster learning? In order to answer the question we survey existing literature to seek satisfactory evidence of robot-based learning. Specifically, our review focuses on the learning activities developed for teaching mathematics and physics in K-12 education.

The remainder of this section summarizes the organization of the paper. Section II provides an updated definition of educational robotics, and summarizes robot-based educational activities featuring mathematics and physics. Section III presents potential robotic platforms that are capable of being used in education and describes the system in terms of processor, battery life, sensors, cost, design and construction process. Finally, section IV constructively critiques the literature in an attempt to answer the titled question and proposes a potential future research direction.

## II. Robot-based learning activities

### A. Updated definition of educational robotics

The term educational robotics is quite vague; the traditional definition predominantly involves developing technical knowledge by constructing and programming the robot [6], [19], [20]. The definition is in-line with modern pedagogical theory of learning: (*1*) Papert's constructionism theory [1], (*2*) learning by design [21], (*3*) principles of active learning [22], and (*4*) social constructivism [23]. This definition focusing on the interactive learning activity is widely accepted, however embarrassingly narrow. Recent trend suggests that the learning domains have broadened, therefore the definition requires an update. Now-a-days, robots are being used to teach non-technical modules; for example, mathematics [24], [25], physics [11], language, and music [26]–[28]. Moreover, robots are socially assisting in the cognitive and intellectual development of children, as well [29]. The role of the robots in such activities is primarily as a tool for learning. However collaborative human-robot interactive learning and robot-based mentoring has also been demonstrated [11].

TABLE I
Summary of the topics covered in educational robotics featuring mathematics and physics.

| Mathematics | Physics |
|---|---|
| Geometric primitives [1], [2] | Distance, time, and velocity [11], [13] |
| Counting [3] | Constant speed, acceleration, and deceleration [10] |
| Multiplication [4] | Work and energy [14] |
| Decimals [5] | Force, gravity, and friction [15] |
| Fractions and ratios [6]–[8] | Doppler effect [16] |
| Coordinate system [2], [8] | Fundamentals of electricity [17] |
| Recognition of quantities [9] | Weight scale and moment computation [18] |
| Problems with operator [9] | |
| Graph construction and interpretation [10], [11] | |
| Angles [11], [12] | |

### B. Robotics and mathematics

Robot-based learning of geometric primitives using the TURTLE/LOGO platform was first introduced in the 80s by Papert under the pedagogical framework of Constructionism [1]. Papert envisioned that student-robot interaction would improve knowledge and problem-solving skills because the introduction of robots in classroom would increase motivation and provide an experimental platform for practice [5], [30]. However, till-date not much significant achievements were made in this regard. Four decades later, Papert's results were reproduced using the iRobot Create in drawing two dimensional geometric primitives and advanced complex shapes; the study reported that as a by product students' sense of coordinate system was improved [2]. Few studies with middle schools [31], [32] reported that robots significantly helped in improving skills with fractions, ratios and coordinate estimation. Further studies emphasized on the importance of the involvement duration: longer robotic intervention effected content learning, while the shorter version effected motivation and attitude [8]. These findings were reinforced by studies which successfully demonstrated the learning of decimals [5] and ratios [6], [7]. A large scale study with 2nd, 3rd and 4th graders in Peru showed improvements in operation solving skills and recognition of quantities; and emphasized on the gender unbiased learning [9]. However, two major studies [33], [34] each involving one year of LEGO formal classroom training showed that only a certain group of 5th grade students displayed improved performance in mathematics. However, these results cannot be definitive because positive engagement with robots involved students who had superior background in mathematics.

### C. Robotics and physics

Existing literature reported several robot-based activities targeting the fundamentals of classical physics. Teachers reported that such activities improved motivation, engagement and attitude [30]. The students demonstrated creative thinking and practical learning of the concepts [16]. The topic of kinematics: the relationship between distance, time and velocity was collaboratively studied and discussed while constructing, programming and studying the motion of LEGO-based robot by middle school students [11], [13], [35]. Kinetics-related activities targeting Newton's law of motion reported that the active manipulation of robot performance variables, like, forces, friction, weight, slope of the ramp, wheel diameter, etc. enhanced content knowledge [15]. Similar construction activities: solar powered car, rubber band-based catapult, and wind-turbine helped teach standard forms of energy and energy conversion techniques [14]. Moreover, studies developed for teaching ratios while constructing robots with cogs and pulleys required theoretical and practical understanding of gear ratio and pulley mechanism. The research findings were promising: students displayed improvements in their written ability to explain science [7]. Furthermore, studies showed that robots helped students in the construction and interpretation of graphs [11]. Follow up studies displayed remarkable results strongly supporting for the use of robots compared to simulators [35]. Similar related studies showed that students can better represent and interpret position-time graphs relating to constant speed, acceleration and deceleration [10]. Please refer to Table I for a summary of the discussed activities.

## III. Robotic Platforms for Education

This section reports robots developed for education and summarizes the design specification in terms of processor, sensors, battery life and cost. Based on the design and construction complexity these robots are classified as: (1) complex LEGO-like brick-based robot assembly kit, (2) minimal mobile robot design kit, (3) robot manipulator design kit, (4) open-source robot design, (5) pre-assembled desktop robots and (6) miniaturized swarm robots.

Please note: The listed robots are mobile and manipulative in nature, and does not include humanoids, aerial, or other types; most importantly this list is not meant to be exhaustive. Furthermore, the information is comparatively presented to assist educators and researchers in the efficient selection of their desired robot platform.

### A. Brick-based robotic toolkits

| Name | Mindstorms EV3 [36] | VEX IQ Super Kit [37] | ROBOTIX TXT Discovery Kit [38] |
|---|---|---|---|
| Company | LEGO | Vex Robotics | Fischertechnik |
| Arm Processor | 926EJ-S<br>4 I/O | Cortex-M4<br>12 I/O | Cortex<br>A8 + M3 |
| Programming | EV3 Software | ROBOTC,<br>Modkit | RoboPro<br>C/C++ |
| Visual Programming | yes | yes | yes |
| Sensors | Speaker<br>Touch<br>Color<br>Distance<br>Bump<br>3 Motors<br>Encoders | Speaker<br>Touch<br>Color<br>Distance<br>Bump<br>4 Motors<br>Joystick<br>Gyro<br>Radio | Speaker<br>Touch<br>Color<br>2 LEDs<br>Camera<br>Switch<br>2 Motors<br>Encoders |
| Design Demo | 5 | 1 | 14 |
| Connection | Bluetooth +<br>USB +<br>Radio | USB +<br>Blue-tooth | Blue-tooth +<br>Wifi +<br>Radio + USB |
| Add-ons | EV3 Gyro<br>(add: $30.00) | Omni-directional wheels, Tank chain tread<br>(add: $100.00) | Power Set<br>RoboPro<br>(add: $115.00) |
| Cost | $350.00 | $330.00-360.00 | $550.00 |

TABLE II
Brick-based (LEGO-like) robot assembly kits.

The robot design kit used in most of the educational activities was primarily the LEGO Mindstorms NXT 2.0. The kit consists of LEGO bricks, motors, gears, sensors (ultrasonic, sound, touch, and color) which can be programmed using the NXT multipurpose controller to design multiple custom shaped robots. The robot-kit documentation provides instruction for constructing four unique robots which includes wheeled, manipulator-like robots or both [39]. Table II summaries some of the available commercial platforms. Despite the wide usage of LEGO-like kits in STEM education, the required formal involvement in the classroom environment is largely missing. Most activities are short-termed and developed informally through extra-curricular activities [40]. The reason is primarily associated to the time consuming unintuitive overwhelming design process which requires excellent inventory and project management skills. As a direct consequence, teachers control over the classroom is reduced, which worsens due to the absence of formal structured curricula linking traditional and robot-based education. Thus the role of the teacher as facilitator, educator, or guide is minimized. Most importantly, given the constrained budget in primary and secondary schools these kits are not always affordable.

### B. Modular robotic kits

To get around the issue of complex construction process, there exists commercial robotic kits which provide minimal design space compared to LEGO-like kits, thereby minimizing the assembly time. Table III and IV provide a compact overview of some of these commercial kits; in particular we focus on wheeled and armed platforms. The reasonable cost and the limited design space provide a convenient platform for classroom. Moreover it provides the students with construction satisfaction while shortening the assembly time, and teachers with enough time to develop and introduce curricula centric activities. Such combination provides space for improved student-teacher collaboration. Table V, in contrast, lists similar open-source robot designs; these robots are not commercially available but can be made using COTS components. The design process is quite involved; it requires soldering, wiring, PCB design and programming. Traditionally, the design is limited to building and programming a differential drive line follower robot with a unique set of sensors. Under proper guidance, the activity could allow students to develop knowledge of electricity, magnetism, sensors, and mechanics. Most importantly, the price is quite reasonable and design space is expandable.

| Name | Servo-botics RA-02 [48] | Lynx AL5x [49] | Robotic Arm Edge [50] | Arxx Robot Mini [51] |
|---|---|---|---|---|
| Degrees of Freedom | 5 | 5 | 5 | 6 |
| Motor | servo | servo | servo | servo |
| Payload (gr.) | very small | 100-283 | 100 | x |
| Height (cm) | 40 | 40 | 38 | 32 |
| Reach (cm) | 31 | 15-20 | 30 | 26 |
| Programmable | yes | yes | yes | C/C++ |
| Connection | Serial | USB | USB | USB |
| Other | | | | 4 LEDs |
| Cost | $250.00 | $360.00 | $66.00 | $150.00 |

TABLE IV
COMMERCIAL LOW COST PROGRAMMABLE ROBOT MANIPULATORS.

### C. Pre-assembled robots

Pre-assembled robots are compact in size and can be installed indoor to work alongside desktop computers. Most of these robots are initially developed at universities for teaching engineering courses and later have been commercialized; for example, the E-puck [59] has been successfully adopted at EPFL and several other robotics laboratories all-around the world. Some of the robots in these category are listed in Table VI and VII. The final class of indoor robots are the miniaturized version of these pre-assembled platforms. Individually, these robots have minimal sensing capabilities, however as a group they are extremely capable. The hardware design is open-source, and the required COTS parts are easily obtainable. Table VIII lists some of these robots. These robots are particularly designed for swarm-related research; however their size and the production cost make them well-suited for K-12 STEM education where each student would have his/her own robot and will collaborate with peers and teachers through the learning activities.

| Name | Hemission [60] | K-Junior V1 [60] | K-Junior V2 [60] |
|---|---|---|---|
| PIC Processor | 16F877 | 16F877 | 18F66K22 |
| Encoders | x | x | x |
| DC Motor | 2 | 2 | 2 |
| Buzzer | yes | yes | yes |
| Switches | 4 | 3 | 3 |
| Diameter (cm) | 12 | 12.5 | 12.5 |
| Battery Life (hours) | 2 | 4 | 4 |
| Obstacle detectors | 6 | x | x |
| IR ground sensor | 2 | 4 | 4 |
| Programmable LEDs | 4 | 3 | 5 |
| IR proximity and ambient light sensors | 8 | 6 | 6 |
| Visual Programming | yes | yes | yes |
| Cost | $250.00 | $900.00 | $800.00 |

TABLE VI
EDUCATIONAL ROBOTS FROM THE K-TEAM.

Two noteworthy designs for academic research and education: The EPFL Thymio [61] and the Infante [72]. EPFL Thymio [61] is one of the most successful commercial full-assembled robot; the platform is re-programmable, rich in sensors and actuators, rechargeable, supports Lego modularity and appreciated by many students. Meanwhile, the Infante robot displayed promising results; studies have reported successful implementation of activities pertaining to mathematical reasoning, geography and recycling [72]. Theoretically, most of the aforestated robots could have replaced the LEGO platform for most of the learning activities mentioned in section II; nevertheless educators use LEGO.

TABLE IX
AR-BASED EDUCATION FEATURING MATHEMATICS AND PHYSICS.

| Mathematics | Physics |
|---|---|
| Construct3D: Geometry [73]<br>CyberChase Shape Quest: Geometry, spatial reasoning and problem solving [74]<br>CyberMath: Differential geometry [75]<br>Alien Contact! Basic mathematics, and problem solving [76] | Physics Playground: Kinetics and kinematics in 3D [77]<br>Newton World: Kinetics and kinematics in 1D [78]<br>Maxwell World: Fundamentals of electromagnetism [78]<br>Graph interpretation [77]<br>Elastic collisions [79], [80]<br>Doppler effect [81]<br>Principles of aircraft flight [81]<br>Work and energy [14]<br>Electricity and magnetism [82]<br>ARex: Light experiment with prism [83]<br>Fundamentals of lens [84]<br>Weight scale and moment computation [18] |

| Name | Mark III [41] | Polulo 3-Pi [42] | Pololu Zumo 32U4 Robot [43] | Arduino Starter Kit [44] | Boe-bot [45] | Qfix [46] | ARobot [47] |
|---|---|---|---|---|---|---|---|
| Processor | PICF877 | ATmega328 | ATmega32U4 | ATmega328 | Basic Stamp II | ATmega128 | x |
| Programming | C/C++ | C/C++ | C/C++ | Visual Programming: minibloq, ArduBlock | PBASIC | C/C++, visually program-mable | x |
| Diameter (cm) | x | 10 | 10 | x | x | x | x |
| Drive System | differential | tank-style differential | tank-style differential | differential | differential | omni-directional | front wheel drive, rear wheel steer |
| Motors | 2 torque servo | 2 micro-metal gear | 2 micro-metal gear | 1 servo, 3 DC | 2 continued rotation servo | 3 gear | rc servo, DC gear |
| Encoder | yes | x | yes | x | x | x | x |
| Proximity | 2 | x | 4 | 1 ultrasound | 3 (ultrasound + IR) | 2 | x |
| Ground Sensor | 3 | 5 | 5 | x | | 1 | x |
| Push-botton | x | 3 | 3 | 10 | 2 | 2 | 2 |
| LEDs | x | x | yes | 27 | x | 2 | 2 |
| Sound | x | buzzer | buzzer | x | x | x | buzzer |
| LCD | x | 82 characters | 82 characters | x | x | x | x |
| Connection | Serial | x | USB | USB | USB, Serial | USB | x |
| Other | x | x | gyro, compass, accelerometer | tilt, 6 lights, and temperature sensor, 1 IMU with altitude | light sensor, 2 bumpers | x | 2 whiskers, PIR motion, light, temperature sensors |
| Cost | $92.00 | $100.00 | $100.00 | $156.00 | $160.00 | $310.00 | $395.00 |

TABLE III

COMMERCIAL LOW COST MINIMAL MOBILE ROBOT DESIGN KITS.

| Name | MIT SEG [52] | Harvard Kilobot [53] | Rice R-one [54] | Infante [55] | Miniskybot 1.0 [56] | Pi Swarm [57] | Evolution ER1 [58] |
|---|---|---|---|---|---|---|---|
| Battery (hours) | x | 3-24 | 4 | x | x | 2 | x |
| Processor | Arduino Pro Mini | Atmega328 | LM3S8962 Stellaris Processor | PIC16F88 | PIC16F876A | ARM Cortex-M3 | Laptop |
| Programming | ArduBlock Graphical Programming | C/C++ | C/C++ Python | Blocky Graphical Programming | C/C++ | C/C++ | C/C++, Python |
| Dimension (cm) | x | diameter: 3 | diameter: 11 | x | x | diameter: 9.5 | x |
| Drive System | differential | differential | differential | differential | differential | differential | differential |
| Motors | 2 servo | 2 vibrator | 2 geared | 2 rc servo | 2 servo | 2 micro-metal gear | 2 stepper |
| Encoder | x | x | yes | x | x | x | yes |
| Proximity | x | yes | 8 | x | 2 ultrasound | 8 | 3 |
| Ground Sensor | 1 | x | x | 4 | x | 5 | x |
| Push-botton | x | x | 3 | x | x | 3 | x |
| LEDs | x | x | 15 | x | x | 11 | x |
| Sound | x | x | speaker | x | x | buzzer | x |
| Connection | Blue-tooth | IR-based Kilobot controller | Radio (2.4 Ghz) | Bluetooth | Serial | USB, RF Transceiver | Serial |
| Other | x | ambient light, inter-robot communication | 8 bumpers, 4 ambient lights, IR beacon global localization, gyro, compass, accelerometer, SC card, planner gripper | Raspberry-Pi based multi-robot controller | x | 3D gyro, compass, accelerometer, temperature, light, ultrasonic range | camera |
| Cost | $20.27 | $43.00 | $300.00 | $110.00 (5 robots) | $65.00 | $245.00 | $900.00 |

TABLE V

OPEN-SOURCE LOW COST MOBILE PLATFORMS DESIGNED FROM COMMERCIAL OFF-THE-SHELF COMPONENTS.

| Name | Thymio [61] | iRobot Create [62] | Wow-Wee Rovio [63] | Surveyor SRV-1 [64] | E-puck [59] | AmigoBot [65] |
|---|---|---|---|---|---|---|
| Battery (Hours) | 2 | 1.5 | 2 | 4 | 3 | 2 |
| Processor | PIC24FJ128 | ATmega 168 | Marvell PXA270M ARM | Blackfin BF537 | dsPIC | Hitachi H8 |
| Programming | ASEBA, Visual Programming | C/C++ | C/C++ Python | C/C++ Python | C/C++ | C/C++ |
| Dimension (cm) | 10 x 10 | diameter: 13 | diameter: 11 | 12 x 10.5 | diameter: 7 | 32 x 28 |
| Drive System | differential | differential | omni-direction | differential tank-style | differential | differential |
| Motors | 2 DC gear | 2 vibrator | 2 wheel, 1 camera | 4 DC gear | 2 stepper geared | 2 DC |
| Encoder | not directly | yes | yes | x | yes | yes |
| Proximity | 7 | 1 | yes | 2 | 8 | 8 ultrasound |
| Ground Sensor | 2 | 4 cliff sensors | x | 4 | x | x |
| Push-botton | 5 touch sensors | x | 3 | x | x | x |
| LEDs | 39 | 3 | yes | x | 10 | x |
| Sound | speaker, microphone | speaker | speaker, microphone | | speaker, 3 omni-directional microphones | buzzer |
| Connection | USB | Serial | Wireless | Wi-Fi | Bluetooth, Serial | Serial, Wireless |
| Other Specs. | IR communication, 3D accelerometer, temperature sensors | 3 bumpers, IR communication, attachable camera | VGA camera, indoor localization using True Beacon NorthStar | 1.3 MP Camera | IR communication VGA camera 3D accelerometer, ambient light sensors | x |
| Cost | $105.00 | $200.00 | $270.00 | $480.00 | $850.00 | $1800.00 |

TABLE VII

LOW-COST FULLY-ASSEMBLED COMMERCIAL MOBILE ROBOTS.

| Name | CotsBots [66] | Robomote [67] | Alice [68] | TERMES [69] | MICAbot [70] | Kobot [71] |
|---|---|---|---|---|---|---|
| Battery (Hours) | 1 | 3.5 | 10 | x | 2.5 | 7-10 |
| Processor | ATmega128L | AT90S8535L | PIC16F84 | ATmega128L | ATmega103L | PIC16F877A |
| Size (in cm) | 13 x 6.5 | 3.81 x 2.23 | 2.1 x 2.1 | 17 x 11 | 8.6 x 6.1 | diameter: 12 |
| Motors | 2 servo | 2 DC | 2 swatch, 1 DC | 2 micro-metal gear | 2 sub-micro servo | 2 high torque DC gear-head |
| Drive System | 4 wheel Ackermann | differential | differential all-terrain caterpillar thread | 4 carved wheg differential | differential | differential |
| Encoder | x | yes | x | x | yes | x |
| Proximity | x | 5 | 4 | x | x | 8 |
| Bumper | 4 | 4 | x | x | x | x |
| Inter-robot comm | yes | yes | yes | x | yes | x |
| Programming | TinyOS | C/C++ | C/C++ | C/C++ | TinyOS | x |
| Sound | microphone, buzzer | x | x | x | microphone | x |
| Connectivity | RF Transceiver | RF Transceiver | IR, Radio | Blue-tooth | RF Transceiver | Wireless |
| Other Specs. | 2D compass, accelerometer, radio-based distance, light, temperature sensors | solar-cell compass | linear camera 2D gripper | 6 ground sensors, tilt sensors, 2 DOF tactile claw-like gripper 3 LEDs | 2D compass, accelerometer, radio-based distance, light, temperature sensors | camera compass |
| Cost | $200.00 | $150.00 | $50.00 | $100.00 | $350.00 | x |

TABLE VIII

OPEN-SOURCE MINIATURIZED SWARM ROBOTS.

## IV. Discussion and Conclusion

The use of robots to learn programming and robotics is well established [40], [85]. Our survey indicates that the field has evolved from conventional robotics education to non-technical learning activities as well – a positive development. Majority of the aforestated studies advocate that robots play a positive role in the learning of educational activities, develop creative thinking, and improve problem-solving skills. Moreover the interaction with robots increases motivation, engagement and attitude towards education. Admittedly, with the simplification of robot design and assembly process; the inclusion of intuitive visual drag-and-drop programming and the gradually reducing cost of educational robot platforms, we are experiencing the advent of a new era in educational technology. However, further advancement would require identification of potential limitations and subsequent rational adaptation.

Based on our study, we identified two important issues which require our attention: (1) standardization of evaluation techniques which are used to quantify robot-based learning: merging statistical analysis, surveys and interviews and (2) development of tailored robot-based pedagogical modules assisting traditional K-12 curricula and associated teacher training programs [86].

The evaluation technique used to quantify the learning from the robot based activities, in most of the studies, is either quantitative or qualitative; ideally it is important to include both. Moreover, careful attention should be devoted in the design of the experiments in terms of sample size and sampling technique. The robust and standard approach is to use random sampling with appropriate sample size [87]; however, many of the studies do not comply. In addition, extreme caution should be exercised in planning the learning activities for the experimental and control group [87]. Furthermore, the quantification of learning must be based on multiple pre, post and retention tests to avoid outliers; the present standard of one pre and post test with substandard questions is not sufficient.

Teacher-student interaction is pivotal; the robot-based activities should be strongly linked with traditional curricula so robots could assist the teachers in day-to-day teaching activities. Because in some studies the students does not perceive or cannot link the learning goals and the robot-based activities. Such decoupling voids the link between use of robot and the associated increase in motivation to learn. This is a problematic issue because increase in motivation has been the crucial sales pitch in educational robotics.

Teachers are the most vital organ in the educational framework; they need to feel comfortable with robots. Such comfortability can only be achieved through proper training and active/pro-active involvement. Many of the teachers are hesitant in dealing with robotics, such behavior does not reflect their unwillingness to learn new concepts, sometimes it can be associated to the lack of standard curricula, and the affiliated long term benefit [86]. These limitations can be minimized by developing standardized and proven stable long-term curricula and related teacher training programs.

Technology is not replacing teachers, rather it is utilized to assist the teachers and the students to create a conducive epistemologically plural learning environment. To reach such milestone, standard curricula needs to be appropriately researched and subsequently adjusted so that it can aptly host the introduction of robot-based activities. Moreover teachers need to be properly trained, and the selection of the technology should be appropriate. For example not all robots can be used for the learning of verbal languages. Furthermore, educational framework should explicitly encourage both individual and collaborative learning.

Our experiences with the Thymio in schools [61], [88], [89] have helped us to realize that the student-robot interactivity and subsequent learning experiences can be further enhanced through the integration of a robot state or affordance visualizer; robots need to be more transparent in their mechanics. Such realization have made us interested in pursuing a new research direction by combining robotics and augmented reality (AR). Augmented reality (AR) is an interactive visualization technique (using cell-phones, tablets, head-mounted visual gears, etc) combining the real and the virtual world through accurate computer vision-based techniques [73], [77]. Our actual intent is to merge the tangibility of robots with the advanced visualization capabilities of AR. The purpose of AR is to display, in real-time, the invisible states and affordances of the robot. We strongly believe that the inclusion of AR would help the students in better visualization of invisible and abstract concepts, like: vectors, forces, gravity, geometry, electromagnetics, etc; and thereby further assist the K-12 mathematics and physics curricula. Based on our short survey of related AR-based educational activity, as summarized in table IX, it is found that AR technology is pedagogically effective for teaching mathematics and physics as it enhances user visualization capabilities, moreover the interactivity increases student motivation and improves learning [90], [91].

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