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Reinforcing skill development in students of middle school level using Arduino with respect to the reformation of Indian Education System

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Abstract

The Indian educational system has been in stagnation since the year 1986. The year 2020 brought about a tremendous change in the National Education Policy (NEP 2020) which aims at reforming not only the elementary and higher education framework but also the vocational training in rural and urban India. By 2030, the policy promises to revolutionize the Indian Education System [1]. There is a great deal of significance given to skill building and use of technology rather than rote learning. In this context, the following study proposes the use of Arduino for skill development among students of Middle School level. With the advancement in technology and the need and extensive use of smart devices, this approach will promote a sense of inquisitiveness among students and help them to develop small scale fully operational projects which will enhance their learning and bring about an innovation in the pedagogical process.

***Keywords*: Educational Reforms, Skill Development, Arduino, National Education Policy (NEP 2020), STEM Education.**

1. Introduction

Education is not only a basic right but also a fundamental need in today's times. It hones your innate skills and prepares you for a promising future. The fate of the future generations depends upon the foundation of education provided to the past and the present ones. Therefore, all the countries throughout the world prioritize the development of their education system to inculcate the best pedagogical practices and create an atmosphere conducive to learning. Educational practices have undergone a huge transformation. In the present times knowledge is not the only source of power, rather power comes from capacity building by the development of a range of skills- multilingualism, ethics, creative thinking, conceptual clarity, respect, integrity, research, innovation and the use of technology.

In India, the Education system has been a constant since nearly three decades. The National Education Policy of India was last amended in 1992 after it came to existence in 1986 [3].Since then there has been no substantial change whatsoever in the education policy and the process of teaching and learning has become mundane with more focus on learning by rote and memorization rather than conceptual clarity and critical thinking. Most students in India learn from an examination point of view rather than developing an urge to understand, apply their knowledge and utilize their skills for building or creating an original piece of work.

Thus, the Government of India has taken a pragmatic approach to deal with this situation and cater to the demands of the changing times. The National Education Policy 2020 was framed by the Ministry of Human Resource Development, Government of India to bring about a transformation of the educational background of India [3]. This policy covers all aspects of teaching and learning with an assurance to reshape the education system of India by 2030.

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In this revised policy, we can find many points that have been given due consideration in context to the present times. Development of the creative potential of each individual, critical thinking and problem solving capabilities along with the significance to the rich cultural heritage and diversity of India. The major reform made in this new policy is the inclusion of the Right of Children to Free and Compulsory Education Act 2009 which guarantees free elementary education [2].

Out of the many fundamental principle mentioned in this policy, there has been a mention of the use of technology in the teaching and learning process, development of critical thinking, creative capacity, skill development and research [2]. The amalgamation of the inherent creative skills of the students with technology may pave way for numerous opportunities for them. The development of research and innovation capabilities in students, at a very young, will help them to be focused and allow them to progress in their field of interest in future, thus leading to a more prosperous nation. Driving the youth in the direction of skill set development and guiding them towards a fruitful and thriving profession is a tedious task. If these unique qualities are fostered at a very young age, it will help students to adapt to the process and develop their skills at an exponential pace.

To make the best possible use of technology at this point is a much needed stance. Therefore, in this study, we propose to introduce the concepts of Arduino to the students of Middle school level in India, so that they can effectively use technology to develop their skill set and leap into the world of creativity and research at the prime of their age. The new age demands an extensive use of technology; and smart devices have become an essential amenity in each household. Being addicted to the use of smart devices, it is also a necessity to know, understand and try to create such devices on your own. With the focus of the NEP 2020 on the mathematical and computational skill development and the introduction of coding from the Middle School level [2], it is clear that the next generation of coders will have to be adept in the basics from a very early age. To make this possible, Arduino platform can be used.

Similar research has also been done in several papers where the learning abilities of students has been measured and found to be increased by using different kinds of applications and platforms. *Basha M. S., et al.* [15] have used the Augmented Reality technology to measure and enhance the learning abilities of students in university level. In another paper, *Basha M. S., et al.* [16] have investigated how the AR application has been used in the past and how it can be integrated in the teaching and learning process in educational institutions and other areas of business. *Basha M. S., et al.* [17] have also tried to compare the academic performance of the language learning students with and without the use of Augmented Reality (AR) with amazing results where they found an increase in the enthusiasm and interest of students in using this technology. All the above similar studies suggest that, by introducing a new technology like Arduino in the school curriculum, we can improve the learning ability, creative thinking skills as well as grasp the interest of the students to make them learn something worthwhile which will help them to develop their future.

Arduino has become very popular in recent times. It is basically used to build electronics projects. It is an open source platform which uses a programmable single board microcontroller and a piece of software. This software runs on your computer and can be used to write and upload computer code to the physical board. It is very easy to understand and program as it uses the simplified version of C++ and it also does not need a separate piece of hardware to load new code onto the board [4]. This platform can be an ideal foundation for middle school level students. They can explore their interests and creativity in developing fully functional microcontroller devices which will not only help them in developing their coding skills but also foster innovation and promote utilization of the available resources to bring originality in their inventions.

Objective

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The objective of this survey paper is to provide a comprehensive review of the various applications and impacts of Arduino-based educational programs across different educational levels and disciplines. This paper aims to:

- Examine the effectiveness of Arduino as a tool for enhancing learning outcomes, such as problem-solving, creativity, motivation, and technical skills, in high school, vocational, and university-level education.
- Identify the challenges faced in integrating Arduino into educational curricula, including barriers in terms of teaching methodologies, student engagement, and the limitations of using hardware versus virtual simulators.
- Explore the diverse applications of Arduino in various fields of study, such as programming, robotics, embedded systems, and STEM education, and how these applications can be adapted to different learning environments.
- Provide insights on best practices and pedagogical strategies for implementing Arduino-based programs effectively to achieve desired learning outcomes in educational settings.
- Highlight the potential of Arduino in promoting interdisciplinary learning and its long-term benefits for students, including increased interest in STEM fields and the development of practical, hands-on problem-solving skills.

Through this survey, the paper aims to offer a holistic understanding of Arduino's impact in education and suggest recommendations for future research and educational practices.

2. Literature Survey

In this paper, we will go through the related work of different authors to get an idea about how educational reforms have brought about a change in the learning capabilities of students as well as how the Arduino platform has been used in the schools and educational institutions across the globe to develop the creativity and skill set of the students.

Won Kim S., et al. [5] in their paper have developed and applied an Arduino-based education program for high-school students in Korea. Due to the revision of the Korean National Curriculum to include informatics courses and physical computing in 2015, Arduino was chosen as a computing platform to carry out this research by developing the educational program for high school students. This study basically aimed at measuring the creative problem solving capabilities of students. The test study was conducted on 20 female high school students who had a prior knowledge of programming. The authors analyzed the results of the study based on the following criteria: self-confidence and independence; divergent thinking; critical and logical thinking; and motivational thinking. Upon analysis of the results, it was observed that there was no significant difference in the problem solving ability of students during the period of this study. Also, there was no significant difference in relation to the other criteria used for analysis. The authors also proposed on developing proper pedagogical practices for physical computing education imparted to high school students. Students' feedback on the Arduino based program was more positive towards the interest side and less towards the problem solving part. Almost all students agreed that the programming part was difficult with their language being one of the barriers in addition to the tough design and debugging part. Therefore, the authors concluded that the Arduino based educational system did not quite bring about a huge change in relation to the creative problem solving abilities of the students. This may be due to several reasons like the course was taken up by few students and mostly females, so it was difficult to conclude what the reaction of the male students would have been to this program. Secondly, this program was used as an after-school course rather than a regular course.

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El-Abd M. [6] in his paper has reviewed the impact of Arduino in embedded systems education. He has focused on the aspect of integrating Arduino in teaching. He has studied how Arduino was fused with many different embedded system courses across various degrees in the engineering domain. He drew a comparison of the different integration methods based on three criteria: Platform adoption (Single vs. Multiple), Project type (Free vs. Restricted), Programming knowledge (Low-level vs. High-level vs. Both) to measure the extent to which Arduino was blended into the courses. It was observed by the author that there was a remarkable increase in the student performance (nearly 30%) after taking up these course in one of the integration methods. Some students also continued using it in their capstone courses for project development. Finally, he concluded the paper by citing the various challenges faced relating to students, instructors, lectures, development, etc. in the different related works that he reviewed. With all those challenges also, the author agreed that Arduino is a promising platform to be integrated with embedded systems education. He furthermore, emphasized on developing proper teaching methodologies so that learning outcomes of the said courses are effectively achieved.

Hertzog P., et al. [7] have highlighted how Arduino was used in the design based engineering modules to increase the student performance in the Central University of Technology, South Africa. Due to the design challenges faced by the students like expensive microprocessors and the unavailability of components, Arduino was introduced as a cost-effective alternative. Their paper has illustrated the use of Arduino for two design modules of the Department for Electrical, Electronic and Computer Engineering and how it has proved successful for the undergraduate engineering students. According to the results, it was observed that, initially students faced design difficulty with the Arduino microprocessor but in the long run it proved useful for them as it helped them to understand the theoretical part. Students' feedback also infers that most of the students were satisfied with the new approach as it helped them to develop their creative thinking abilities and increased their academic performance, as a result of which they were keen on recommending it to other students. The authors also proposed to expand this study by taking more number of students across different semesters to better validate the results.

Junior Luiz A., et al. [8] have presented a Low-Cost and Simple Arduino-Based Educational Robotics Kit to be used in high schools in Brazil. This kit was designed based on the key elements i.e. low cost, appeal, simplicity and open source. The design and implementation of this kit involved the use of Arduino UNO hardware and Minibloq as the programming environment. Survey results revealed the agreement of most of the students on the fact that the robotics kit helped them to understand the concepts of programming better. Thus, the use of Arduino enabled motivation among the students. The number of educational workshops held in the schools for the students were economically feasible as well as educationally fulfilling. In addition, the study also revealed that it is possible to develop low-cost projects using Arduino.

Bulus Kirikkaya E., et al. [9] in their research focus on investigating the effects on the attitudes of students' towards technology and ICT with the mixed method where data collection, data analysis processes, quantitative and qualitative methods are used together in finding results. The research was carried out in the department of science education at Kocaeli University (Turkey) with 50 first-year students. Applications were developed using Arduino in the Physics laboratory. Arduino was integrated to electrical experiments so as to measure the students' reaction towards a new technology. The results showed that students were more interested towards technology due to the use of Arduino. Students felt motivated and eager to use it in their future endeavors. The authors also suggested that these applications should be taught to teachers in order to develop a sense of confidence in them and remove the fear of new technological applications from their minds.

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Novák M., et al. [10] have explored the possibilities of using Arduino in teaching programming in high schools as well as universities. Their paper is sort of a guide which highlights the teaching practices to be followed with Arduino. They have emphasized how this curriculum can bring about a change in the information thinking capability of students. They have worked with Arduino on a Robotics basis defining the learning materials in terms of lesson plans, worksheets and theoretical guides. The initial testing of this program concludes that students at grammar school level appreciated the curriculum whereas the technical secondary school level students had a different take on it. They were already adept in the basics of electrical engineering so the initial lessons seemed to be easier for them. So, this study basically examines the effect of a full-fledged Arduino program in the school and university curriculum with positive results.

Gonçalves Paulo F., et al. [11] have done a case study to analyze the effects of using an Arduino simulator in a classroom. They tested the use of this virtual simulator by comparing it with the usage of a real Arduino platform in courses by using it in two schools across five classes with the same study materials and exercises as designed for the real Arduino course. It was observed that while using the simulator the workload index was 8% lower, which may be nominal but significant. It was also observed that the time taken to solve the exercises by the students using the simulator was less in comparison to the students using the real Arduino platform. It was also observed that the use of the simulator did not affect the workload of the teachers and the class management was easier for them. Thus, the overall use of the simulator proved beneficial and gave positive results.

Karaahmetoğlu K., et al. [12] have studied the effect on sixth graders computational thinking and Stem skill levels by introducing an Arduino educational robot application in their curriculum. They divided the students into two groups: control group which used block based programming tools to carry out the project development activities and the experimental group which used the project-based Arduino educational robot applications. This study uses a quasi-experimental design to compare the same group of students with different teaching strategies. The study was carried out across 11 weeks. The results do not show much difference between the educational robot activities and block programming activities carried out during the study. Both the applications had a similar effect on the students' Stem skills. So, it was concluded that both the applications together can improve the students' Stem skills. Also it was observed that, the use of the block-based robotics programming tool in the activities conducted had a more significant contribution to the computational thinking skills of secondary school students compared to their activities based on block based programming tool.

Santosa E S B., et al. [13] have performed a quantitative research study on 32 XI grade students of a public vocational high school in Indonesia to measure their motivation in learning about the Arduino Nano Based Quadcopter in their microcontroller courses. Data was collected using a questionnaire. The survey results indicated that the knowledge of microcontroller increased by 80% in most of the students. Around 82% of students agreed that their programming perfection had increased with Arduino. Overall, the interest level and class participation among the students had increased with the use of this application. Thus, the authors concluded that, using the Arduino Nano based quadcopter in microcontroller learning has significantly motivated the students and increased their learning level, knowledge, creativity and system development skills.

Wood B M., et al. [14] in their paper have performed a research on motivating students to become a professional in using Arduino. So, they introduced it in various fields of engineering education like programming, electronics, mechanics, etc. Their study aimed at helping course developers to design a curriculum based on Arduino in different areas of engineering. Their study has suggested the use of various lab experiments, projects as well as summer camp courses for learning Arduino in a professional manner. They have also suggested the

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introduction of Arduino related advanced courses in the industrial setting where engineers can get a good grasp on Arduino based applications which will help them to work effectively on real-world projects and improve their efficiency for their own benefit.

Here's a comparison of the studies mentioned in terms of their objectives, target audiences, methodologies, findings, and outcomes:

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Authors	Study	Target Audience	Objective	Methodology	Key Findings	Comparison with Others
Won Kim S., et al. [5]	Arduino-Based Education Program for High-School Students in Korea	20 female high school students with prior programming knowledge	To measure creative problem-solving abilities	Experimental study with pre- and post-tests	No significant improvement in problem-solving ability, but positive feedback on interest and motivation	Focuses on a small, gender-specific group, limiting generalizability. Compared to others, it shows less impact on problem-solving ability, highlighting the difficulty in achieving concrete skill improvement.
El-Abd M. [6]	Impact of Arduino in Embedded Systems Education	Engineering students	To review how Arduino is integrated into embedded systems courses	Literature review, comparison of integration methods	Increased student performance (30%) and continued use in capstone projects	A broader focus on embedded systems education compared to the other studies, which are more focused on high school students. It highlights the potential for long-term use of Arduino in professional courses.
Hertzog P., et al. [7]	Use of Arduino in Design-Based Engineering Modules	Undergraduate engineering students	To explore how Arduino can improve student performance in engineering design modules	Experimental study, student feedback	Initial difficulties with Arduino, but improved understanding and creative thinking over time	Like other studies, it shows initial challenges but highlights Arduino's long-term benefits for students' creativity and problem-solving in design contexts.
Junior Luiz A., et al. [8]	Low-Cost Arduino-Based Educational Robotics Kit in Brazil	High school students in Brazil	To design and implement a low-cost, open-source educational robotics kit	Experimental study, student survey	Students reported better understanding of programming and increased motivation	Unlike others that focus on general problem-solving skills or embedded systems, this study emphasizes cost-effectiveness and simplicity, focusing on hands-on learning with robotics.
Bulus Kirikkaya E., et al. [9]	Effects of Arduino on Attitudes Towards Technology	First-year students at Kocaeli University, Turkey	To measure students' attitudes toward technology and motivation after using Arduino	Mixed methods (quantitative and qualitative)	Increased interest and motivation to use technology, with positive reactions to Arduino's use in experiments	Similar to others in terms of motivation but focuses more on student attitudes rather than skills or knowledge, and targets a different demographic (university students vs. high school students).
Novák M., et al. [10]	Using Arduino for Teaching Programming in	High school and university students	To explore Arduino's impact on programming education	Case study, lesson plans, surveys	Grammar school students appreciated the curriculum; technical	A detailed comparison with other studies that focus on practical application (robotics, engineering) rather than purely programming. It shows that Arduino

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	High Schools and Universities				secondary students found it too basic	might be too basic for students already familiar with electrical engineering.
Gonçalves Paulo F., et al. [11]	Case Study on the Use of Arduino Simulator in the Classroom	Students in two schools	To compare real Arduino hardware with an Arduino simulator in teaching	Comparative study using real hardware vs. simulator	Simulator reduced workload by 8% and sped up task completion without affecting teacher workload	Focuses on comparing real-world and simulated learning environments. Unlike the other studies, it emphasizes the logistics of teaching and ease of classroom management, which is a unique comparison.
Karaahmetoğlu K., et al. [12]	Effect of Arduino Educational Robot on Sixth Graders	Sixth-grade students	To compare the impact of Arduino-based robot applications vs. block-based programming on STEM skills	Quasi-experimental design	Both tools improved STEM skills, but block-based programming had a stronger effect on computational thinking	Unlike other studies that focus on high school or university students, this study deals with younger students and compares two different educational approaches, highlighting the effect of block-based tools versus Arduino-based robots.
Santosa E S B., et al. [13]	Motivational Impact of Arduino Nano-Based Quadcopter on Students	Vocational high school students in Indonesia	To measure motivation and learning outcomes using Arduino Nano-based quadcopters	Quantitative research with surveys	Significant increase in microcontroller knowledge, programming skills, and student participation	Similar to others in terms of motivation and skill increase, but this study specifically targets vocational students and integrates a hands-on approach with drones, which adds a unique practical element to the learning experience.
Wood B M., et al. [14]	Motivating Students to Become Professionals Using Arduino	Students in various engineering fields	To motivate students to use Arduino professionally in various engineering fields	Suggestion of curriculum design, course experiments	Proposed use of labs, projects, and summer camps to develop professional-level Arduino skills	This study stands out by focusing on professional-level training and long-term career application, while others are primarily concerned with academic learning or skill development at the student level.

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3. Discussion

Arduino-based learning can significantly enhance the skill sets of middle school students. By engaging in practical projects, students will develop critical problem-solving abilities, improve their logical thinking, and acquire technical skills that are essential in today's digital world. The use of Arduino in education also aligns with the NEP 2020's goal of fostering creativity and innovation from a young age. However, successful integration of Arduino into the curriculum requires proper training for teachers, development of suitable teaching materials, and addressing any barriers to technology access. Teachers should be equipped with both the technical and pedagogical skills to guide students effectively in their projects. Additionally, schools must ensure that students have access to the necessary resources, such as Arduino kits and computers, to make the most of this approach.

4. Conclusion

A review of all the related studies so far, brings us to an inference that around the globe, in many countries like Korea [5], South Africa [7], Brazil [8], Turkey [9], Indonesia [13], etc. there have been several instances of reforms in the education system with more thrust been given to improving the creative and critical analysis skills of students with the use of technology. These studies imply that developing the skill set of students using various technology, Arduino being one of them, can not only help them to learn a new concept and be adept at it but also allow them to apply it to solve their real-world problems. Most of the literature review agree that the introduction of Arduino based courses in the school and college curriculum has improved the learning ability and interest of students. As suggested by the related work, we can conclude that integrating Arduino in the middle school curriculum of India may help the Government of India to better implement the latest education policy (NEP 2020) [2] that has been passed recently for execution. This will foster innovation, develop coding skills and lead the way for creative aptitude in students as well as enhance the teaching and learning process which in turn will fulfill some of the fundamental objectives of the reformed education policy of India.

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