Effect of Microcontrollers on Engineering Education

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The demand for “work-ready” engineers becomes more prevalent each year, highlighting the importance of combining the education of mechanical systems with electronics (Li, 2021). Since the 1970’s, there has been rapid development in the field of microcontrollers and computers (Mahmood, Ahmed, Mahmood, 2022, p.2). Furthermore, A. Mahmood, Ahmed, and H. Mahmood argue that “microcontrollers have become the basis for the design of a large number of devices, so learning of them becomes imperative, not only for students of engineering colleges but even for school children” (Mahmood, Ahmed, Mahmood, 2022, p.3). The explosion of low-cost microcontrollers such as Arduino and Raspberry Pi have thrust microcontrollers into everyday households. Their simple user friendly interfaces combined with numerous functionalities makes them incredibly versatile.

The prevalence of these types of microcontrollers is redefining how engineering education is taught. Firstly, low-cost microcontrollers have the ability to replace expensive laboratory equipment while providing students with the option to learn outside a designated classroom. Secondly, the access to these microcontrollers benefits students by providing hands-on learning instead of limiting prospective engineers to theoretical knowledge and calculations. According to Fidai, Momin, and Umatiya, hands-on learning allows more students to learn the skills needed to solve complicated real-world problems. Further, microcontrollers are impacting students' enthusiasm for engineering courses. At the University of Wyoming, a 2018 study found that “students’ perception about their own creativity in STEM fields underwent a statistically significant change after students engaged with a coding/microcontroller intervention (Bicer et al., 2018, p.4).

The goal of this paper is to analyze the impact of microcontrollers on engineering education, taking into account both the benefits of hands-on education in engineering as well as how microcontrollers play a role. In this analysis, I will begin by providing an overview of the current state of affairs in engineering education and how microcontrollers fit in. Additionally, I will be using the Social Construction of Technology (SCOT) model to discuss the adoption of this technology across education institutes. I will consider the various impacts that these technologies have on higher education and its stakeholders, including students, instructors, and researchers.

History

In order to accurately analyze the impact of microcontrollers on education it is imperative to first discuss their history and development that led to the current market options available to students and educators today. In 1971, two engineers working at Texas Instruments, Gary Boone and Michael Cochran, invented the first microcontroller, the TMS 1000. Since then, there has been rapid development in the field of microcontrollers and computers (Mahmood, Ahmed, Mahmood, 2022, p.2). According to Dimosthenis E. Bolanakis, a microcontroller unit constitutes a synchronous digital circuit that incorporates a *central processing unit (CPU)* and a memory for holding the firmware code (that is, the *program memory*) as well as the data generated during the code execution (that is, the *data memory).* Essentially, microcontrollers are compact, stand alone boards containing a processor, memory and input/output (I/O) peripherals.

Then, over 30 years later, 2005, Massimo Banzi, David Mellis, and David Cuartielles created Arduino at the Interaction Design Institute Ivrea (IDII) in Ivrea, Italy with the goal of creating a cheaper alternative to the microcontroller they were currently using in their studies. Similarly, Eben Upton, based out of the United Kingdom, found that one of the largest issues with the education system was the price of computers. To combat this, he began prototyping low-cost computers before forming the Raspberry Pi Foundation in 2009 with the goal of selling Raspberry Pi microcontrollers, as seen in Figure 1, to students for as little as $30. While there are a plethora of similar microcontrollers on the market today, I mention these two as they are the most widely known as well as the fact that they were invented to aid in education. I will be using the SCOT framework to analyze how microcontrollers have inserted themselves into education as well as their effects on engineering student experiences.

Figure 1: Raspberry Pi

SCOT Analysis

The Social Construction of Technology framework argues that technology is not determined solely by its functional characteristics but rather shaped by social and cultural factors. There are four main components of the SCOT model: interpretive flexibility, relevant social groups, closure and stabilization, and the wider context (Klein, Kleinman, 2022). Interpretive flexibility is the idea that “technology design is an open process that can produce different outcomes depending on the social circumstances of development” (Klein, Kleinman, 2022, p.29). I will begin by first discussing the adoption of microcontrollers in general and then proceed to specific options available to students and educators today.

Microcontrollers are small computers that can be programmed to perform specific tasks and functions. Their uses can be found in various fields including robotics, automation, and education. In recent years, microcontrollers have experienced a surge in popularity due to their ease of use, low cost, and effectiveness as a teaching tool for programming and engineering. Many boards are easily accessible to the average consumer, allowing them to tinker with electronics outside of an educational setting. Though the many benefits microcontrollers provide can be attributed to their use in education, I aim to discuss societal factors such as technological literacy and availability of resources that have shaped their adoption.

Technological literacy is becoming increasingly important in education today. As the world becomes more digitized, students must adapt in their education by using the appropriate technology. Morever, technology is ubiquitous in the modern world and students must be equipped to navigate and use technology effectively. Microcontrollers can be found in almost all electronic devices ranging from automobiles to LED lights. Rick Stehmeyer (2016) argues that "this new market [of microcontrollers] is flourishing as everyday people program them to hack cars, build 3-D printers, and augment drone functionality" (p.42). As their use in electronics expands, it is imperative that students learn how to program and control their devices.

With this increasing reliance on technology, educational institutions have begun adapting their curriculums to better reflect the needs for students to become successful engineers. More and more universities are adding mechatronics degrees and courses that combine the field of mechanical engineering with electronics and computer science. Universities across the globe are arguing how it is imperative that educators "introduce the broad field of mechatronics to non-traditional mechanical engineering students" (Li, 2021, p.1). The University of Virginia has adapted to this change by requiring a mechatronics course for mechanical engineering students starting in the mid-late 2000's. With mechatronics becoming more prevalent in engineering, the microcontrollers used in this field have also found themselves as essential components in education.

One of the main driving factors in the use of microcontrollers in education is the availability of resources. The cost of microcontrollers has decreased significantly in recent years, making them ideal for educational settings. There is also a plethora of open source online resources that teach the functionality of various boards and processors. Arduino and Raspberry Pi provide free open source software and inexpensive hardware that can be used by teachers and students alike. Fidai, Momin and Umatiya (2021), argue that microcontrollers such as Arduino have “reduced the costs of laboratory equipment and made hands-on engineering more accessible to more students (p.2). Further, according to Pradip Sheth, a former professor at the University of Virginia, “thanks to the proliferation of inexpensive microcontrollers in recent years, machines that were formerly passive can now be made intelligent” (Feignoff, 2008, p.1).

Additionally, inexpensive microcontrollers allow students to work on their own projects and studies without being restricted by limited lab space of materials. Mechatronics Professor Gavin Garner at the University of Virginia used the benefit of low-cost microcontrollers to aid in teaching during the COVID-19 pandemic. In prior years, students shared lab kits to complete their projects in the mechatronics lab. However, with the limitation of in-person instruction, individual students were given their own lab kits for the semester. The individual lab kits for students were so successful that students still use their own kits even after in person instruction has resumed.

Along with the many social circumstances contributing to the development and use of microcontrollers in education, it is also imperative to discuss the relevant social groups involved. The second component of the SCOT model, relevant social groups, relates the idea that separate groups, all with their own interpretation of the technology, negotiate over the design and application of the technology (Klein, Kleinman, 2022). In this case, the relevant social groups can be summarized as educators, students, industry professionals, and developers. A diagram displaying the relevant social groups can be seen below in Figure 2.

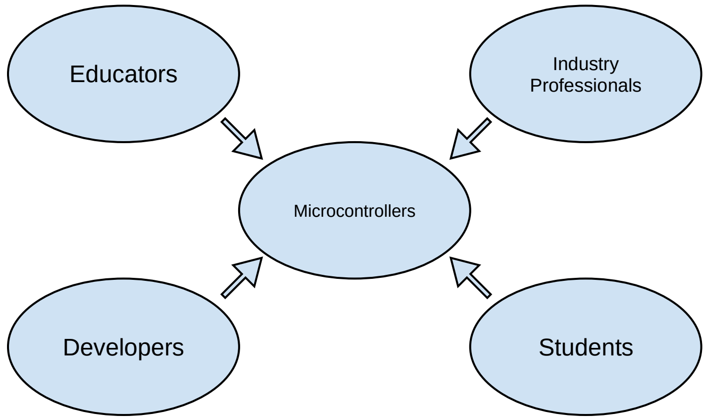

Figure 2: Relationship between relevant social groups

Educators, ranging from elementary school teachers to university professors, have played critical roles in the use of microcontrollers in education. By creating the curriculums and activities which use microcontrollers, they are inherently altering the various demands and consequently microcontroller design. Meanwhile, students have been instrumental in the advancement of microcontrollers as the users who experiment with the technology and push its limits through their classwork. Industry professionals have also played a significant role in the development and adoption of microcontrollers. Through leveraging their expertise in engineering, they have created new uses for microcontrollers in commercialized settings while making it more accessible and affordable to a wider audience. In the HVAC industry, as commercial needs are evolving, new low cost microcontrollers are entering the market that give users more control over their systems (Stehmeyer, 2016). Furthermore, developers have been instrumental in improving microcontrollers by designing and producing more powerful and efficient products. As the developers analyze the use of their products in the market, they are continuously developing new boards to meet the needs of consumers and consequently pushing the boundaries of microcontroller development. Through their work, they have helped enhance the performance of microcontrollers, making them more reliable and efficient.

The relevant social groups contributing to the development and adoption of microcontrollers in education play a critical role in the third component of the SCOT model: closure and stabilization. As one would expect, various groups contributing to the development of one technology will produce conflicts and controversies. Closure refers to the process by which a particular design or use of a technology becomes established and is no longer subject to significant change (Klein, Kleinman, 2022). For example educators requiring specific curriculums have affected the necessary application of specific microcontrollers. As more and more professors adopt similar curriculums, the design of microcontrollers thus becomes less subject to change.

On the other hand, stabilization in the use of microcontrollers in education has also been shaped by students, and industry professionals. Students have also contributed to the stabilization of microcontroller use by developing particular skills and competencies related to their use. Students may develop proficiency in programming languages such as C++, Python, or Java, and gain practical experience in designing circuits and implementing microcontroller applications. Industry leaders, such as Arduino and Raspberry Pi, have also played a role in the stabilization of microcontroller use by providing standards, certifications, and training programs for educators and students. As the various groups develop particular curriculums, establish routines and establish training and certification programs, microcontroller development has consequently become more polished and refined.

Although playing a lesser role in the SCOT model, the fourth component of wider context is still integral to the development of microcontrollers in education. Various factors such as the availability of resources and the Internet of Things greatly influence technological design. As previously discussed, the availability of resources affects society in numerous ways and is no different in the use of microcontrollers in education. The internet of things (IoT) can be considered as another driving factor to the adaptation of microcontrollers in engineering education. The IoT is a network of connected devices that communicate with each other and the internet. As more and more devices are connected to one another through intelligent systems, the importance of microcontrollers grows as well. The integration of microcontrollers with the IoT has made it possible for engineers to design and build intelligent systems that can monitor and control a wide range of devices. Due to the increasing number of connected devices and microcontrollers laying at the heart of systems, providing students with experience working with microcontrollers will better prepare them for the engineering industry.

Discussion

In order to accurately discuss the effect of microcontrollers on engineering education, one must analyze hands-on education in engineering as a whole. Engineering as a field of study involves studying theoretical and scientific principles and then applying them to real-world issues. In most engineering curriculums, concepts and information are taught to students through lectures and then students use these concepts in laboratory settings. Hands-on experience in engineering education is critical for skill development, career advancement, and innovation.

Skill development is vital to the success of engineering students. However, oftentimes lectures and readings can only take a concept so far, leaving students in the dark. Take the concept of geometric tolerancing for example. Geometric tolerancing involves designing parts with various tolerances so that they will fit together without interference. On paper, this concept is relatively simple as it involves comparing the dimensions of parts. However, in actuality, there are major factors that must be considered depending on the material of parts being created. In 3D printing, computer aided design (CAD) models can be accurately simulated but when the part is actually printed many of the dimensions may be incorrect. In this case, depending on the printer being used, there are various tolerances that must be taken into account due to how the object is being constructed. Printing a part in one orientation will not necessarily achieve the same result when printing it in a different orientation. Through hands-on experience, students are able to expand upon the concepts they learned in class, apply their knowledge, and better hone their skills as engineers.

Hands-on engineering experience is vital for students' career preparation in engineering. Many early career engineering positions require applicants to have experience working in the respective field. Theoretical knowledge and concepts does not necessarily immediately translate to solving issues one would find in the engineering industry. Employers value practical skills and experience that are a direct reflection of receiving hands-on education. Through laboratory experiences and capstone projects, students acquire the skills necessary to solve real-world problems in the workplace. Having hands-on experience on one's resume makes them more attractive candidates for positions opposed to a student who only possesses the knowledge of theoretical and scientific concepts.

Despite the importance of hands-on learning in engineering education, many curriculums do not include a plethora of opportunities for students. This issue can be attributed to the cost of laboratory equipment and the lack of laboratory spaces available to students. For the mechanical engineering curriculum at the University of Virginia, there are only 5 lab courses available in 8 semesters. However, the introduction of low-cost microcontrollers to the market in recent years has helped ameliorate the issue across institutions.

Microcontrollers are becoming key components to students' learning experience due to their ease of use and plethora of functions. Exposing more students to microcontrollers ignites their creativity in various science, technology, engineering, and mathematics (STEM) fields (Bicer et al., 2018). Many microcontrollers provide a cost-effective platform for rapid prototyping and practical coding. The inherent plethora of capabilities of microcontrollers means they can be used to teach a variety of engineering concepts and skills ranging from circuit design and programming to system integration. The wide range of coding languages used to program microcontrollers makes them ideal educational tools for students with various levels of coding experience. Moreover, microcontrollers can be used in various engineering fields, from mechanical and electrical engineering to computer science. Using microcontrollers in education encourages creativity and offers students the opportunity to build their own practical projects while promoting critical thinking and the knowledge learned in class.

On the other hand, it is important to also note the disadvantages of using microcontrollers in education. One of the biggest cons to their use in the classroom is the need for the instructor to have adequate knowledge of the device. With microcontrollers on the relatively new side of education and engineering, there are only so many professors with adequate knowledge to teach their uses to students. Additionally, the rapid evolution of microcontroller technology means that educational institutes and instructors must constantly adapt to keep up with the current technology. For example, instructors creating assignments with one version of a board may not be able to replicate the same project if a newer board is used.

Further, requiring institutions to keep up with current technology can also strain funding and in some cases, prevent students from acquiring the resources needed to succeed. Additionally, due to their prototyping capabilities, many microcontrollers can also be easily broken. For example, if a student were to wire a circuit incorrectly, creating a short, it could potentially fry the whole board rendering it useless. This further emphasizes the point that proper training is essential to make the most of their use. Another challenge is the potential reliance on microcontrollers, which may lead to a lack of understanding of fundamental engineering principles and theories. Students may become focused on the technical aspects of programming and controlling a microcontroller without fully understanding the underlying principles of the system they are designing. Due to the prototyping nature of microcontrollers, students may unnecessarily rely on trial and error instead of first attempting to fully understand the engineering concepts behind their project.

To overcome these challenges, it is important to discuss the use of microcontrollers in engineering education with a balanced and thoughtful perspective. Educators must carefully consider the benefits and drawbacks of implementing microcontrollers into their curricula in order to ensure students are exposed to the necessary engineering principles and practices. One potential solution would be for teachers and professors to discuss with their peers how they are implementing microcontroller education. In doing so, they will also reduce the impact of various drawbacks such as the need for training and the costs associated with upgrading equipment. If many professors at different universities teach the same course and use the same microcontroller, they can collaborate to get the most out of their product. Further, industry leaders such as Arduino, are beginning to make educational based microcontroller kits for use in classrooms ranging from elementary school to universities. By aiming to standardize their use, many of the limitations can be ameliorated. Ultimately, the successful integration of microcontrollers into the educational field will require collaboration from educators, students, industry professionals and other relevant social groups impacting the engineering community.

Conclusion

Technology as a whole has improved immensely over the past decade and has been impacting many different aspects of daily life. The versatile application and accessibility of microcontrollers has shown them to be effective educational tools for engineering students. While I do not expect them to be used in place of current lab spaces and experiments, they have proven to be helpful in reducing the cost of lab equipment as well as allowing more students to have access to hands-on learning. Further, their connection to the IoT makes them more important each day as the world becomes more digitized. As more students gain microcontroller experience,more students will be prepared to work in the engineering industry after graduation.

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