

JYU DISSERTATIONS 866

Khaula Zeeshan

**Developing Technology-Enabled
Integrated STEM-IT Education:
Preparing the Workforce for
Next-Generation Digital Economy**



UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF INFORMATION
TECHNOLOGY

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ABSTRACT

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The primary objectives of this research endeavour were twofold. First, it aimed to focus on the development of science, technology, engineering and mathematics (STEM) and information and communication technology (ICT) education at the kindergarten through 12th grade (K-12) level to harness 21st-century skills to meet the challenges of the future digital economy. Second, it sheds light on how emerging technologies can be used in educational settings to provide sustainable education with quality and equity. To keep humans in central role in human-machine (H-M), and machine-machine (M-M) working environments, humans need to learn new skills and embrace continual adaptability and development. This research thesis presents a detailed analysis of the 21st-century challenges, the role of STEM and ICT education, the role of technology, such as artificial intelligence (AI) and internet of things (IoT) in education, and the need for sustainable education for all. Our research work proposed a framework for technology-enabled STEM and ICT education based on project-based learning. This thesis addresses educators, policymakers, and learners to prepare them for the future economies, where automation, technology, digitisation, and sustainability will be the key drivers.

Keywords: 21st-century skills, Fourth industrial revolution, STEM education, ICT, Digital literacy, Digital Economy, Artificial intelligence, Internet of things, Project-based learning, Scenario-based learning

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Zeeshan, Khaula

Teknologiapohjaisen integroidun STEM-IT koulutuksen kehittäminen: Työvoiman valmistaminen seuraavan sukupolven digitaalisiin talouksiin

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Tämän tutkimushankkeen päätavoite on kaksijakoinen. Ensinnäkin se pyrkii keskittymään STEM-IT (tiede, tekniikka, insinööritaito ja matematiikka, tietotekniikka) -koulutuksen kehittämiseen perusopetuksessa ja toisen asteen koulutuksessa valjastaakseen 2000-luvun taitoja vastaamaan tulevaisuuden digitaalitalouden haasteisiin. Toiseksi se valaisee, kuinka uusia teknologioita voidaan käyttää koulutuksessa laadukkaan ja tasapuolisen kestävän koulutuksen tarjoamiseksi. Jotta ihminen pysyisi keskeisessä roolissa ihminen-kone- ja kone-kone-työympäristöissä, ihmisten on opittava uusia taitoja ja pystyttävä jatkuvasti sopeutumaan ja kehittymään työssään. Tutkimustyössä analysoitiin yksityiskohtaisesti 2000-luvun työvoiman haasteita, STEM- ja ICT-koulutuksen roolia, teknologiaa, kuten tekoälyä ja esineiden internetiä, sekä kestävän koulutuksen tarvetta kaikille. Tämä opinnäytetyö on suunnattu kouluttajille, poliittisille päättäjille ja oppijoille valmistakseen heitä tulevaisuuteen, jossa automaatio, teknologia, digitalisaatio ja kestävä kehitys tulevat olemaan talouden avaintekijöitä.

Avainsanat: 2000-luvun taidot, neljäs teollinen vallankumous, STEM-koulutus, ICT, digitaalinen lukutaito, digitaalitalous, tekoäly, esineiden internet, projektipohjainen oppiminen, skenaariopohjainen oppiminen

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Khaula Zeeshan

GLOSSARY

4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
AR	Augmented Reality
CT	Computational Thinking
DE	Digital Economy
DT	Digital Transformation
Gen Z	Generation Z
H-H	Human-human
H-M	Human-machine
ICT	Information and Communication Technology
IoT	Internet of Things
M-H	Machine to Human
M-M	Machine to Machine
OECD	Organisation for Economic Co-operation and Development
PBL	Project-Based Learning
SBL	Scenario-based Learning
STEM	Science, Technology, Engineering and Mathematics
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual Reality

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- I Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki. Renewing mathematical and digital education initiatives in the Asian countries: A review. *International Journal of Education (IJE)*, 2(1), 2021.
- II Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki. Problem-solving skill development through STEM learning approaches. *2021 IEEE Frontiers in Education Conference (FIE)*, pages 1–8, 2021.
- III Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. Internet of things for sustainable smart school: An overview. *Sustainability*, 14(7), 4293, 2022.
- IV Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. ChatGPT for STEM education: A working framework. *International Journal of Learning and Teaching*, 10(4), 544–548, 2024.
- V Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. Computational thinking and AI coding for kids to develop digital literacy. *International Journal of Education*, 12(3), 55–74, 2024.
- VI Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. Project based learning and integrated STEM-IT education for 21st-century skill development. *Informaatioteknologian tiedekunnan julkaisuja*, 105, Jyväskylän yliopisto, 2024.

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1 INTRODUCTION

Today's world is embracing digital transformation (DT) at a fast pace. To embrace rapidly changing technological advances and DT, human preparation response must be well planned and well conceived. DT is perceived as a driver of change in all contexts, most notably in business, and influencing all aspects of human life based on the use of technology, including in education.

DT refers to changes arising from digital technologies, whereas digitization refers to the conversion of information from analog to digital form, and the automation of processes through the use of information technologies. The term "transformation" comprises the understandability to take the required actions when the organizations face new technologies; it is not to be confused with simple change [1]. A continuous stream of technological innovations is driving this digital transformation. The impact of information and communication technology (ICT) is evident in the rise of the digital economy and has been well documented by researchers. These advancements have introduced emerging technologies, such as artificial intelligence (AI) that drives search engines, social networks, smartphones, e-commerce, e-learning, advanced digital learning platforms, smart and digital schools, the Internet of things, which drives the smart city concept, augmented reality (AR), virtual reality (VR), cloud technologies, robotics, and cryptocurrency. As advanced technologies rapidly reshape the world in which we live, the demand to address the related challenges is ever-increasing.

The next-generation industrial revolution is driven by a fast-paced digital transformation which requires a new set of skills from the future workforce. In turn, the development of such skills in our young learners need a holistic approach in the field of education. At this point, there is a dire need to reshape education to meet the future demands. Technology should be used to equip educators with more effective teaching techniques, and technology education, including science, technology, engineering, and mathematics (STEM), must be harnessed at the level of basic education to deliver the desired results.

STEM and ICT education at the kindergarten through 12th-grade (K-12) school level with a focus on 21st-century skill development will enable our young

learners to play a creative and fruitful role in society in the future. At the same time, the fear of losing jobs to AI and searching for new jobs in an era of AI and digital revolution will also diminish. With the passage of time, digital tools will become increasingly more common in our everyday lives. In every area of life, machine-machine and human-machine interaction will be increasingly embedded in society. Therefore, a holistic approach is needed to train today's young minds to become problem-solvers, critical thinkers, creative thinkers, and those who can not only communicate with machines but also control and develop machines for the betterment of humanity (Article V).

The prime objectives of this research endeavor are twofold. First, it aims to focus on the development of STEM and ICT education at K-12 school level to harness the 21st-century skills to meet the challenges of the future digital economy. STEM and ICT education is important to prepare young learners for the future challenges of the next-generation industrial revolution. The generation of Alpha, which is the term for generations born between 2010 and above, has the characteristics of a digital native, but how to bring that talent in mainstream as thinkers, creators and problem solvers is main question. Therefore, the focus of the study is on educational efforts, initiatives, technologies, educational content/material, and educational approaches to deal with the industrial revolution 4.0–5.0.

Second, the research aimed to focus on how technology can play a vital role in providing education in a smart and sustainable way. That is, how can we use emerging technologies to equip today's educators with sustainable, high quality resources? How can educational technologies bridge the gap between developed and developing worlds by providing education to billions of people who are underprivileged and deprived of basic schooling? (Article I)? To answer these questions, this thesis also sheds light on the use of technology in education and its impact on providing sustainable education for all.

1.1 Research Framework

This research endeavor is oriented towards the development of smart learning scenarios based on STEM and ICT education utilising modern educational technologies to deliver the skill sets needed to succeed in the digital revolution.

The following objectives guide this motivation:

1. Acknowledging the need of time as the world is shifting rapidly towards the full-scale digital era. Therefore, today's education has to adapt the technology to provide sustainable learning with equity and equality to prepare the future workforce for the next-generation industrial revolution. The education based on STEM and ICT learning has the potential to create thinkers, creators and problem-solvers as the human resources for a job market consisting of M-M and H-M scenarios.
2. Assessing the potential of STEM and ICT in education and how education

can play an important role in developing 21st-century skills and serve the purpose. How emerging technologies like IoT and AI can play an important role in education.

3. Unveiling the role of STEM and ICT in developing 21st-century skills required by the digital economies from next generation human workforce.
4. This research also seeks to enrich educational pedagogy by suggesting a STEM-IT framework and making recommendations based on the needs and challenges posed by the next-generation digital economy.

Based on the above objective background, this research is guided by the two main question:

1. How the STEM and ICT education at the K-12 level help develop 21st-century skills in young learners to fulfil the demand for skilled human resource of the future digital economy?
2. How can the educational system leverage burgeoning technologies to provide a sustainable education for all?

The following research questions address these two main lines of inquiry:

1. Why is scientific and digital literacy needed to address the challenges posed by future digital economies? How do initiatives taken by different nations address the challenge?
2. How does education leverage from emerging technologies to provide sustainable smart education to the masses?
3. How does STEM and ICT education play a vital role in developing 21st-century skills needed by the next generation industrial revolution based on digital transformation.
4. What would a working framework for STEM-IT education look like?

The research framework as shown in Figure 1 explains how this research is conducted to search for the answers of the main questions mentioned above.

RQ1 is addressed in Article I. Article I showcased the mathematical and digital initiatives taken by different countries to provide young learners 21st-century skills. RQ2 is addressed by Articles III and IV, in which the research study showcased that how technology can play a vital role in educational setups. Article III presents the role of IoT in developing a sustainable smart school and, in Article IV, the role of AI in education is discussed. We presents an example from Generative AI tool ChatGPT, and illustrate its possible role in STEM education. RQ3 is addressed in Articles II and V, which shows that STEM and ICT education plays a vital role in developing digital literacy and the development of skills like problem-solving, computational thinking, critical thinking and idea creation.

RQ4 is addressed by the proposed framework for integrated STEM-IT education in Article VI

The research methodology followed a qualitative research displaying qualitative study design. Qualitative research design is a commonly used research method in education, information systems, nursing, information science, and political science. Data collection is based on qualitative data. The data is used and analyzed to interpret the results.

In this research, we did the extensive literature study and collected related information to support our topic. After that, we applied research based on the qualitative data. We collected data in the form of surveys, interviews, Google forms. Extensive qualitative data is also collected from the reports published by prestigious organisations and institutions in the world in the field of education policy making. This data is then critically analysed and discussions, recommendations and conclusions are made. A framework is formulated and proposed for the integrated STEM and ICT education at K-12 school level.

1.2 Structure of the thesis

This dissertation is structured as follows:

Chapter 1 is dedicated to the introduction to the theses consisting of the research objectives, research questions and research methodology.

Chapter 2 discusses the background of the main objective of this research endeavour focusing on the challenges and needs to develop 21st-century skills focusing on STEM and ICT education.

Chapter 3 describes the role of technology in the field of education by presenting how the digital revolution is making an impact on education. This chapter also discusses how education equipped with modern technologies can bridge the gap between the developed and developing parts of the world to provide a sustainable and equal education for all.

Chapter 4 discusses our proposed idea of STEM-IT education at basic education level for young learners. This chapter also discusses the proposed framework and makes recommendations for the transformation of educational setup in a holistic way to prepare the next-generation workforce to be able to work in M-M and H-M environments.

Chapter 5 provides the summary of the included articles.

Chapter 6 provides the conclusion and recommendations for the future research directions.

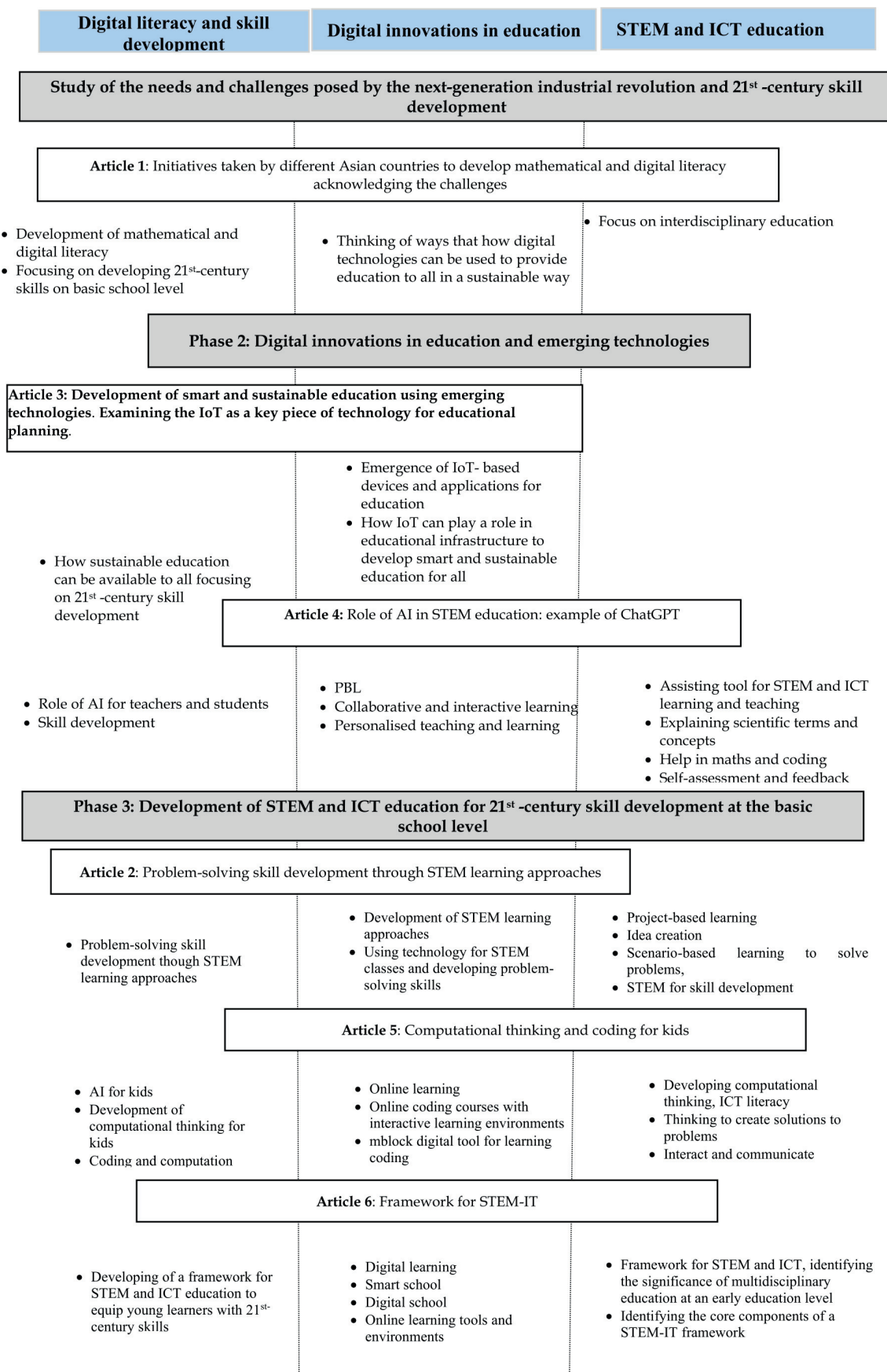


FIGURE 1 Research Framework

2 21ST-CENTURY DIGITAL AGE AND ITS CHALLENGES

With the advent of the 21st-century, the world is seeing a new revolution of technology that embraces automation and digitalisation. Artificial intelligence, advanced wireless technologies, and the Internet of things have already transformed our world. Our future will be autonomous based on smart environments and intelligent machines. When we talk about smart and intelligent systems, we think of machines replacing humans. Only the skilled work force will manage to find jobs in the future work industry. In that scenario, we can see a gap emerging between fast-paced technology development and the scarcity of a skilled work-force capable of working with advanced technologies. This gap will widen if educational systems fail to embrace scientific and digital education as regular components of education along with reading, writing, coding, and mathematics skills.

The Organisation for Economic Co-operation and Development (OECD) has presented a framework for 21st-century skills which identifies three dimensions of future skills: information, communication and ethics and social impact [2]. This framework clearly emphasises on ICT education under the communication dimension to develop critical thinking, computational thinking, problem-solving and innovation and creative skills for the future. The Partnership for 21st-century learning (P21) has also published a framework for 21st-century skills and identified ICT, technology, media, and communication education as an important set of competencies to deliver skills like creativity and innovation, critical thinking and problem-solving, communication and collaboration. European Union's (EU) digital competence framework for citizens stresses the importance of the digital literacy of its citizens to prepare them to meet the challenges of the future digital economy by developing proficiency in technology use and digital innovation and creation. EU's DigComp 2.0 project identified the main digital competencies in its conceptual reference model. These competencies are: information and data literacy, communication and collaboration, digital content creation, safety and problem solving (EU's DigComp 2.0) [3].

There is a dire need to integrate ICT education in regular school curriculum

at very early school age to achieve the goal of skilled workforce for future. While we talk about technology education, we not only need an integrated curriculum but also trained teachers and advanced pedagogies to achieve the ICT literacy goal. However in this research, our main focus is learners and policymakers. We investigate the significance and need of STEM and ICT education, the pedagogical methods applied to develop scientific and digital literacy at different levels of education, and initiatives that have already been implemented taken at the K-12 level as mentioned in literature.

2.1 The Next-Generation Industrial Revolution

The so called Fourth Industrial Revolution (4IR) represents a fundamental change in the way we live, work and relate to one another. It is a new era in human development, enabled by unprecedented technology developments. These advances are merging the physical, digital and biological worlds in ways that create both huge promise and potential peril. The speed, breadth and depth of this revolution is forcing us to rethink how countries develop, how organizations create value and even what it means to be humans and how we will prepare for this change. This revolution is about more than just technology-driven change. It is an opportunity to help everyone, including leaders, policymakers and people from all walks of life to harness converging technologies to create an inclusive, human-centred future [4].

In 1760, the first industrial revolution geared up with the invention of the steam engine. The steam engine shifted the world from agriculture and farming to the industry and manufacturing processes. The main energy source was coal. Textile and steel were dominant industries, and trains were the main source of transportation. The second industrial revolution started in 1900 when the internal combustion engine was invented and led to an age of rapid industrialisation using oil and electricity to power mass production. The third industrial revolution began in 1960 and is known for the rise of the electronics and information technology to automate production. The fourth industrial revolution is now characterised by the computer-generated product design, three-dimensional (3D) printing, and disruptive technologies like VR, AR, IoT and AI [5].

2.2 Future Needs and Challenges

We live in an age of computers and digital technology where digital transformation has revolutionised our lives enormously. Instead of a pen and paper we have digital screens and keyboards, Netflix as TV, Uber as the taxi, and Airbnb replacing traditional hotels. Thus, when we talk about the 4IR, it is not just about machines and technology. Rather its a total paradigm shift in the way we live our

lives. Newfangled disruptive technologies are making an impact on our civilizations. The Fourth Industrial revolution is bringing benefits as well as challenges. 3D technology will likely reduce barriers between inventors and markets [6]. AI will create significant economic disruption by replacing the human workforce in many job sectors with automated systems. Almost half of the present jobs will be replaced by AI automation [7]. IoT is another emerging technology which will offer advanced connectivity of devices, systems, and services that goes beyond M-M communications and covers a variety of protocols, domains and applications. With the realm of IoT in various industrial systems, more security issues will emerge, and the need for cyber security will be felt more than ever before [7].

Education is already been revolutionised in significant ways due to the emergence of the technologies that drive the 4IR. We can see that the physical, digital and biological spheres are merged by these new technologies. Advanced modes of curriculum, teaching, and learning have arisen, and the focus has changed from modes of teaching to modes of learning. Alternative curricula are constantly being developed. The concept of digital schools, online learning environments, virtual worlds, gaming and augmented reality-oriented learning spaces are already around us [8, 9]

The challenge faced by the educational systems posed by the 4IR is twofold. First, the traditional subject-based educational approach that focuses on basic subjects will not be enough to prepare the next-generation workforce. Today's education needs a holistic way to develop a skilled workforce for future needs. Taking into account future needs and challenges, our educational systems should focus on developing skills in the young generation, such as digital literacy, ICT literacy, computational thinking, problem solving, idea creation, coding, business management, innovation, technology, and communication [10].

Second, bridging the gap between the developed and developing nations is an important task on which to focus. Emerging educational technologies can be used to bridge that gap by developing, for example, digital schools which will require only a device and the internet to provide learners with the basic education that will help build a literate society that can play a part in developing economies. This way modern educational technologies will play a crucial role in bridging the gap and providing smart and sustainable education rather than increasing the gap as explained in [10] and Article III.

2.3 21st-Century Skill Development

Frameworks for 21st-century skills have been presented by different world-renowned organizations. The Partnership for 21st Century Skills (P21), organization of economic cooperation and development (OECD), European Union (EU), and United Nations Educational, Scientific and Cultural Organization (UNESCO) [11] have recommended ICT literacy as a core competency of 21st-century skills framework. These organizations have consistently emphasized the integration of ICT

in curricula and the adoption of digital tools in teaching and assessment of these skills [12]. It has also been noted that 21st-century skill development requires competent and well-prepared teachers to deliver the curricula; therefore, teacher training must be a part of the whole process. The 21st-century skill framework presented by P21 has three main groups of skills, “Life and career skills”, “Learning and innovation skills” and “Information, media and technology skills” as shown in Figure 2.

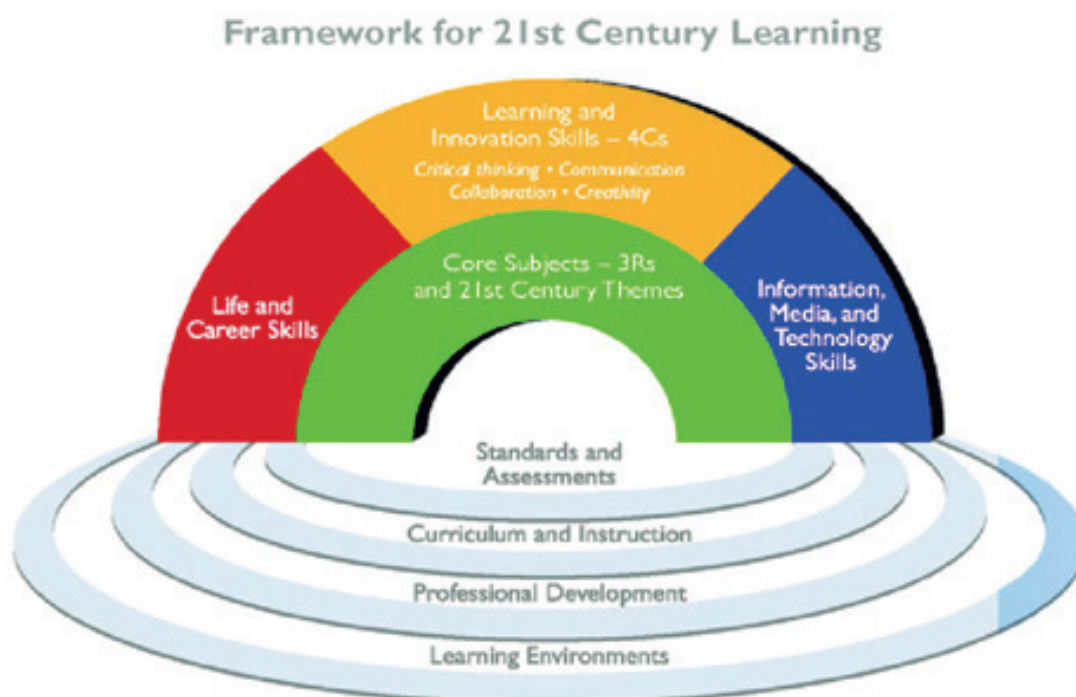


FIGURE 2 Framework for 21st-century Learning

This research focuses on the development of the 21st-century skills required by the future digital economy to address the challenges posed by the next-generation industrial revolution. STEM and ICT at the K-12 level can revolutionize the way we think about education. Preparing the future workforce can only be done when young learners will have enough knowledge of science, engineering, mathematics and ICT, including coding and computer programming. The process of developing digital literacy focuses on the development of the following skills (see Figure 3):

- Research and inquiry
- Analytical thinking
- Critical thinking
- Problem-solving
- Computational thinking

- Collaboration
- Design thinking
- Evaluation
- Active human and machine interaction
- Testing and validation
- Redesigning and troubleshooting
- Security and privacy
- Ethical responsibility

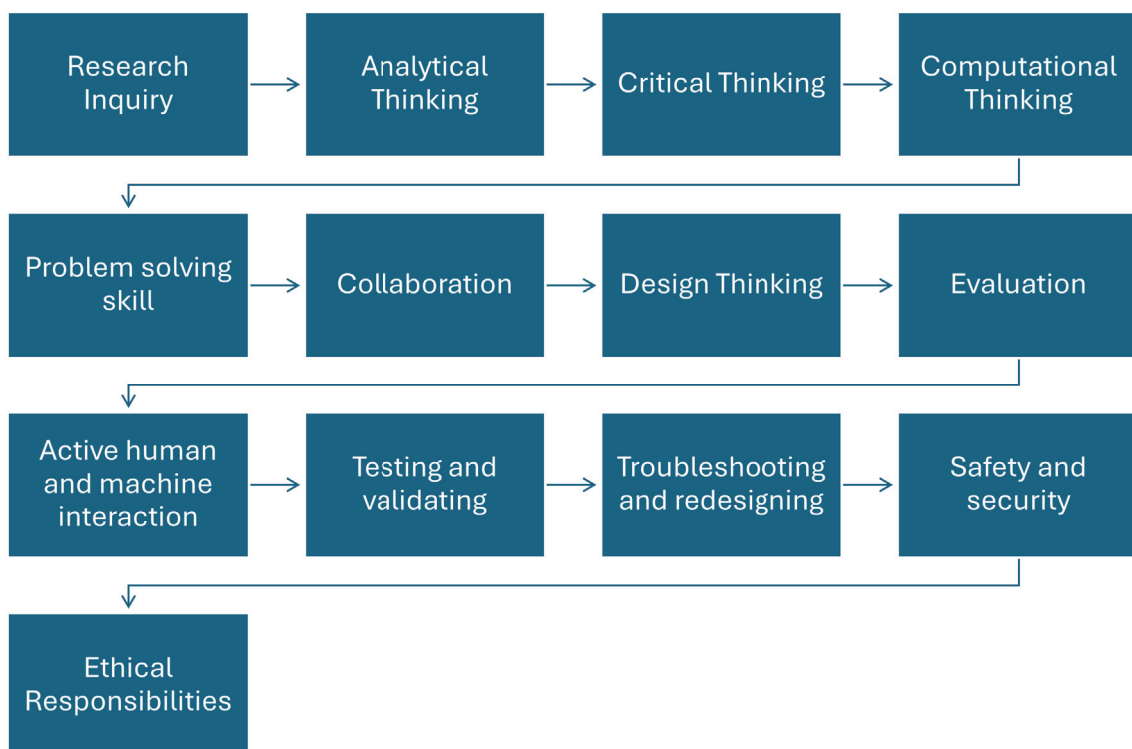


FIGURE 3 Skills and competencies

Computational thinking (CT) conceptualises and brings all the science working behind different computer science tools and software. CT provides a set of skills in which coding is one piece of the puzzle to complete the whole picture of computational thinking. We can develop CT skills in pupils by teaching them coding, which is a form of writing to create solutions to certain problems. According to wing, thinking as a computer scientist means more than being able to program a computer [13]. The digital learning process shown in Figure 4 illustrates how these skills can be developed. Articles I, II, and V discuss in detail the skill development processes and initiatives taken by different governments and organisations.

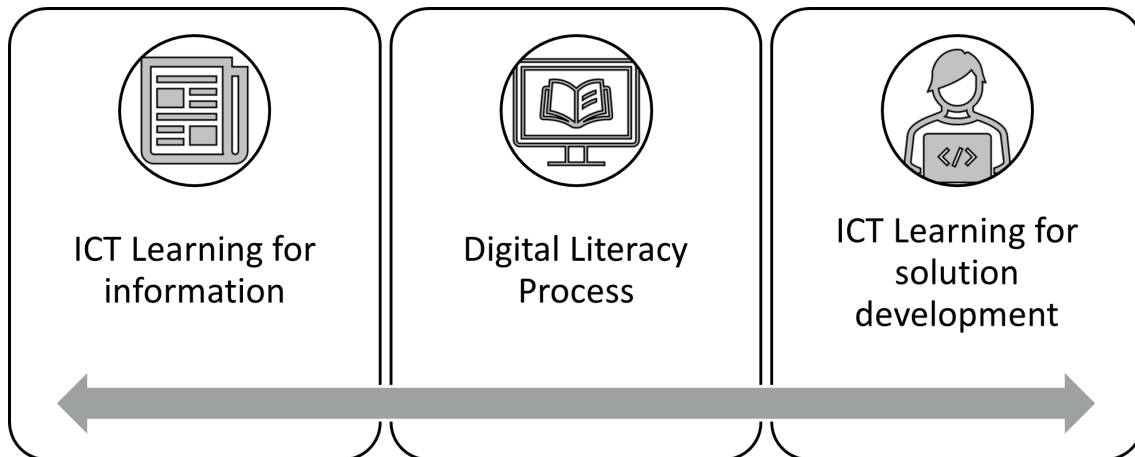


FIGURE 4 The Digital Literacy Process

Role of STEM and ICT education in developing 21st-century skills cannot be neglected. Increasing curricular emphasis on STEM and ICT skills is aligned with the goal of preparing students for a fast-changing world of work in the 21st-century as indicated in Article II.

3 DIGITAL REVOLUTION IN THE FIELD OF EDUCATION

Since the dawn of the new millennium, the widespread usage of mobile phones and modern gadgets have revolutionized the very concept of digital technology. Mobile learning devices, such as tablets and mobile phones have emerged as an integral components of digital technology [14]. In recent times, the burgeoning applications of AI technology in the education sector has played a vital role in enriching the digital technology lexicon. ChatGPT, for instance, has emerged as an indispensable tool which has a significant potential to revolutionize future education as discussed in [15] and Article IV. Articles III and IV showcase the implementation of technologies, such as AI and IoT, in educational settings and their benefits to educators, learners, and managers of education.

3.1 Educational Technologies and Emerging Pedagogies

Artificial intelligence (AI) has the potential to address many big challenges in education as well as bringing innovation to teaching and learning practices. At the same time, the application of these technologies must be guided by the principles of inclusion, equity, and ethics, as discussed in the research article [16].

This research endeavour focuses on two aspects of education. One is the STEM and ICT education to develop scientific and digital literacy, while the second is the role of technology in education to facilitate effective learning and provide flexible education modes to all with equity and sustainability. ICT and modern technologies are revolutionizing our education in a way that has never been experienced [17]. Article III describes how the IoT can be used to create a smart and sustainable school. A school enabled by IoT offers sustainable resource management, technology driven smart classrooms, reliable and secure ICT infrastructure, advanced pedagogies, curriculum and interactive learning management systems (Article III).

Similarly, Article IV discusses the considerable impact that AI is making

on education. This research article focuses on AI tool Chat GPT and provides a detailed framework of how Chat GPT can be used by STEM and mathematics teachers to enhance learning. The research also discussed the use of this AI tool from the perspectives of both teachers and students.

Innovative pedagogies enabled by digital technologies for competency development and creativity in learning and teaching provides educators a new era of educational revolution [18]. Likewise AR and VR have been widely embraced in education in recent years. One example is the use of wearable devices, such as smart watches, fitness tracking bands, and smart glasses. Although challenges like high costs, scalability and accessibility remain, such technologies, including mobile applications and digital platforms, enhances students' immersive digital experiences [19].

Project-based learning (PBL) is an instructional approach that immerses learners in realistic, often complex scenarios where they have to apply their knowledge and skills to solve problems and make decisions. By simulating real-world situations, scenario-based learning (SBL) provides a safe and engaging environment for learners to experiment, learn from their mistakes develop a deeper understanding of the practical implications of their ideas and concepts and play their role in creating solutions to the problems presented to them. Article II examines the implementation of PBL in STEM learning.

Finland is an impressive example of digitalisation and embracing of educational technology. The Finnish education system has been revolutionized by digital technologies and knowledge-creation pedagogies. Sixty-nine percent of Finnish students use digital devices in a week as compared to other EU countries [20].

Finnish students also use different digital learning environments. One such example is Ekapeli, developed in collaboration between the University of Jyväskylä and the Niilo Mäki Institute to teach basic reading and arithmetic. Another example is the peda.net school network, which offers its members online tools as well as training, support, development and research services [21]. Behind all of these pursuits is an aim to promote appropriate use of information and communication technology in facilitating learning and achieving teaching goals.

The embracing and integration of emerging technologies as mentioned in Figure 5 in education offers an opportunity for education systems to introduce novel and innovative pedagogical strategies to improve their existing educational setups as well as to prepare both teachers and learners to grow in an increasingly digital world [22]. Developing digital literacy demands new sets of functional skills and critical knowledge for reading, writing, and interacting with the digital media, the web, the web-mediated networked communities. The emerging technologies entail a continuous and adaptive learning of new technology skills, problem-solving skills, computational and critical thinking.

We refer all of these modern teaching instruction setups as emerging pedagogies which focus on new dimensions of teaching and learning by taking into account networked knowledge society, knowledge economy, digital literacies, and a digitally transformed next-generation workforce [22]. Such emerging pedagogies

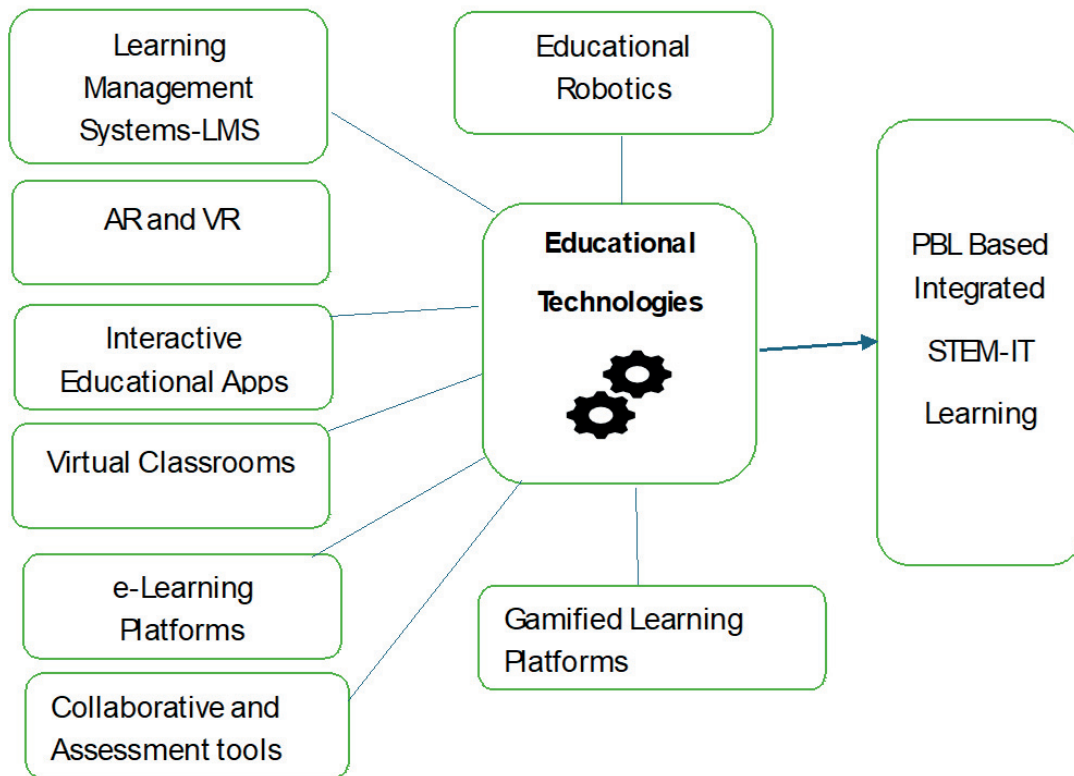


FIGURE 5 Educational Technologies

can be based on different constructs, such as text, video, audio, gaming, reading, writing, and immersive experiences. These pedagogies focus on skill development to meet the needs of a digitally transformed society in which H-H, H-M, and M-M interaction will be the key elements.

3.2 Education in Global Perspective: Bridging the Gap

With the advent of modern technologies and the evolution of the industrial advancement and progress, the world is increasingly global while at the same time increasingly polarised in terms of some parts of the world enjoying progress while others are deprived of even basic needs, including the education of children. This visible divide calls for a sustainable approach to bridge the gap between the developed and developing world. By sustainability we mean to adopt ways of teaching and learning, educational technologies and pedagogies which are more effective, long-lasting and available for everyone.

Any educational setup that can reach the masses would be more sustainable and effective. According to UNESCO, 250 million children and youth are out of school globally, 765 million adults lack basic literacy skills and 70 percent of countries allocate less than 4 percent of their GDP to education [23] which, in reality, is a very sad state of affairs.

One of the emerging challenges is that the new technologies are being intro-

duced at such a fast pace that the gap between developed and developing nations is widening more rapidly. To address this challenge, our research offers a framework recommendation:

Mobile technology: With the advent of mobile technology, the internet and mobile phones have revolutionised in the world in an impressive way. For example, in Pakistan, there are 111.0 million internet users, according to recent data [23]. According to UNICEF Pakistan, Pakistan is one of the least-developed countries with an alarming rate of out of school children (OOSC), a rate that is estimated at 22.8 million children aged 9-16 who are not attending school [23]. In this scenario, mobile technology can be used as an e-school to provide basic education to children. All that is required is a mobile device and the availability of internet connectivity instead of an expensive building, books and teachers.

Internet Connectivity: Apart from digital devices such as mobiles and tablets, free Internet connectivity should be made available.

e- material: A systematic collection of easy-to-follow learning materials should be tailored to meet the needs of basic education. Such material should be openly available free for students. A curriculum guide for each level should also be available. Online testing should be available for students to pass to the next grade level. Learning and guiding videos should also be part of the courses.

Reading and writing materials: Different books suitable for different age groups should be available online to read. Students should be provided with free books and notebooks. School supplies should be totally free for students.

Skill development: 21st-century skill development and ICT literacy should be the core focus of the curriculum.

Local teacher in charge: There should be a local teacher in charge of teaching and facilitating learning and should provide help on weekly basis to ensure a smooth-running of e-school.

Feedback and assessment system: There should be a central feedback and assessment system for each grade level. The system should provide an automatic feedback and assessment for students on the completion of the course in each level.

Funding and scholarships: The funding for the e-school will be used to run the school as well as provide scholarships for deserving students who cannot afford expenses for education. This funding should be provided by the local businesses that are well off, individual people, organisations, and governments. For this

purpose a fund treasury should be setup to take care of finances in a transparent way.

Valid certification: A valid certification from the e-school as shown in Figure 6, should be provided, which would be accepted by the local education governing bodies. With such a certification, after receiving a basic education between the ages of 9 and 17, students could continue on to higher education.

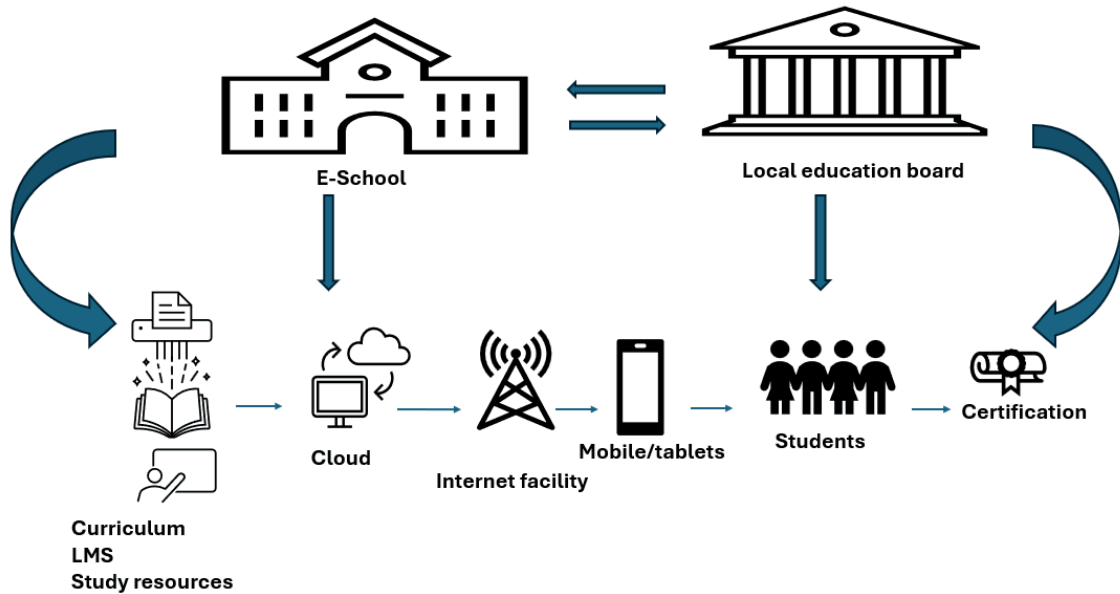


FIGURE 6 Proposed e-School Model

4 STEM-IT EDUCATION AND DIGITAL ECONOMY

We believe in a learning theory that emphasizes the active role of learners in building their own understanding. The theory of constructivism provides the basis of our argument for how knowledge construction can be achieved by embracing a multidisciplinary approach and offering learners the knowledge of science, technology, engineering, and mathematics along with ICT literacy and competencies [24].

STEM education constructs knowledge that focuses on STEM literacy, designing shareable technologies, leveraging technologies, and developing technological literacy, collaboration, communication, scientific argumentation, reasoning and validation and, critical and creative thinking [25]. In our research, we argue for a critical approach to teaching ICT literacy to students on a daily basis and applying digital competencies in working life. What is needed is a well-established conceptual framework and pedagogical strategies for digital and media education to meet the new challenges posed by a digitally transformed world driven by new technologies [26].

4.1 Digital Economy

The Digital Economy that is driving the fourth industrial revolution refers to a collection of economic and commercial activities that utilise digital technologies and electronic communications. This type of economy includes economic activities such as e-commerce, digital marketing, digital content production, digital financial services, software development, computer games, mobile applications and cloud services as discussed in [27] and [28].

The Digital Economy, an innovative economy, involves economic and commercial activities that utilize digital technologies and electronic communications [29]. The characteristics of the Digital Economy include Internet connectivity, mobility, personalization, networking, availability, ubiquity, digital content, and automation; similarly telecommunication, electronic devices, E-Commerce, so-

cial media, disruptive technologies such as AI, IoT, Cloud Computing, AR, VR, Digital Data, and Digital Platforms as mentioned in Figure 7. Such an economy relies on H-M and M-M interaction. In a digital economy, many jobs currently performed by humans will be taken over by machines, and many new jobs based on technology will be created, which requires that the workforce possess appropriate skill sets.

Automation, digital platforms and other innovations are changing the fundamental nature of work. Understanding these shifts can help policymakers, business leaders and workers move forward and address the challenges posed by these transformations and disruptions [30].

Characteristics of DE	Components of DE
<ul style="list-style-type: none"> • Connectivity • Mobility • Personalization • Networking • Availability • Ubiquity • Digital Content • Automation 	<ul style="list-style-type: none"> • Internet • Electronic Devices • E-Commerce • Social Media • Disruptive Technologies • Digital Data • Digital Platforms

FIGURE 7 Characteristics and Components of a Digital Economy (DE)

4.2 Integrated STEM-IT

We argue here that the knowledge created through science, technology, engineering, mathematics, and ICT education will enable young learners to prepare for future jobs and work environments. Scientific and technical knowledge develops the skills required by the future job market. Additionally, integrated STEM and ICT education based on the project-based learning can provide learners a hands-on practising to think and solve complicated problems, as shown in Figure 8. Article VI explains the framework for integrated STEM-IT education in detail.

STEM-IT consists of the integrated learning of STEM and ICT subjects as

components of a basic school curriculum focused on the development of 21st-century skills enabled by emerging technologies such as, the IoT and AI. To prepare learners for the AI-driven digitally transformed future, we need to provide them with practical, hands-on experiences. Scenario-based learning (SBL) and multidisciplinary project-based learning (PBL) offer powerful tools for achieving this goal. With an integrated STEM-IT approach based on SBL, learners can immerse themselves in realistic scenarios where they can apply their knowledge to solve complex problems as explained in [15] and [31].

In a multidisciplinary STEM-IT approach, students might work on a project that requires them to design a solution to solve a problem by considering not only its technical aspects but also its potential impact on society, health, environment, human behaviours and the economy. This approach allows learners to foster both the creative and critical thinking skills that are essential for navigating the challenges and opportunities in a continuously transforming world.

For instance, understanding the ethical implications requires knowledge of not only the technical field but also philosophy, ethics, social sciences as well as analytical capability. Similarly, comprehending the impact of their actions on the environment requires insights from environmental and biological sciences. In a constantly changing world, when the AI-based systems will affect the job market, there will be new kinds of jobs that requires knowledge of ICT-related skills alongside other subject knowledge. Thus, this is the time to prepare the next-generation workforce for the next-generation digital economy.

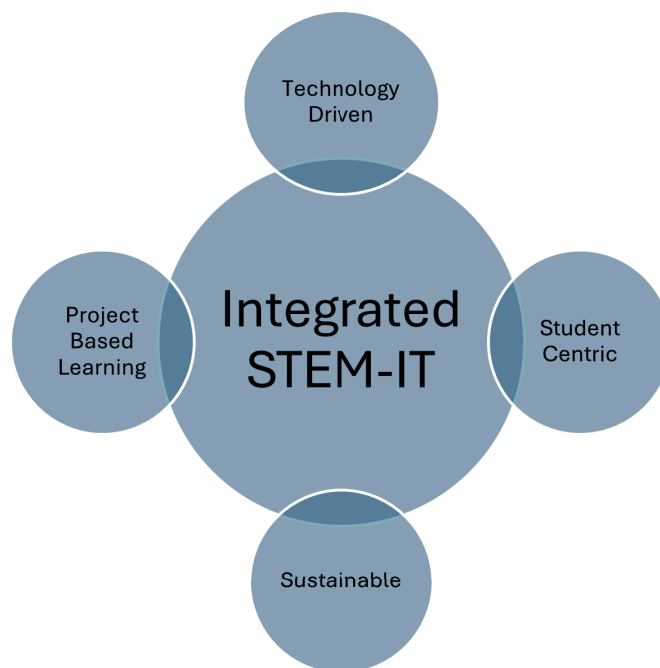


FIGURE 8 Integrated STEM-IT Learning

4.3 Project-Based STEM-IT Learning

Education reformers and policymakers increasingly support a more expansive and holistic vision for public education that aligns with the deeper learning goals of PBL. We argue that technology can support successful PBL implementation and enhance its effectiveness as we see an immense advancements in the field of educational technology.

PBL can be introduced into STEM-IT classes in many different ways. For example, teachers and curriculum planners can make use of externally developed PBL curricula or develop their own PBL approaches, or PBL can be part of a whole-school reform effort. Implementing PBL is often challenging. PBL learning approaches redefine the teacher's role from instructor to facilitator. This kind of learning requires sufficient time to plan and execute the lesson and it involves scenario-based tasks and goals to achieve. PBL promotes the construction of knowledge, student collaboration and engagement, idea creation and problem-solving skills.

PBL encompasses STEM-IT subjects in the form of a tailored project specifically designed to help students construct knowledge in different fields of science and technology. The STEM teacher can choose topics related to the integrated STEM and ICT, set the goals and craft a problem. Therefore, the STEM-IT multidisciplinary PBL/SBL approach with student-centric learning environments is a way forward to address the future challenges and needs. The process of PBL knowledge construction is shown in Figure 9. Integrated STEM-IT learning based on PBL approaches to develop 21st-century skills as mentioned in Figure 3.

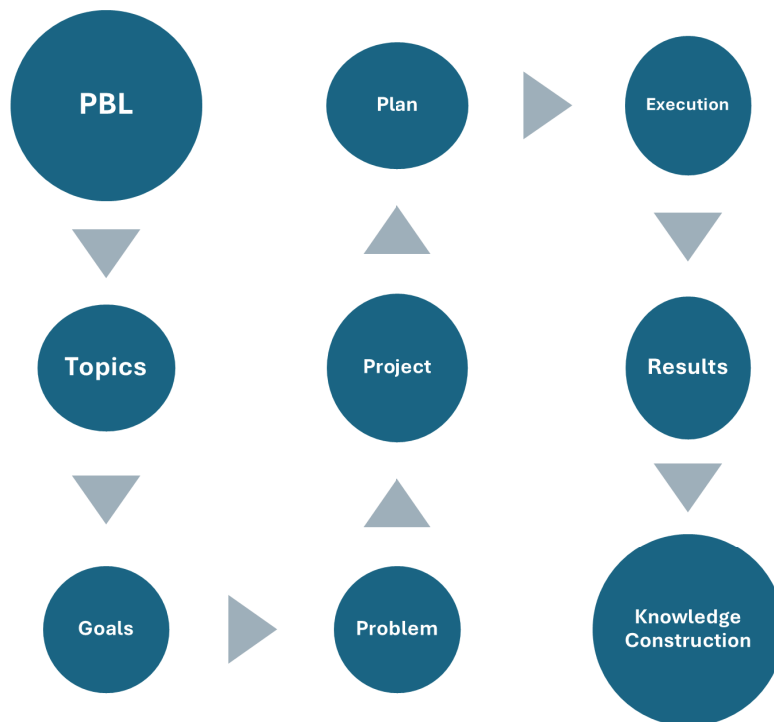


FIGURE 9 PBL Knowledge Construction

4.4 Framework for Integrated STEM-IT

As we have discussed, it is important to begin STEM and ICT education at the elementary school level and continue it through high school. We have also discussed the challenges that are emerging due to fast-paced digital transformation. In this vein, we propose a framework for STEM and ICT education in an integrated form called the STEM-IT framework (see Figure 10):

Integrated STEM-IT curriculum: We propose an integrated interdisciplinary approach for teaching pupils science, technology, engineering, mathematics and ICT in a way that the pupils learn at the same are acquiring related skills. Therefore, it is necessary to develop an integrated curriculum that focuses an integrated curriculum is required to develop, which would focus all of these subjects. The aim would be to develop in students a 21st-century skill set as previously described.

Learning spaces: Fast-paced digital transformation and emerging technologies are the enabling key factors of new learning spaces. Learning spaces can be physical, online or hybrid. Schools can be e-schools or physical schools, and classroom can be online, offline or in person.

Connectivity and digital devices: The free availability of Internet access along with digital devices, such as tablets and laptop computers, are important compo-

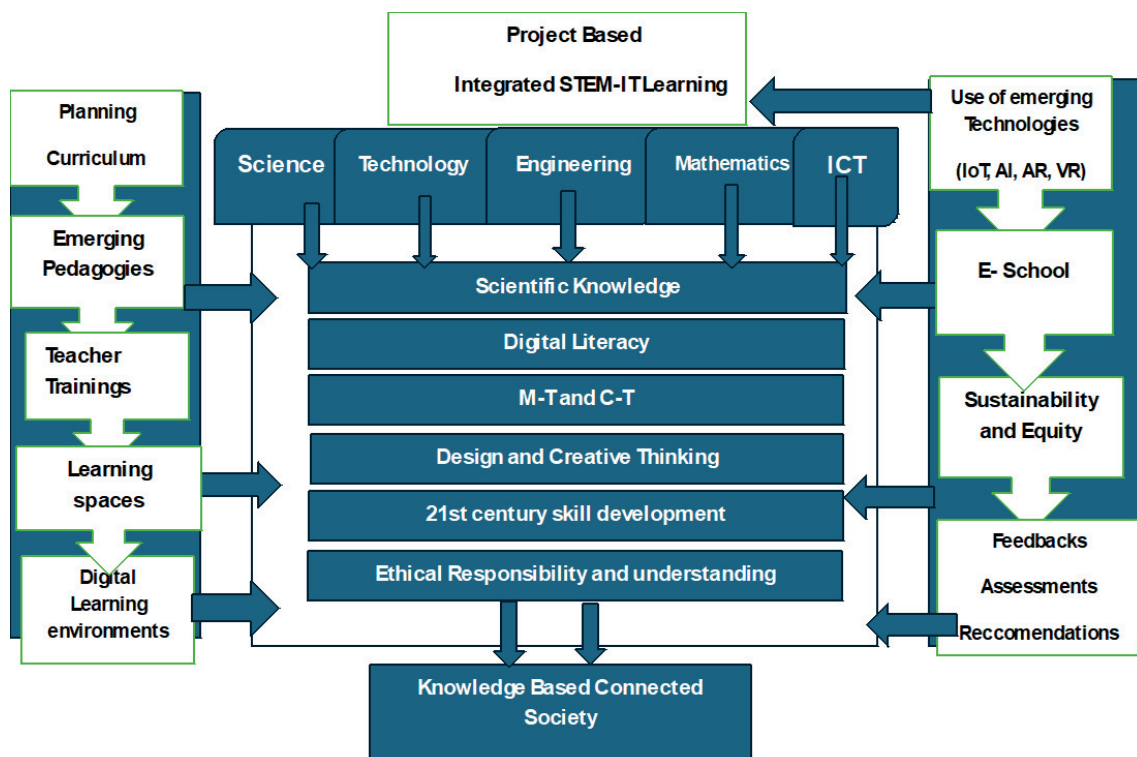


FIGURE 10 Proposed Framework of Integrated STEM-IT Education

nents of the STEM-IT framework.

Emerging Pedagogies: Emerging pedagogies can be based on different constructs such as text, video, audio, gaming, reading, writing, and immersive experiences. These emerging pedagogies focus on skill development to meet the needs of digitally transformed society in which, H-M, and M-M interaction would be the key element. Project based learning with student centric approach would be the core teaching technique.

21st-Century skill development: The main purpose of STEM-IT education system is to develop 21st century skill development such as digital literacy, mathematical and computational thinking, analytical thinking scientific knowledge, design and creative thinking, ethical responsibility and understanding, etc.

Teacher training: Teachers should be continually trained for the ever-changing teaching environments. They should be familiar with using different educational technologies to deliver interdisciplinary competencies to learners.

Sustainability and equity: There should be sustainability and equity factor. Any solution which is sustainable and available to all is actually going to deliver the purpose. Therefore, STEM-IT relies on sustainability and equity.

Bridging the gap: Millions of children are unable to attend schools and learn. Our proposed e-School concept can bridge to narrow the gap between the developed and developing worlds by providing education to those who are unable to afford it.

Educational technologies: Educational Technologies based on disruptive technologies such as AI, IoT, AR, VR, and robotics can be used as enabler technologies.

A knowledge-based connected society: As a result of STEM-IT education, we will be able to develop a knowledge-based society with skilled human resources available for the next-generation digital industry. In this way, we can create a digital economy that removes the fear of job loss due to lack of technology skills. Instead, humans will be prepared to embrace new kinds of jobs [32].

5 SUMMARY OF INCLUDED ARTICLES

This chapter provides the results of the articles included in this dissertation.

5.1 Article I: Renewing mathematical and digital education initiatives in the Asian countries

Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki (2021). Renewing mathematical and digital education initiatives in the Asian countries: A review. *International Journal of Education (IJE)*, 2(1).

Research Objectives

The research objective of this article was to present a research review of initiatives taken by different Asian countries by focused on both developed and developing countries. Another research objective was to shed light on the need of developing new ways to promote mathematical and digital education initiatives at elementary school level.

Results

We emphasized on the development of mathematical and digital literacy and focused on developing 21st-century skills at elementary school level. we discussed the ways how digital technologies can be used to provide education to all in a sustainable way. Our research article focused on interdisciplinary education and presented the initiatives taken by eight Asian countries (China, Japan, South Korea, Singapore, Pakistan, India, Nepal, and Bangladesh) to develop mathematical and digital literacy at the K-12 level. Our research article provided a comparison of above mentioned eight Asian countries in digital literacy initiatives, mathematical literacy initiatives, ranks in mathematics and science in PISA results 2018, and ranks in inclusive development index IDI 2018. For more detailed results we

refer the readers to Article I.

5.2 Article II: Problem-solving skill development through STEM learning approaches

Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki. (2021). Problem-solving skill development through STEM learning approaches. In 2021 IEEE Frontiers in Education Conference (FIE), pp. 1-8. DOI:10.1109/FIE49875.2021.9637226

Research Objective

The prime objective of this research article was to showcase how STEM learning approaches play a crucial role in developing problem-solving skills in young learners.

Results

We showcased how in a class we can develop problem-solving skill through project-based STEM learning approaches. We applied here project oriented problem-based learning approach as a fundamental pedagogical approach. This research article has provided a good example to teachers how they can integrate science subjects in class to develop problem-solving skills through scientific-based learning methods and design-based learning method in young learners at primary education level.

5.3 Article III: Internet of things for sustainable smart school: An overview

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. (2022). Internet of things for sustainable smart school: An overview. *Sustainability*, 14(7):4293. DOI:10.3390/su14074293

Research Objective

The research objective of this article was to analyze and search for the possible applications of IoT in educational settings for a smart and sustainable education provision.

Results

We discussed in our research work that the IoT could prove to be a paradigm shift as an enabler of sustainable smart schools. We emphasized sustainable edu-

cation methods promoting smart learning environments. IoT plays a vital role to optimize the needs of educational settings. We showcased in detail how IoT can be used for smart school management, smart school teaching, and smart school learning. We also presented the challenges in the application of IoT for education and addressed the security and privacy issues related to the IoT.

5.4 Article IV: ChatGPT for STEM education: A working framework

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. (2024). ChatGPT for STEM education: A working framework. *International Journal of Learning and Teaching*, 10(4), 544–548.

Research Objectives

The first objective of this research was to analyse the application and implementation of Generative AI in STEM education. ChatGPT is an emerging AI tool with its benefits and challenges. Another objective of this research article is to guide the educators how they can use ChatGPT for teachers and students.

Results

In Article IV, we proposed a working framework for the educators how to use ChatGPT for STEM subjects learning and how AI can play a constructive and productive role in STEM learning and skill development. Our research article showcased many ways to use the Gen AI tool for teachers and students such as feedback, assessments, interaction, idea creation, customized learning, mathematics and coding learning, scientific knowledge learning and language development. our research article also discussed about the limitations and ethical issues related to Gen AI in education.

5.5 Article V: Computational thinking and AI coding for kids to develop digital literacy

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki (2024). Computational thinking and AI coding for kids to develop digital literacy. *International Journal of Education*, 12(3), 55–74.

Research Objectives

The main objective of this research article was to present literature knowledge on computational thinking skill and how we can develop this skill in young learners

to harness digital literacy in them. Additionally we aimed to find out how coding skills contribute to the 21st century skill development.

Results

This research article has provided a theoretical knowledge of digital learning process and digital literacy development. Additionally, our research article discussed in detail the computational thinking skill development process and showcased a case study of online coding class and discussed how it helps in developing digital literacy and computational thinking. The main contribution of this research work was to highlight the significance of coding learning and development of digital literacy and computational thinking in young learners.

5.6 Article VI: Project-based learning and integrated STEM-IT education for 21st-century skill development

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki. (2024). Project-based learning and integrated STEM-IT education for 21st-century skill development. *Informaatioteknologian tiedekunnan julkaisuja*, 105/2024.

Research Objective

The research objective of this article was to propose a working framework for STEM and ICT at the K-12 educational level.

Results

In this research article, we explained the STEM-IT education as the solution to develop 21st-century skills to meet the needs of next generation industrial revolution. We explained the components and characteristics of the digital economy. We proposed a working framework for PBL-based Integrated STEM-IT education and explained the important features of PBL-based Integrated STEM-IT learning setup at the K-12 educational level. We discussed about digital learning, smart e-school concept and online learning tools and environments.

6 CONCLUSION AND FUTURE RESEARCH

There is an old, wise saying 'A stitch in time saves nine. How we act in the present determines our future fate. We live in a constantly changing world that is digitally transforming at a faster pace. The fastest-growing next-generation industry is driven by technology, digitalisation and sustainability. The human role digital economy is centric and should remain centric. Therefore, living in a challenging and changing environment puts a great responsibility on humans to constantly develop and prepare oneself to adapt to the changing environment. Technology-driven systems and environments demand new skills and trainings to open new jobs and opportunities to today's youth. The McKinsey Institute's report on future jobs estimates that between 400 million and 800 million individuals around the world could be displaced by automation and need to find new jobs by 2030. Out of the total displaced, 75 million to 375 million may need to switch jobs or occupation and learn new skills [33].

This research presents a detailed analysis of the 21st-century workforce's challenges, the role of STEM and ICT education, the role of technology such as, AI and IoT in education, and the need of sustainable education for all. This thesis addresses to the educators, policymakers, and learners to prepare them for the future, when automation, technology, digitisation, and sustainability will be the key drivers. To keep humans in a centric role in H-M, and M-M working environments, humans need to learn new skills and embrace continuous adaptability [34].

STEM and ICT education plays a vital role in developing 21st-century skills such, as analytical thinking, problem-solving skills, creative thinking, computational thinking, collaboration and communication [32]. Articles I, II, and V address this issue in detail. Articles I and II discuss the role of STEM and ICT education in developing 21st-century skills in young learners. In Article II, we argue that student-centric PBL and SBL are effective pedagogical strategies to develop 21st-century skills such as problem-solving skills, creative thinking, idea creation, analytical thinking, collaboration and communication as well as ethical responsibility and awareness.

Emerging technologies exert a great impact on every walk of life including

on education. Our research focuses on the enabling technologies, such as IoT and AI. Article III analyses and presents a detailed overview of the implementation of the IoT to develop a smart and sustainable school. We emphasize on bridging the gaps between developed and developing nations using emerging technologies to provide sustainable and quality education to all to deliver the SDG (sustainable development goals) set by UN. Article IV discusses the role of AI in STEM education taking ChatGPT as an enabling tool presenting its possible role and implementation in STEM teaching and learning, both for teachers and learners. Article VI proposes a framework for STEM and ICT education at the K-12 education level.

In a nutshell, this research provides insights and direction to the educators and policymakers for how technology-enabled STEM and ICT education plays a key role in skill development, how enabling-technologies play their role in ensuring sustainable, equal education for all and how we can prepare our young learners for the future work environments by developing their skill.

This study lays the foundation for further research into how we can develop integrated STEM-IT curriculum outlines and different PBL approaches using AI as an enabler technology for young learners at the K-12 educational level by taking into account the limitations and challenges posed by AI. Acknowledgment of research limitations is fundamental for transparency, therefore, we consider the limitations and practical challenges in implementing some of our theoretical results. However, we hope to play our part in building our society in a most sustainable way.

In the future, we will aspire to develop a solution for STEM-IT education following our proposed framework. Secondly, we will aim to launch an e-school pilot project in a remote Pakistani area with the local government.

YHTEENVETO (SUMMARY IN FINNISH)

On vanha viisas sanonta: Parempi katsoa kuin katua. Se, miten toimimme nykyhetkessä, määrittelee tulevaisuutemme kohtalon. Elämme jatkuvasti muuttuvassa maailmassa, joka digitalisoituu nopeammalla tahdilla. Nopeimmin kasvava seuraavan sukupolven teollisuus perustuu teknologiaan, digitalisaatioon ja kestäväan kehitykseen. Inhimillinen rooli on keskiössä ja siinä sen tulisi pysyä. Haasteellisessa ja muuttuvassa ympäristössä eläminen asettaa suuren vastuun ihmisille. Heidän on jatkuvasti kehitettävä itseään ja valmistauduttava sopeutumaan muuttuviin olosuhteisiin. Teknologiaan perustuvat järjestelmät ja ympäristöt vaativat uusia taitoja ja koulutuksia, mikä avaa uusia työpaikkoja ja ammatteja. McKinsey-instituutin raportti arvioi, että vuoteen 2030 mennessä maailmanlaajuisesti 400–800 miljoonaa ihmistä voi jäädä automaation vuoksi työttömäksi ja heidän on löydettävä uusi työpaikka. Kokonaisuudessaan 75–375 miljoonaa ihmistä saattaa joutua vaihtamaan työtä tai ammattia ja oppimaan uusia taitoja.

Tämä tutkimushanke esittää yksityiskohtaisen analyysin 2000-luvun työvoiman haasteista, STEM- ja ICT-koulutuksen roolista, teknologioiden kuten tekoälyn ja esineiden internetin (IoT) roolista koulutuksessa sekä kestäväan koulutuksen tarpeesta kaikille. Tämä opinnäytetyö on suunnattu opettajille, päättäjille ja oppijoille, jotta he valmistautuisivat tulevaisuuteen, jossa automaatio, teknologia, digitalisaatio ja kestävyys ovat keskeisiä tekijöitä. Jotta ihmiset pysyisivät keskiössä H-M (ihminen-kone) ja M-M (kone-kone) -työympäristöissä, heidän on opittava uusia taitoja ja sopeuduttava jatkuvasti muuttuviin työympäristöihin.

STEM (tiede, teknologia, matematiikka ja insinööritiede) ja ICT (tieto- ja viestintäteknikka) -koulutuksella on keskeinen rooli 2000-luvun taitojen kehittämisessä. Artikkelit I, II ja V käsittelevät tätä asiaa yksityiskohtaisesti. Artikkelit I ja II käsittelevät STEM- ja ICT- koulutuksen roolia nuorten oppijoiden 2000-luvun taitojen kehittämisessä. Artikkelissa II väitämme, että opiskelijalähtöinen projektipohjainen oppiminen (PBL) ja skenaariopohjainen oppiminen (SBL) ovat tehokkaita pedagogisia strategioita kehittää 2000-luvun taitoja, kuten ongelmanratkaisutaitoja, luovaa ajattelua, ideoiden luomista, analyttistä ajattelua, yhteistyötä ja viestintää sekä eettistä vastuullisuutta ja tietoisuutta. Artikkelit VI esittää STEM-IT-nimisen kehyksen STEM- ja ICT-koulutukselle varhaiskasvatuksen tasolla.

Uudet teknologiat vaikuttavat voimakkaasti koulutukseen niin kuin jokaiseen elämän osa-alueeseen. Tutkimuksemme keskittyy mahdollistaviin teknologioihin, kuten IoT:hen ja tekoälyyn. Artikkelit III analysoi ja esittää yksityiskohtaisesti IoT:n käyttöönottoa älykkään ja kestäväan koulun kehittämiseksi. Korostamme syntyvien kuilujen ylittämistä uusien teknologioiden avulla, jotta voimme tarjota kestäväan ja laadukasta koulutusta kaikille ja saavuttaa kestäväan kehityksen tavoitteet. Artikkelit IV käsittelee tekoälyn roolia STEM-koulutuksessa ottaen käyttöön generatiivisen tekoälyn (Gen AI) työkalun Chat GPT mahdollistavana työkaluna ja esittää sen käyttämistä STEM-aineiden opetuksessa ja oppimisessa sekä opettajille että oppijoille.

Yhteenvedona voidaan todeta, että tämä tutkimusopinnäytetyö tarjoaa opettajille ja päättäjille näkemyksen ja suuntaviivoja siitä, kuinka voimme valmistaa nuoria oppijoita tulevaisuuden työympäristöihin kehittämällä heidän taitojaan, miten mahdollistavat teknologiat vaikuttavat koulutusympäristöihin kestävyys-, tasa-arvon ja yhdenvertaisuuden näkökulmasta, sekä miten STEM- ja ICT-koulutus näyttelee keskeistä roolia taitojen kehittämisessä.

Tämä tutkimus luo perustan jatkotutkimukselle siitä, miten voimme kehittää tekoälyä käyttäen integroitua STEM-IT-pedagogiikkaa 7–15-vuotiaille nuorille oppijoille ottaen huomioon tekoälyn aiheuttamat rajoitukset ja haasteet. Tutkimusrajoitusten tunnustaminen on olennaista läpinäkyvyyden vuoksi, joten otamme huomioon rajoitukset ja käytännön haasteet joidenkin teoreettisten tulostemme toteuttamisessa. Toivomme kuitenkin voivamme vaikuttaa yhteiskuntamme rakentamiseen kestävämmällä tavalla.

Jatkossa pyrimme kehittämään STEM-IT-koulutukseen ratkaisun ehdottamamme viitekehyksen mukaisesti. Toiseksi pyrimme käynnistämään sähköisen koulun pilottihankkeen etäisellä Pakistanin alueella paikallishallinnon kanssa.

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ORIGINAL PAPERS

I

RENEWING MATHEMATICAL AND DIGITAL EDUCATION INITIATIVES IN THE ASIAN COUNTRIES: A REVIEW

by

Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki 2021

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RENEWING MATHEMATICAL AND DIGITAL EDUCATION INITIATIVES IN THE ASIAN COUNTRIES: A REVIEW

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ABSTRACT

This review report presents an overview of the mathematical and digital education initiatives taken by eight different Asian countries. In this report, we have discussed that how different Asian countries are developing their mathematical and digital education to provide quality education to their populations and preparing them to meet future challenges posed by advancement in new technologies. Our paper included eight Asian countries (China, Japan, South Korea, Singapore, Pakistan, India, Nepal, and Bangladesh).

KEYWORDS

Mathematics education, digital education, PISA, OECD, Asian countries, economic development, future workforce

1. INTRODUCTION

Programme of International student assessment (PISA) publishes after every three-year results of participant countries on the bases of their student's performance in mathematics, reading and science literacy. PISA defines mathematical literacy as an individual's capacity to reason mathematically and to formulate, employ and interpret mathematics to solve problems in a variety of real-world contexts" [1]. It includes concepts, procedures, facts, and tools to describe, explain and predict phenomena. It helps individuals know the role that mathematics plays in the world and make the well-founded judgments and decisions needed by constructive, engaged, and reflective 21st Century citizens. Mathematical and digital skills are the key tools to solve critical real-life problems and are utilized in all other applied sciences to demonstrate and solve real world problems and create innovative ideas. PISA has published the 2021 mathematics framework as shown in the figure 1 below [1]. In addition to mathematical literacy, digital literacy and science education plays a key role in the economic development of a country. Data gathered by different organizations like world Economic forum, OECD, and PISA reveals that the countries with quality education provision have sustained and developed stronger economies.

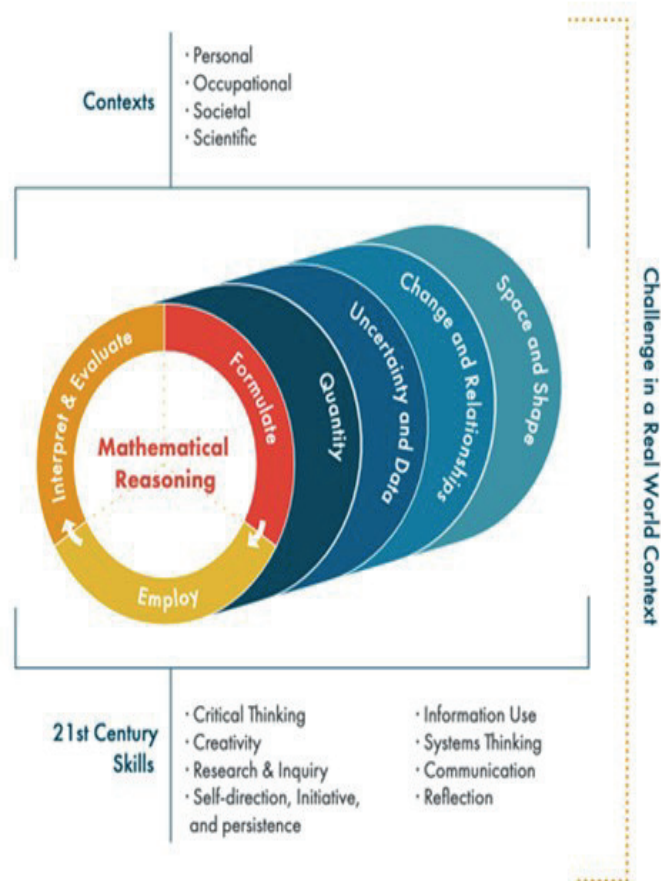


Figure 1. Mathematical framework 2021 adapted from PISA

A research finding has suggested that realistic mathematical education and learning through games is fruitful in developing learner's capability of thinking and solving real life problems [2]. Therefore, mathematical, and digital literacy has a vital role to play in the development of future workforce and economic growth of a country in sustainable way.

2. AIM OF THE REPORT

In this review paper we aim to showcase the efforts of different Asian countries in renewing mathematical education and digital initiatives. We take four developed and four developing countries from Asia and find how they are developing their mathematical and digital education. This report firstly aims to highlight state of the art initiatives taken by different Asian countries in renewing mathematical and digital education. Secondly, our report aims to show a correlation of good scientific and digital education practices with the development of the economy. The

report focuses on four developed Asian countries (China, South Korea, Singapore, Japan) and four developing Asian countries (Pakistan, India, Nepal, Bangladesh) and draws relation between their economic development and quality education provision. Advanced Asian countries have done well in their PISA results [3]. Therefore, the main purpose of the review report is to see what kind of mathematical and digital initiatives have been taken by different Asian countries and how economic development is linked to the advancement in mathematical/scientific and digital literacy?

2.1. Methodology

The nature of the research done in preparing this report is qualitative. We have gathered related information from scholarly research articles. We also collected state of the art information from official websites of the respective countries (China, Japan, Singapore, South Korea, Pakistan, India, Bangladesh, and Nepal). Additionally, we gathered data from open sources like OECD, PISA, UNICEF, World Economic Forum. In tabular form we presented the comparison of the countries in terms of mathematical initiatives, digital initiatives, latest PISA ranking if applied and inclusive development index IDI ranking.

3. CHINA

People's republic of China is an East Asian country, with 1.4 billion of population. Mandarin is China's official language. Primary school education starts at the age 6 or 7. China's basic school education includes 9 years of education, 6 years of primary school education and 3 years of Junior Secondary School education. Basic school education is mandatory of every child according to Chinese law. China has performed well on PISA [3] and OECD test scores. Shanghai has developed its own assessment system on the bases of PISA's state-of-the-art methods and ideas of assessment and evaluation. [4]. Therefore, PISA acts as an assessment tool to help countries make their education systems better.

In March 2011, the Shanghai developed a set of green indicators for the comprehensive evaluation of academic quality. The set of green indicators considers 10 different aspects [4]. 1. Education level of student 2, student's eager to learn, 3. Study load 4. Teacher's relationship and engagement with student, 5. teaching methodology, 6. the curriculum management, 7. the effect of students' socioeconomic backgrounds on their learning and development achievements, 8. students' general behavior and moral ethics, 9. Overall health (Physical, mental) of the student, and 10. Academic progress of the student over a certain period. Green indicators help in understanding students' academic situation at the regional and school levels. Green indicators provide educators an insight into education management and helps them to evaluate student's performance, therefore provides schools and teachers with detailed, and targeted teaching recommendations. The evaluation information is then applied to the teaching improvement. This makes a cycle of standards, teaching evaluation and on the base of its improvement for the provision of quality education.

3.1. Mathematical Thinking (MT)

Mathematical thinking (MT) support sustainable mathematics learning and is one of the key objective of mathematics education. Mathematical thinking has emerged as an important feature of Chinese mathematics education. Mathematical thinking helps to nurture critical thinking and problem-solving skills in learners. Mathematical thought is also recommended by Chinese researchers recommended mathematical thinking as a thought process to help students understand scientific concepts and develop reasoning [5].

3.2. Artificial Intelligence (AI) in basic education

In China, the development of AI human resources has become a national education strategy, and Chinese curriculum is making its way to include artificial intelligence-related education at the elementary, middle, and high school stages.

SenseTime is a leading company and is building the largest artificial intelligence computer center in the Asian area [6]. SenseTime in collaboration with Huadong Normal University in Shanghai is to create basic artificial intelligence educational materials for high school students in China. This teaching material would be used at 40 top-level high schools nationwide, including Tsinghua University High School, Huadong Normal University Second High School, and Shanghai Jiao Tong University High School. SenseTime would provide these schools with artificial intelligence labs that will produce focusing on building new teaching models.

China is investing its resources in taking strong mathematical and digital initiatives and reforming its education vanquish future challenges.

3. JAPAN

Japan an island country in East Asia with comprising of 126.3 million of population. The current Japanese education system includes six years of elementary school, three years of Lower secondary school education, three years of upper secondary school and, finally, four years of higher education [7]. Japanese students spend many hours per week in mathematics learning. They are facilitated by parents at home with private mathematics lessons as well [8]. In Japan, the mathematics curriculum taught privately is complimented with public school's teachings. Chinese mathematics has played a key role in the development process of Japanese mathematics. Japanese algebra oriented from Chinese mathematics [8].

3.2. Japanese Mathematics Curriculum

Japanese mathematics curriculum consists of three parts: 1. Curriculum for the basic school education includes mathematical learning objectives for primary, lower secondary, and upper secondary school levels, 2. Curriculum with objectives targeted to different grades, and 3. Plan of the recommended syllabus. In Japan, all educational institutes follow a particular syllabus for mathematics which includes aims, objectives, pedagogical approaches for mathematics teaching, tasks and activities, outcomes, and assessment of the student's learning [9].

3.3. Common core standards for teaching mathematics

Japanese teachers use a technique called *jogyokenkyu* (lesson study). It is an invaluable way for teachers to improve their instruction. In this technique, teacher prepares a demonstration lesson and delivers his/her lesson in the class in the presence of other teachers and a university professor. Later participants and the teacher reflect on the demo teaching lesson. This kind of Lesson Study helps teachers to get a feedback for their improvement and future teaching lessons. During this process, the teacher selects a mathematical topic, create a problem question, and finally implement the study plan. In this way teachers improve their mathematical teaching with feedbacks and reflections, and therefore engage students in effective learning [10].

3.4. Mathematical Innovation

Japan's Ministry of Education, Culture, Sports, Science and Technology outlined document for mathematical innovation. According to which various social issues can be solved fundamentally through mathematics innovation, which is difficult in problem-solving research in individual fields [11]. Mathematical innovation can be achieved by [11,12];

1. Activities that connect the discovery of needs for mathematics to collaboration between mathematics and various sciences and industries
2. A common meeting or discussion place can provide a one roof for people from research and industry to sit together and find innovative ideas for solving different real- life problems while utilizing mathematical approaches.
3. "Mathematics Collaboration Program" initiated by the Ministry of Education, Culture, Sports, Science and Technology offers workshops, events and meetings to students and researchers in the field of mathematics.
4. Promotion of mathematical research through collaboration between mathematics researchers and various sciences and industries
5. Development of human resources necessary for mathematical innovation
6. Dissemination of information and development of results
7. Improvement in statistical education

3.5. Artificial intelligence strategy 2019- Educational reform

Japan has made Artificial Intelligence utilization strategy for an AI ready society 5.0. Education for AI is proposed for all. Mathematics is the backbone of AI. Therefore, Japanese education system is stressing hard on developing good mathematical education practices to support AI literacy in Japan [13].

Japan's idea of Globalization of knowledge explains the promotion of science, technology, and engineering (STI) for SGD's. Under this initiative, Japan has given its 2019 plan for AI. The globalization of knowledge initiative stresses on the promotion and teaching of science, technology, and engineering to make their nation global citizens. Japan has introduced AI and mathematical education compulsory at all levels [14].

4. SINGAPORE

Republic of Singapore is an island city-state in Southeast Asia with 5.704 million inhabitants. Singapore performed exceptionally well for science, reading and mathematics in the 2009 and 2012 Program for International Student Assessment (PISA). Singapore stands number one position in the global school ranking for its performance in mathematics and science and secure

second position in 2018 [3]. Education system in Singapore has improved consistently over the past years. McKinsey report published in 2010 named Singapore's education system as "Great" because of its consistent improvement [15].

Singapore's education system has a 6+2+2 school system which includes 6 years of primary education, 2 years of lower secondary and 2 years of higher secondary education. After this basic school education students may continue 2-3 years of pre university education at Junior colleges or other centralized institutes. Students may also join polytechnic institutes for professional education or may join the workforce [16]. Three very important and successful features of Singapore education system are [17];

1. **An ability driven system:** The ability driven education system based upon an Integrated Program (IP) where students skip the GCE 'O' level exam and join directly the GCE 'A' level exam or the International Baccalaureate (IB) diploma. Ability driven education system emphasizes on the mental, physical, and educational development of learners in the field of. science, sports, arts and mathematics.
2. **Customized and interdisciplinary curriculum:** focus on the future skill development. Students are given free hand in subject selection and they are free to choose different combinations of subjects.
3. **Teach less learn more strategy (TLLM):** focus on the teacher's role as a facilitator of learning, who support, facilitate, and engage students in student centered learning environments. Ministry of education has given teachers more freedom by reducing the content of the curriculum. In that way teachers are less pressurized and more encouraged to engage students in more interactive ways of learnings.

4.1. Mathematics philosophy

In 1982, Singaporean Minister of Education initiated a math program named as Primary Mathematics Series years [16], taught in Singapore's schools for twenty years. Singapore math became a registered trademark under the name of Singaporemath.Com Inc in 1998 and has been applied to US schools and got attention worldwide. In 2003, Trends in International Mathematics and Science Study (TIMSS) scores revealed Singapore's fourth graders and eighth graders were the top math performers in the world, public education started taking a closer look at the method. Singapore remained at the top as of the 2015 TIMSS [9].

The Singapore math method implements CPA (Concrete, Pictorial, Abstract) approach, mental math strategy, bar modeling, and number bonds. This kind of math methodology helps students to think mathematically [18].

4.2. Computational thinking (CT)

Computational Thinking (CT) is one of the 21st century skills that should be taught at the primary and secondary school levels. Global digitalization, industrial automation and advancing computing technologies demand new set of computational skills from future workforce.

Singapore has initiated many educational programs focusing on developing computational thinking in their students, from early education. Such programs include the Code for Fun and Applied Learning Program. Computing courses are added in O-level and A-level curriculum [19]. In Singapore, the importance of computational thinking development and education is understood on all levels. Government, educational institutions, parents, and private institutions, all are working together.

4.3. Strengthening digital and mathematical literacy: Initiative 2020

In the wake of digitalization, it is inevitable for economies to survive without digital literacy. Future workforce will be more skilled based and digitally literate. To join the pace with the increasingly digital world Singapore's Ministry of Education has given a National Digital Literacy Program 2020 [20]. Strengthening Digital Literacy Program focuses four components for the digital age that is, Find, Think, Apply, and Create framework.

At Primary level:

The focus is to engage students in developing computational thinking and learning simple coding through the 'Code for Fun' program.

At Secondary and pre-University level:

1. Use of personal learning devices (PLD) will be rolled out to develop digital literacy of students by 2028. Students will use their personal learning devices with Singapore Student learning space (SLS).
2. The computing subjects will be offered by O-Level and A-Level schools.
3. Mathematics curriculum will be tailored to induce computational thinking in students.
4. Syllabus for Lower Secondary Science will be revised/updated and rolled out in 2021 that will develop interest and basic understanding of advanced technologies like Artificial Intelligence (AI) and other computation technologies.

At Institutes of higher learning level

5. The new curriculum applied to all educational institutes by 2021 is focused on nurturing 21st century skills like digital competencies, computational thinking, problem -based thinking and reasoning.
6. Artificial intelligence (AI) related topics will be taught to higher institutes. As in future there will be demand of AI competencies in sectors, such as transport and logistics, health, and finance [20].

5. SOUTH KOREA

South Korea is a growing economy in East Asia with a huge population of 25 million people. Korean language is commonly spoken language of the country. In the South Korean education system Pre-school is optional and is offered from the age of three. Compulsory schooling starts from the age of 5 or 6 referred to as middle school (Jung Haggyo), and then High School

(Godeung Haggyo). The Korean public education structure is divided into three parts: six years of primary school, followed by three years of middle school and then three years of high school. Korea's educational progress is characterized as a sequential bottom-up process. During 1950, Korea implemented its low-cost approach and achieved its universal elementary education. Then, during the 1960s and 1970s, it implemented the equalization policy to reduce competition and inequalities in access to secondary education. From 1980-1990, South Korea improved the quality of higher education. As a result of South Korea's sequential bottom-up approach, the country developed economically. South Korea's low-cost approach, policy of equity, and implementation of plans and policies are the key instruments of South Korea's economic growth [21].

5.1 South Korea's smart education

Korean education is introducing a new educational paradigm called "Smart Learning" in South Korea. Korea is adopting highly advanced Information Technology (IT) in education and therefore Korea's smart education is a convergence concept of Ubiquitous Learning (u-Learning) and Social Learning [22]. South Korea has initiated its smart learning plan along with the concept of digital textbooks focusing on the idea of no more heavy backpacks. South Korea has invested \$2 billion to develop digital textbooks for all schools by 2015. A research study highlighted the challenges of Korean digital textbook projects. Korean digital book pilot project is a major step in smart learning, but there are certain issues of weak internet connectivity and cyber security [23].

5.2 Korean mathematics

South Korea revised its middle school mathematics curriculum in August 2012 [24]. The focus of revision was to develop students' mathematical creativity and sound personalities. The revised mathematical curriculum emphasizes on 1. contextual learning for developing mathematical concepts and making connections with everyday lives situations; 2. manipulation activities through which students may create and innovate; and 3. ability to justify results based on their learning and experience.

South Korea has performed well and improved in last years in mathematical performance. According to a comparative study [25] done by comparing OECD countries with South Korea in terms of digital literacy and usage in schools, the results show Improvements in 2018 over 2015 in 'access of ICT at school', 'access of ICT at home', and usability of digital devices outside of school for non-learning purposes. The study has shown that the national index of digital literacy is low as compared to other OECD countries. Therefore, South Korea requires more efforts in developing mathematical and digital literacy prior to the fourth industrial revolution.

6. PAKISTAN

Pakistan is one of the Asian countries who is seeking educational reforms for the development of its economy and meeting the challenges posed by the global digitalization and industrial automation in future. Unlike the above mentioned four Asian countries, Pakistan is lagging in providing basic education with equity and quality. Lack of effective reforms, lack of finances, poverty, corruption, and inconsistency in policies are the main factors contributing to this incapability. New Pakistani Government in 2018, initiated many plans for the educational

reforms focusing on introducing digitalization and ICT education in basic education [26].

6.1. Pakistan`s educational system

Pakistan`s education system is divided into six levels [27]:

1. Preschool (for the age from 3 to 5 years)
2. Primary (grades one through five)
3. Middle (grades six through eight)
4. High (grades nine and ten, leading to the Secondary School Certificate or SSC)
5. Higher Secondary grades eleven and twelve, leading to a Higher Secondary School Certificate or HSSC
6. University programs leading to undergraduate and graduate degree and post graduate studies leading to PhD.

6.2. Digital Pakistan Initiative

Pakistan ministry of Information technology along with Pakistan ministry of education has initiated Digital Pakistan initiative, under which the idea of Digital education is initiated. Around 423 Federal Government educational institutions in ICT are providing educational services to 220,000 students from kindergarten level to postgraduate level [28]. Ministry of education is now focusing on digitalizing the educational management systems and introducing systems such as.

- Online admission systems
- Online learning courses
- Blended learning system: Project for implementation of Blended Learning System in 200 classrooms is initiated
- Online monitoring system
- Smart Board system in 75 female institutions by the collaboration with JAZZ and Smart learn Pakistan companies. This system will be extended to more institutions in future [28].

6.3. National education policy framework

The government launched National Education Policy Framework 2018 [29, 30] envisaging;

- Enrolling 25 million out of school children
- Provision of quality education
- Skill development
- Uniformed syllabus across the country

- Education volunteers' program would also be launched soon to make educators available to far flung areas.
- Establishment of National Skill University
- 27,300 out of school children in capital city of Islamabad will be brought back to school [29].
- Future skill development programs
- Uniformed syllabus across the country
- Smart schools to fulfil teacher's shortage in different part of country

6.4. Pakistan educational policy 2021

The Ministry of Federal Education and Professional Training is working on Pakistan National Education Policy 2021 through a widespread consultative process. Pakistan Education Policy 2021[29] focuses on national harmony, unity among different religious and ethnic communities. PEP 2021 aims to develop educational standards by paying special attention to education management systems, teaching standards and teacher training systems, examination and admission management systems, digital literacy and provision of basic education for all children.

6.5. Pakistan mathematical society

The Pakistan Mathematical Society (PMS) is the most engaged scientific society of Pakistan in mathematical education and research. PMS organizes seminars, conferences and meetings for the promotion and development of mathematical knowledge on national and international levels[31].

The educational reforms in Pakistan are focusing on the provision of basic education to the masses and means to bring out of school children back to school. Pakistan is not having special initiatives regarding mathematical education. Mathematics is taught as the basic subject from grade 1 to grade 10. After that, it is up to the choice of the student to take mathematics as a subject to further study. For engineering study, mathematics is a compulsory subject.

Pakistan is the world's second country with highest number of out-of-school children (OOSC) with 22.8 million children aged 5-16 not attending school. It represents representing 44 per cent of the total population in this age group. In the 5-9 age group, 5 million children are not enrolled in schools and after primary-school age, the number of OOSC doubles, with 11.4 million adolescents between the ages of 10-14 not receiving formal education. Disparities based on gender, socio-economic status, and geography are significant; in Sindh, 52 percent of the poorest children (58 percent girls) are out of school, and in Balochistan, 78 percent of girls are out of school [32]. As a result of this, the literacy rate of the country is not growing sufficiently. To keep pace with economic development and global digitalization, skillful education is the steppingstone.

7. INDIA

India is the second largest country, situated in south Asia with population of about 1.3 billion. After getting independence from Britain in 1947, India inherited British education system and tried to seek reforms in past years. Indian and Pakistani education system has its roots from the colonial times. Different languages are spoken in different Indian regions, but Hindi is the most common language. The education system in India is a “10 + 2 + 3” system. Lower primary school education lasts from the age 6-10, upper primary school education from the age 11-13, secondary 14-16, and upper secondary school education from the age 17-18 [33]. First ten years of basic education is mandatory for all children. This means that the first decade of a child’s education is mandatory. Most students begin their schooling at age five, in the form of preschool. Primary school education begins at the age of 6. Students are obligated to attend school up to age 14, after that they can join the workforce.

7.1. Digital India Program

Technologically driven 21st century has equipped everyone with digital devices. One such technology Mobile Applications (M-App). Digital India program is using this technology to change the future of India and its citizens. Government of India is initiating many digital programs for learning and governance, such as M learning apps for digital India [34]. Indian Government has initiated 28 digital initiatives under the digital education program. Some of the main initiatives are [35];

- Availability of MOOC courses
- Virtual labs
- Digital libraries
- Mobile apps for mathematical education
- SOS tools
- Text Transcription of video content etc.

Online learning has become more common phenomenon in schools to facilitate learners in learning different courses. Majority of the schools are offering online and digital learning programs [36].

7.2. National education policy 2020

India’s National Education Policy 2020 [37] has paved the way forward for educational reforms both at School level (Kindergarten to 12th- Senior Secondary Education) and in Higher Education.

1. The national education policy focuses on equity, access, use of technology effectively and importance to teacher development and professional training.
2. Teaching of basic coding would start from Grade 6 and students would be exposed to basic computer skills. Also, internships for Grade 6-8th with local and indigenous craftsmen would be a part of the opportunities.
3. The Govt of India has created Atal Tinkering Labs program which focused on applied science and problem-solving funding tinkering labs at the Schools.

4. Government will be funding innovative ideas to spark entrepreneurship at the campuses.
5. The govt is enabling teacher training through MOOCs, bringing in flexibility on transfer of credits, interdisciplinary approach, giving similar credit to Fine Arts and sports as well.
6. All India Council for Education- regulatory body for Technical Education in India has made decision that from 2021, for entrance to Engineering Education in India, Maths and Physics would not be a compulsory subject.

7.3. Mathematical initiatives

No separate initiatives for mathematical education are taken. Mathematics is taught as the basic subject from 1-10 grade. After that student can continue to study if he/she likes to study mathematics as a subject. There are approximately six million out of school children in India. Drop -out rates are higher in India as out of 100 students, 29 percent of girls and boys drop out of school before completing their basic elementary education [38]. Challenges remain because most of the children who are in school are not learning at grade appropriate levels. Most common reasons for high number of drop out are poverty, early marriage, child labor, violence or abuse, and poor teaching practices. Other factors include seasonal migration, and lack of access and awareness of social protection measures [38]. India's National education policy 2020 is aimed to address the drop out problem and paving way to equity and inclusive education [37].

8. BANGLADESH

Bangladesh is a South Asian country with 163 million people. Bengali is the common language of Bangladesh. In Bangladesh, twelve years of basic education is mandatory for all children. Mandatory education consists of eight years of primary school level education and four years of high school level education. School system in Bangladesh consist of three pathways: General Education, Madrasah (religious) Education, and Technical/Vocational Education [39].

8.1 Digital Bangladesh

Government of Bangladesh has taken initiative called Digital Bangladesh. Under this initiative, Bangladesh is preparing to provide digital health, digital education and digital commerce and automation to industrial level [40].

Bangladesh is thriving to increase the literacy levels throughout the country. Through Digital Bangladesh is making it possible for its pupils to access education everywhere. Digital materials, online courses, and mobile applications are helping country in improving its digital and overall literacy. Use of digital white boards, tablet devices and learning apps are helping to integrate digital learning in conventional learning. Bangladesh is reforming education with digitalization, the digital initiatives include;

1. Providing virtual classrooms [41].
2. Online courses
3. Digital libraries
4. Learning mobile applications
5. Digital devices and equipment usage

Although general education on a basic level is improving in Bangladesh but the country is still facing a drop out challenge. According to UNICEF the increase in dropout rate remains is due to children's need to help with farming, child labour, poor teaching practices, poverty, and crowded classrooms[42].

9. NEPAL

Nepal became a republic in 2008. The country has population consisting of approximately 28 million inhabitants. Official language of Nepal is Nepalese. Nepal's education system consists of 10+4+2 system. It includes ten years of basic school education, four years of college level studies (two years of intermediate and two years of bachelor program), and two years of the master's program at the university [43].

9.1 Digital education

In Nepal, the initiative of introducing ICT in school education is progressing. Nepal's education Master Plan executes the implementation of the Information and Communication Technology Education Master Plan [44] which has increased the access to computers, internet, and digital learning materials in schools, therefore developing digital literacy at basic school education level.

9.2 School sector development plan (2016-2023)

The recent national educational plan that is School Sector Development Plan (2016–2023) integrates and focuses on use of ICT in government schools. This demonstrates the commitment on the part of the government. E-textbooks are in process of development and adoption [45].

According to UNICEF [46], Nepal has number of challenges posed by poor quality and inequity, geographical remoteness, gender, and socioeconomic and ethnic differences.

10. DISCUSSION

From the table below we can find a correlation of educational development in terms of mathematical and digital education and the economic development of a country. However, the impact of their educational strategies on the growth process of economies can be seen after 5-10 years. Digital initiatives are taken by almost all countries however their pace and affectivity are different to different countries and their resources. Strong mathematical initiatives are taken by China, Japan, Singapore, and South Korea. There are no separate initiatives for mathematical education are taken by Pakistan, India, Bangladesh, and Nepal.

China being at first place and Singapore at second place took the top ranks in PISA 2018 ranking. South Korea retained its place among top ten countries with rank 9 and Japan places at rank 15. PISA is not applied to Pakistan, India, Bangladesh, and Nepal as these countries are not participated in PISA [3]. Although, PISA ranking is not a precise tool for measuring the educational performance of a country. However, in recent years it has been observed that PISA has emerged as a performance evaluator and help countries to evaluate and develop their educational systems more effectively. PISA provides a feedback also to check and correct any shortcomings or make improvements in the educational systems if required.

Table. Comparison of eight Asian countries in digital literacy initiatives, mathematical literacy initiatives, ranks in mathematics and science in PISA results 2018, and ranks in inclusive development index IDI 2018 [47]

Countries	Mathematical initiatives	Digital initiatives	Ranks in mathematics and science education in PISA/OECD 2018 Out of 70 country participated	Ranks In inclusive development index IDI 2018 Out of 189 countries participated
China	√	√	1	26 out of 74 emerging economies (Emerging economy)
Japan	√	√	15	24 out of 29 advanced countries (Advanced economy)
Singapore	√	√	2	NA
South Korea	√	√	9	16 out of 29 advanced countries (Advanced Economy)
Pakistan		√	Not Applied	47 out of 74 emerging economies (Advancing economy)
India		√	Not Applied	62 out of 74 emerging economies (Advancing economy)
Bangladesh		√	Not Applied	34 out of 74 emerging economies (Slowly advancing)

				economy)
Nepal		√	Not Applied	22 out of 74 emerging economies (Advancing economy)

Inclusive Development Index (IDI) reflects more closely the criteria by which people evaluate their countries' economic progress [47]. In IDI index countries are classified as advancing countries (emerging economies) or advanced countries (advanced economies). Table below shows that China, Japan, Singapore, and South Korea are performing well in IDI index. China is fast emerging economy, while Japan, Singapore and South Korea are advanced countries. Pakistan, India, Bangladesh, and Nepal are emerging/advancing economies according to the inclusive development index.

It is noted that all the above Asian countries are driving towards the digital literacy. Advanced countries (China, Japan, South Korea, and Singapore) are well ahead in digital education focusing on Artificial intelligence, computational sciences, coding and mathematical literacy and developing mathematical thinking, mathematical innovation and computational thinking in their core curriculums. On contrary, developing Asian countries are behind on taking initiatives for mathematical education but well on track in terms of taking initiatives for digital literacy and digitalization. Digital education initiatives are taken by Pakistan, India, Bangladesh, and Nepal. However, there are factors related to limited resources, huge populations, poor teaching methods and lack of planning and implementation which hinders the process of development.

3. CONCLUSIONS

Fast economic growth requires human development. Human development can be achieved with the provision of quality education, modern skills, digital and mathematical literacy. We have presented here a case of four highly emerging/developed countries (China, Japan, South Korea, and Singapore). The developing or advancing countries can follow the path to fast economic growth and development by learning lessons from developed countries. New emerging technologies are posing challenges to the future workforce. Therefore, to meet those future challenges and achieving economic growth and development on a faster and stable pace, the progress in mathematical and digital education is inevitable. No nation can earn economic development without their human development. Future industrial change due to automation and digitalization will create a big economical gap between developing and developed countries, if skillful workforce will be unavailable in developing countries due to the lack of the provision of digital and scientific education to their youth. Therefore, digital and mathematical/scientific literacy is a key to the future industrial skill development and economic stability.

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II

PROBLEM-SOLVING SKILL DEVELOPMENT THROUGH STEM LEARNING APPROACHES

by

Khaula Zeeshan, Chihiro Watanabe, and Pekka Neittaanmäki 2021 2021

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Problem-solving skill development through STEM learning approaches

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Abstract—This research to practice full paper presents problem solving skill development through STEM learning approaches. There is a rapid growing interest in STEM (science, technology, engineering and mathematics) education. One reason for this ever growing interest is to develop the skills in pupils, which are required by the industry 4.0 (Artificial intelligence, big data, Internet of things) in an era of global digitization. One such skill is problem-solving skill. In this article, we present a brief overview of related studies and conceptions in the past related to STEM education, why STEM education is needed? What is problem-solving skill development in context of STEM education? This article aims to highlight that how STEM education can develop problem-solving skills in learners at primary education level through thinking, and creating solutions for real life problems.

Index Terms—STEM education, problem-solving skill development, problem-based learning, global digitization, K-12 education, primary education, design-based learning, scientific method-based learning

I. INTRODUCTION

With the advancements in new technologies (Artificial intelligence, big data, Internet of things etc.) and global digitization, the need for the availability of skilful human workforce is growing abruptly. To fill the gap between the technological advancements in industries and the required skilled workforce, a proactive approach in education sector is needed. Fields of engineering, and applied sciences are merging. Therefore, STEM (Science, technology, engineering and mathematics) education has an important role to play in that scenario. To meet the challenges of future industrial requirements, the educational settings are required to embrace approaches which deliver design engineering based scientific thinking to the learners. So that, from the early education, the pupils learn to critically think and solve the problems of daily life. Standards for technological and engineering literacy [1] provide a road map for the role of technology and engineering in STEM education which paves a way to the development of problem-solving skill development [1]. The structure of this article is as follows. First, the definition of STEM is discussed and the need of STEM education from the Primary level of education is explained. Second, we shed light on the problem-solving skill development through STEM education. Third, this article discusses how different

approaches in STEM education develop critical thinking and problem-solving skills in young learners. For that purpose, we have given two different problems from daily life to solve, to the kids of grade 2-6 and applied STEM approaches to solve that. Finally, we make conclusions upon our findings and provide recommendations for the future research work.

II. RELATED WORK

In this section, the related research work is presented. There are similar studies done by utilising STEM approaches like problem-based, project-based, or scientific based learning to nurture professional skills in learners.

In the study [21], author applied problem-based learning approach in STEM teaching about bamboo toothpick houses. Students in this study learnt successfully to design and implement solution for building houses from bamboo. In another research work [22], STEM-based learning is applied to enhance collaborative problem-based competencies among the college students through the dietary plan lessons. The study includes 77 twelfth-grade students. The results of the study revealed that students improved three main competencies through this activity. First competency, "Establishing and Maintaining Shared Understanding, second competency, "Taking Appropriate Action to Solve the Problem, and the third competency, "Establishing and Maintaining Team Organization". The research work in [23] [24] presents how problem-based learning helps students in developing skills required by global digital economy. In [26] a study is conducted in a local primary school with two STEM teachers and 8 primary school students. Data is collected in the form of interviews during the STEM teaching sessions. The study concludes that STEM classes, taught with project-based learning approach facilitates students in developing problem-solving skills and critical thinking. The study [26] also revealed that students developed cooperation among themselves, positive behaviour towards learning and took more interest in classes. Another research work [27] investigated the impact of problem-based learning on learner's content knowledge and critical thinking towards STEM learning. The study suggested that problem based learning is an effective learning tool for STEM integration and problem solving skill development especially in K-

12 education. In [28], research consisted 27 students of 10th grade from a local vocational school. This research analyzed student's problem solving skills in current electricity STEM based learning lessons. The research study concluded that there was a remarkable improvement in student's problem-solving abilities because of the implementation of the problem and project-based learning in STEM-based learning. Research conducted in [29] studied the effect of the scientific approach based learning on problem-solving skills in early childhood. This research study revealed in its findings that scientific approach-based learning is a way to increase young learner's physical activity and mentality which leads to the problem solving abilities. Therefore, scientific inquiry based learning is another STEM education tool for nurturing problem solving skills in students [30].

It is evident from the related research work that STEM education approaches like problem-based or design-based learning and scientific enquiry-based learning are the key instructional tools which foster problem-solving skills in learners, where teacher acts as a facilitator in a student-centred learning environment.

III. WHAT IS STEM?

STEM is a multi-discipline approach of education where different disciplines of scientific education merge to develop scientific literacy among learners. Therefore, one way to define STEM education is that technology, engineering and mathematics concepts, knowledge and process understandings, "through efforts to combine some of all of the four disciplines into one class, unit or lesson that is based on connections between subjects and real world problems" [2]. International technology and engineering educators association (ITEEA) in 2015 [3] defines STEM as Integrative STEM education, which is "the application of technological/engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is broadly applicable to different learning environments and study levels.

A. Why STEM is needed?

Across the world, STEM receives tremendous attention in education reform efforts. The International Council of Associations for Science Educators [4] recently urged member countries to work together to improve access to, and the quality of, STEM education in order to prepare all students for global citizenry. In the USA, the National Science Foundation (NSF) [5] has played a significant role in the STEM education movement by calling for research related to science, mathematics, engineering, and technology. The National Science Foundation (NSF) first used the term "SMET," acronym for science, mathematics, engineering and technology education, revised into the term "STEM" acronym for science, technology, engineering and mathematics education in the early 2000s [6]. US government issued several studies on the state of STEM learning, and schools increased their STEM-focused

learning. Numerous legislative actions also emerged at this time related to computer science, STEM teachers, and STEM as career and technology education (CTE) [7]. Policymakers, parents, and business communities are calling for STEM education. Therefore, STEM literacy is viewed as critical for the economic success and sustainable growth of nations. In December 2015, the Australian state and territory governments endorsed the 'National STEM School Education Strategy 2016-2026' [8]. World is moving towards global STEM literacy and STEM education has garnered great attention and acceptance. In order to achieve global citizenship and to meet the challenges posed by fast paced technological advancements, STEM education is needed to achieve global competencies. The global competence matrix of Asia's society, 2011 includes four types of global competencies: (1) investigating the world; (2) recognizing perspectives; (3) communicating ideas and (4) taking actions as shown in Fig 1. Through STEM educational settings educators can inculcate such competencies in young learners and make them prepare to face the future world challenges and solving real world problems [9] as shown in Fig 1. All of the above mentioned competencies require an approach of critical thinking and problem-solving skills. STEM lesson models include, students identify an issue or

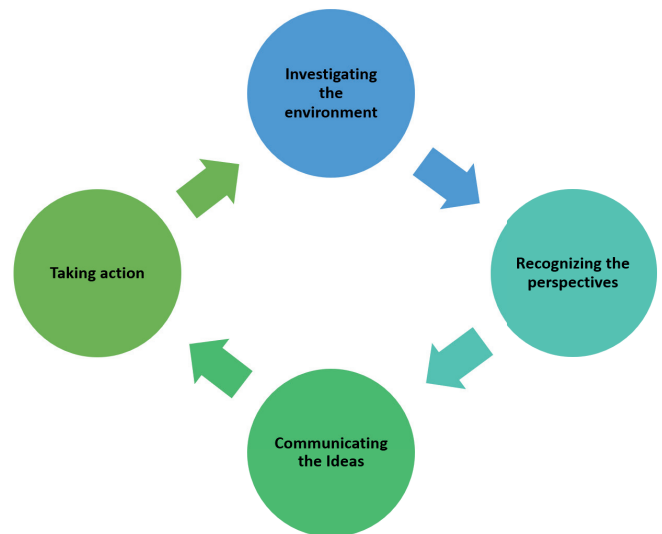


Fig. 1. Asia Pacific Society Metric for Global Competencies

challenge, conduct an investigation, design a solution, test and evaluate the solution, and communicate the results [10]. Therefore major STEM education involves following learning processes: (1) Identifying an issue or challenge; (2) Conducting an investigation; (3) Designing a solution; (4) Testing; (5) Evaluating the solution; (6) Communicating the results as shown in Fig 2.

IV. PROBLEM-SOLVING SKILL

One of the skills known as "21st century skills", defined by Partnership for 21st century learning (P21), is the problem-solving skill [11]. Problem-solving skill development, through

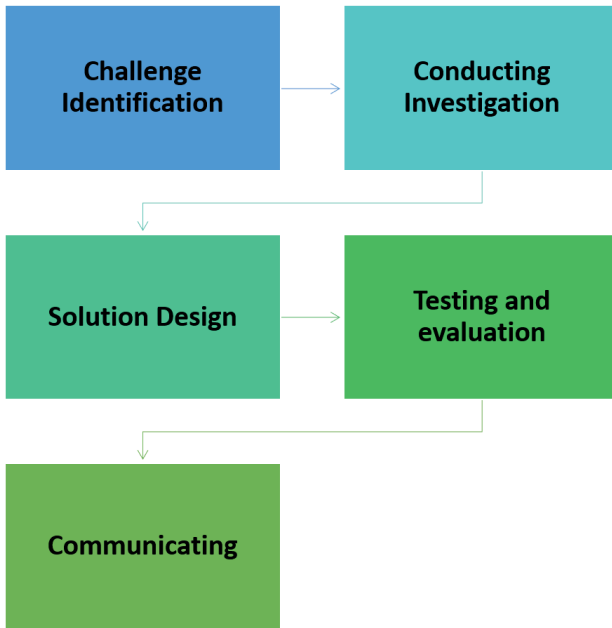


Fig. 2. STEM Learning Process

classroom instruction with real-world scenarios is always been a pedagogical challenge and an opportunity at the same time. STEM education from the primary level can inculcate this highly demanding future skill through integrating different science subjects addressing real life problems. In this way, from early childhood education, learners can acquire problem solving skill through critical thinking and problem based learning. Standards for technological and engineering literacy [12] has provided a road map for the role of technology and engineering in STEM education which paves a way to the development of problem solving skill development. In literature, problem solving skill is defined as rule acquisition and rule acquisition aligned with problem solving phases [13]. Another study suggested that routine aspect and non-routine aspect should be considered as two interacting systems. Real life problem-solving is actually the interaction between the two systems. Skills utilized in the routine aspect of the problem are defined as recurrent skills, while skills employed to solve non-routine aspect of the problem are defined as non-recurrent skills, which vary from situation to situation [14]. Recurrent skill is the ability to understand the problem and find some solution for it, while non-recurrent skill is the ability to ameliorate the existing solutions. Therefore, the interaction between recurrent and non-recurrent skills termed as a problem solving skill which is a process of problem identification, investigation, solution design, testing and evaluating, improving and communicating.

V. APPLIED PEDAGOGICAL APPROACH:PROJECT ORIENTED PROBLEM BASED LEARNING

Project oriented problem-based learning (POPBL) approach is fundamental pedagogical approach applied in this research

work. POPBL focuses on the problem, then analysis of the problem leading to the idea creation and designing solution for the problem and finally the implementation of the project by executing the designed activity to create the solution for the problem [20]. POPBL learning approach foster analytical and critical skills and an ability to find, argue and present innovative solutions to challenging problems in learners. POPBL is Student-centered, Problem-oriented, focuses on the learning process to address solutions. It promotes team work, social and communication skills. It also teaches learners to work in collaboration in performing actions and achieving certain goals to address challenging problems. Problem based learning enables students to efficiently and effectively analyse problem, design solution, implement and evaluate the results [24]. Therefore, POPBL is an effective approach in STEM education to engage students scientifically and allow them to think and implement their knowledge with confidence and communicate their results and actions to others.

In our research work we applied POPBL as a fundamental pedagogical approach. We planned two activities by presenting two problems to the students and facilitated them with their learning process in finding solutions for the presented problems.

A. Problem-solving skill development through STEM education

The integrated nature of STEM education takes flavours from all subjects like natural sciences, mathematics, and engineering. This integrated educational platform helps learners to develop knowledge of different fields of sciences and nurture a set of skills (critical thinking, problem-solving skill, creation and innovation etc.) commonly known as 21st century skills. Therefore, STEM education is essential for individuals to develop 21st-century skills. A study [15] has described integrated STEM education as integrative STEM education refers to "technological/engineering design-based learning approaches that intentionally integrate content and process of science and/or mathematics education with content and process of technology and/or engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, etc. Problem-based learning is the root methodology of integrated STEM education [16] [17].

Design-based learning: is one of the STEM education approach [18] [25] for problem-solving skill development which follows a learning process from thinking of a solution to the communication of the solution. Such kind of approach allows young thinkers to play, understand, think, and design a solution to the problem. Design-based learning or problem-based learning approach involves the identification of problem, brainstorming for the solution, designing a solution, testing and evaluating, redesigning and delivering the solution. In addition, learners learns to work in teams, interact, engage, collaborate, and communicate.

Scientific method-based learning: is another learning approach [19] which shows a real picture to the learners that

how scientists work and engage with science to solve real world challenges. Scientific method based learning involves a systematic process of seeking an answer/solution to a problem. Young kids learn to seek answers to many problems by asking questions, making hypothesis, doing experiments, making observations, critically analyzing and making conclusions to share their findings.

By applying above approaches in STEM lessons, we enrich young learners with scientific thought process, problem-solving skills, a realistic mind set considering real world problems, and eagerness to solve them.

VI. PROBLEM-SOLVING STEM ACTIVITY WITH LOCAL PRIMARY SCHOOL STUDENTS

In this section we demonstrate design based learning and scientific method based learning STEM approaches for problem-solving skill development by presenting two different problems to primary school students of 1-6 grade. The basic aim of this demonstration is to present how young learners engage in scientific learning and how they learn to solve problems by following a scientific way of finding solutions.

A. Methodology

Two problem solving STEM activities are done with local primary school students of grade 1-6. We applied design based learning approach and scientific inquiry-based learning approach in our learning sessions. There were three sessions. In session 1 there were 12 students, in session 2 there were 8 students and in session 3 there were 15 students. So altogether 35 students participated in this activity. We divided groups as group 1 comprising of 1-2 grade students, group 2 as 3-4 grade students and group 3 as 5-6 grade students.

We collected data in terms of pictures, observations, students replies to the set of questions asked to them, and student's comments. We applied content analysis method to analyze the collected data.

B. STEM Activity 1: Design-based or problem-based learning

We presented a problem, related to the environment saving to the kids from 1-6 grades in session 1,2 and 3. We applied design-based/ problem-based learning approach so that kids think and design the solution on their own.

Problem: How we can make a table from news-papers, which can hold book/books.

Motivation: Motivation to solve this problem is to save trees and avoid paper-waste by reusing it.

Materials: News-papers, tape, scissors, pencil, paper shown in Fig 3

Time of the activity: 30 min.

Questions asked in the beginning:

1. From what paper is made of?

A: Trees, wood. (a 2nd grader replied)

2. Why we need to save trees?

A: It gives us oxygen. (a 3rd grader replied)

A: It gives us food. (a 4th grader replied)

A: Because trees are animal's home. (a 1st grader replied)



Fig. 3. Materials for activity 1

we get shade from it. (a 1st grader replied)

3. How we can save trees?

A: By not cutting trees (a 3rd grader replied)

A: By planting more trees.(a 6th grader replied)

A: By not wasting paper. (a 5th grader replied)

4. What is global warming?

A: It means temperature of the earth is getting warm. (a 6th grader replied)

A: Trees are getting less. (a 5th grader replied)

Observations: After asking few questions, we gave materials to the students and they started the activity in groups. As a result of this activity, students practiced how to think and design a solution. Many students first drew the design of the table on the paper and then started making it. We got many different designs of paper tables. Students created innovative designs. It was also observed that students got trouble in making balancing their tables but then they did rethinking and managed to solve the problems. Students worked in teams and they were eager to build something. Some kids even made more than one table. It's important to notice here that students followed a design process and accomplish their task with a design based problem solving approach. Finally, all the groups tested their tables by placing book/books and teacher appreciated their work. We added some pictures of tables made by different students shown in Fig (4-10).



Fig. 4. Making table

Comments of the kids at the end of the activity 1:

"It was a fun."

"I liked to do this again."



Fig. 5. Paper table in making

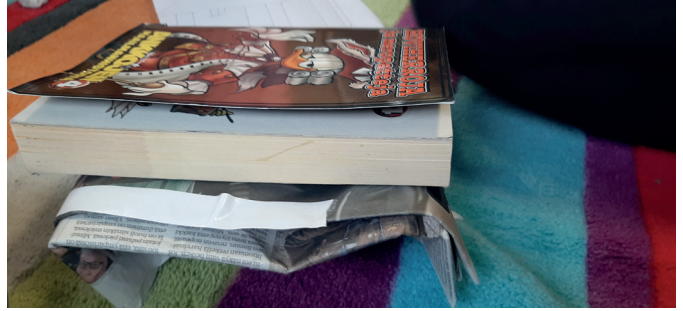


Fig. 9. Paper table



Fig. 6. Paper table



Fig. 10. Paper table



Fig. 7. Paper table



Fig. 8. Paper table

"I did it, my table is holding two books."
 "Now I want to make a chair out of paper."
 "Can we do it next time again?"
 "It took us some time to think how table could be made?"

C. STEM Activity 2: Scientific method based learning

We presented a problem related to saving a medicine from spoilage, to the kids from 1-6 grades in session 1, 2 and 3. We applied Scientific method based learning approach so that kids think, experiment, observe and find the solution. We provided students with paper and pen to write down their observations.

Problem: How we can keep a medicine cold without freezer at very low temperature for some time to avoid spoilage?

Motivation: Motivation is to solve this problem by using kitchen ingredients without freezer or other cooling device. Medicine needs temperature below 0 Celsius (very low temperature).

Materials: Medicine to be saved, ice cubes, salt, sugar, thermometer, plastic bag, pen and paper for making observations as shown in Fig 12.

Time of the activity: 30 min.

Questions asked in the beginning of the activity:

1. At what temperature water freezes?
 A: At +3 Celsius. (a 1st grader replied)
 A: At 0 Celsius. (a 4th grader replied)
 A: At 0 Celsius (a 6th grader replied)
2. What is water, liquid or solid?
 A: Liquid. (a 1st grader replied)
 A: Liquid. (a 2nd grader replied)
3. What is ice, liquid or solid?



Fig. 11. Thermometer

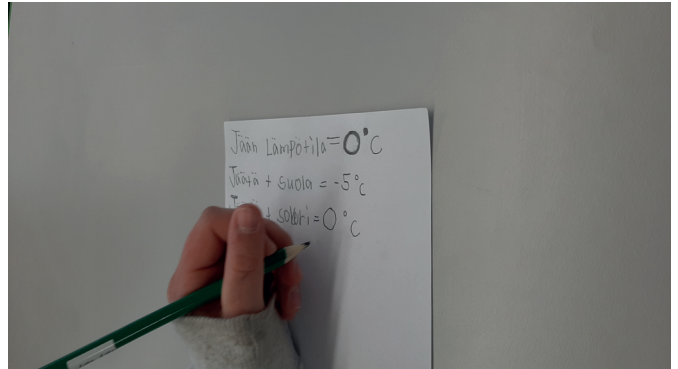


Fig. 13. Making observations



Fig. 12. Materials for activity 2



Fig. 14. Ice and salt

A: Solid. (a 2nd grader replied)

A: Solid. (a 3rd grader replied)

4. What is the boiling point of water?

A: 80 Calcus (a 2nd grader replied)

A: +100 Calcus (a 4th grader replied)

A: 100 Calcus (a 5th grader replied)

Students made their hypothesis in the beginning of the experiment.

Some said (Hypothesis 1): ice and salt can make low temperature.

Some said (Hypothesis 2): Ice and sugar can make low temperature.

They took observations as;

Temperature needed by medicine = below 0 Calcus

Temperature of the ice = ?

Temperature of the ice + sugar = ?

Temperature of the ice + salt = ?

Students took observations and wrote them in table as shown in Fig 13 and Fig 15.

D. Comments of the kids at the end of the activity 2

"I want to become a scientist".

"I love to do experiments".

"Thinking and finding solution is fun."

VII. DISCUSSION

Problem-solving skill is a 21st century skill required by the future workforce. Global digitisation, industrial automation

Only ice	0°C
ice + salt	-10
salt + ice + Sugar	0°C
ice + Sugar	0°C

Fig. 15. Observation table

and advancement in new fanged technologies demands a skill full human resource for future. To meet the future industrial challenges and to create practical solutions to real life problems, we need critical minds with scientific knowledge. STEM education in early school days with project oriented problem based learning approach nurture skills like problem-solving skills, critical thinking and analytical thinking in learners. In addition, young learners get motivation to opt for scientific careers in future. They show interest towards STEM subjects.

Results from our STEM activities has shown that by integrating knowledge and techniques from multiple disciplines facilitates learners to develop their professional skills to competently address real world problems and challenges. Young minds learn the scientific approaches to solve problems in real life situations. Our STEM lesson sessions achieved following objectives;

- Develops interest in young learners to choose scientific careers in their future.

- Learns to work in teams and learn how to communicate, engage and interact within the teams/groups to solve a problem.

- Design thinking

- Learn to think about their surrounding and about phenomenon happening in their surroundings

- Develops critical thinking to evaluate and analyze certain outcomes, phenomenon, findings etc.

- Learns to rethink, troubleshoot and design the solution again to fix the problem and bring better solution.

- Finally, deliver the solution and communicate the results/findings to others.

Although, our study focused on the primary school education and participants of the study were young learners aged 7-12, but we can apply the same strategy within the higher education setting. Problem-based learning approach fosters practical skills in learners rather than theoretical knowledge only. Therefore, shifting from knowledge-focused teaching to competence teaching is necessary for educators to inculcate practical skills in learners for the future work force development. Engineering education, technology education and natural sciences education requires problem oriented problem based learning approach to develop 21st century workforce.

STEM education is a stepping stone in building scientific thought process, problem-solving skills, and critical thinking in young learners. Today's young learners are tomorrow's workforce. To meet the challenges of 21st century industrial revolution, STEM education focusing on problem oriented problem-based learning must be the part of the basic education to inculcate 21st century skills in future's workforce and to attain sustainable economical development.

VIII. CONCLUSION

Problem-solving skill is an important skill, which enables humans to bring ideas, innovate, create and make this world better to live. In this article we demonstrated that how STEM education nurtures problem-solving skill in young learners by applying different STEM learning approaches. In future

work, we will investigate that how technology can help STEM learning and catalyzes skill development processes in young learners.

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III

INTERNET OF THINGS FOR SUSTAINABLE SMART SCHOOL: AN OVERVIEW

by

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki 2022

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Article

Internet of Things for Sustainable Smart Education: An Overview

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Abstract: In the realm of fourth-generation industrialization, there will be great demand for a skilled workforce. To produce a skilled workforce, we need sustainable education with quality and equity. Conventional ways of delivering and managing education would not fulfil the demands of the fourth industrial revolution (4IR). Disruptive technologies, such as Internet of Things (IoT), have great potential in revolutionizing the current educational setup. Therefore, this research work aims to present an overview of the capabilities of IoT applications in educational settings. Our research article digs into recent research carried out referring to IoT applications in education and provides a detailed insight into the topic from three different perspectives, i.e., from the perspective of school management, teachers, and learners. The present research explains the ways in which IoT has been applied for the benefit of school managers, teachers, and learners, showcased in the recent literature. The paper also sheds light on bottlenecks for IoT applications and explains security, privacy, scalability, reliability, and dehumanization as main constraints in IoT applications in educational settings.

Keywords: Internet of Things for schools; sustainable education; web learning; school management



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1. Introduction

Conventional educational settings remain the Achilles heel of sustainable education. Newfangled technologies are infiltrating our daily lives in ways we never imagined. The world we live in has changed dramatically in the previous decade as a result of technological advancements and digitization. Abrupt advances in wireless technologies and digital devices have ushered in a technological revolution all around us. The fourth industrial revolution, in this scenario, is bringing automation to every aspect of life, including schooling. It is critical to consider inclusive, equitable, and high-quality education at this stage of development. The digital divide is widening in the sense that the developed part of the world has more resources than the developing world. The only thing which can narrow the gap is sustainable quality education, provided equally to the masses. We must consider how technological advancements can assist in upbringing the world's underprivileged population. To keep the pace with technological advancements and the digital revolution, we have to embark new ways of educational systems.

The initiation of education and workforce policies which develop superior talent is one of the five policies identified by the World Economic Forum [1]. One way of narrowing the bridge between developed and developing countries is to reform educational settings by harnessing new technologies to uplift educational systems, therefore providing quality education for sustainable development. Educators can use advanced technologies not only for educational system development but also for developing a skilled workforce for future digital economies.

IoT, as one of the disruptive technologies, can play a vital role in enhancing quality of learning experiences and the performance of the learners, supporting teachers' daily work, school building management, school transport systems, and distanced learning provision. The Internet of Things has the potential to provide sustainable quality education and provide solutions for the everyday challenges which education providers and managers

face. From our point of view, the Internet of Things can enable equitable, quality education and can play a role in sustainability. Data-driven smart systems will be the cornerstone of the fourth industrial revolution. Therefore, the IoT is the key driving technology for the data-driven smart systems in future. However, we also think that there will be challenges related to IoT applications. In our research work, we explore the role of the Internet of Things as an enabler for smart schools in data-driven smart societies. We see this topic as a new research direction.

This article provides an overview based on recent research carried out related to the application of IoT for education. The research work provides an introduction to IoT and then moves on to a discussion of IoT applications in education. We showcase how IoT can be applied in educational contexts from school manager's, teacher's, and a learner's perspectives, to create a sustainable smart school. Finally, the study discusses the constraints of using IoT solutions in educational contexts.

2. Research Questions and Methodology

2.1. Research Questions

In our research article, we are aiming to answer the following research questions:

Question 1: How can the Internet of Things be applied in educational settings from school manager, teacher, and learner perspectives to provide sustainable smart education. To seek answers for Question 1, we have delineated the three following parts

- What is smart education, and how can the smart school concept be explained
- What does sustainable education mean? How can a smart education can be a sustainable education?
- How can the Internet of things be applied in educational settings from school manager, teacher, and learner perspectives

Question 2: What are the main challenges in applying the Internet of Things in educational settings?

2.2. Methodology

To answer the above research questions, this study presents an overview by reviewing the scientific literature published in the last 10–11 years.

We carried out our literature review using search engines such as Google Scholar, IEEE, and ERIC, using selected keywords: Internet of Things, smart school, Internet of Things and education, web learning, virtual learning, smart sustainable education, and educational management and Internet of Things. These are the main keywords used for the search, and we collected most of the literature addressed in this paper by using these keywords. Google Scholar, IEEE, and ERIC were used for the literature search because we found more recent work related to our search from these sources. These sources provided us with numerous recent studies. We retrieved almost 65 articles using the above-mentioned keywords. The total number of references included in the manuscript is 58. Out of which, 47 references refer to the included articles, and the remaining 11 refer to official websites and other authentic sources of information. The criteria for the articles to be included was partly based on the year of publication, because we are focusing on articles published in last 10-11 years. Two articles included were published before 2011. The reason for adding those articles is that they explained sustainability in a significant way, and in the authors' opinions, it was valuable to include those articles in the manuscript. Secondly, the articles were selected on the bases of their contribution on the topic of the Internet of Things in the field of education. We excluded some articles because some of them were published more than 11 years ago, and some articles had overlaps in discussion—for example, there were overlaps in reviews on IoT, challenges in IoT applications, and sustainable education. It is also noted that most of the work carried out on the topic has been published in recent years. Out of all the available papers, we selected the most relevant papers. The information related to research articles search and collection is summed up in Table 1.

Table 1. Information related to research articles search and collection.

Total Number of References	Total Number of Article-Based References	Total Number Official-Website-Based/Other-Information-Based References	Publication Period of Included Articles	Search Engines Used for Article Collection	Keywords for the Article Search
58	47	11	2011–2021	Google Scholar, IEEE, and ERIC	IoT, smart school, IoT and education, web learning, virtual learning, smart sustainable education, educational management and IoT

The study also analysed related information available on the internet from reliable resources, such as the official websites of the United Nations Educational, Scientific, and Cultural organization (UNESCO), United Nations (UN), and United Nations Development Program (UNDP). It is also noted that this topic is new, as application of IoT in education is in its infancy stage and is a new direction of research; therefore, there is not much work that has been carried out and published.

We divided the searched articles in three categories: (1) Internet of Things applied for solving school management problems; (2) Internet of Things applied for facilitating teachers in their daily work; (3) Internet of Things for facilitating learners. Furthermore, we looked for the bottlenecks in IoT applications from an educational perspective. The authors carried out a content analysis [2] of the collected research articles and present a detailed overview of the topic in discussion.

3. Smart and Sustainable Education

The Internet of Things has the capability to revolutionize the current conventional education system. Recent research has identified that IoT application in educational settings could prove to be a paradigm shift. Current research has pointed out that IoT has diverse services to offer for school managers, teachers, and learners. This section of the paper presents an overview of IoT applications for schools presented in recent research work. Although information and communications technology (ICT)-driven smart schools are not a new concept, there has not been much work carried out in that direction.

3.1. What Is a Smart School?

A smart school is a technology-driven physical or virtual learning environment equipped with modern technologies, devices, tools, and applications for interactive learning, engagement, collaboration, teaching, and management [3]. The term “smart” refers to intelligence, wisdom, efficiency, and effectiveness. So, smart education refers to a medium of learning which enables learners to think intelligently, act efficiently, and solve problems effectively. Therefore, a smart school aims to provide an intelligent learning environment, based on student-centric, personalized, and adaptive learning services, with interactive and collaborative tools characterized by unhindered access [3].

Worldwide, we can see various examples of smart schools. Malaysian smart schools focus on nurturing 21st century skills in learners by developing creativity, thinking, and fostering technology-driven, personalised learning [4]. Schools in Singapore have embraced technology-based education to enrich their learners with advanced learning experiences. Schools in Singapore have developed a national education and learning architecture for life-long learning. Schools in Australia have introduced the smart school concept by developing a multidisciplinary, learner-centric education system, providing digital learning platforms,

smart monitoring systems, adaptive curriculums, and interactive technologies for students and teachers [5].

Schools in Finland have been leading the world by implementing user-driven, motivational learning solutions, incorporating technology in daily school work, focusing on student-centred, project-based pedagogical approaches [6]. Schools in New York have already started smart school ventures, focusing on 21st century skill development. Schools in New York have developed technologically integrated class rooms, focusing on student performances and collaborative interactions [7]. Schools in the United Arab Emirates (UAE) started developing a smart learning program—the Mohammed Bin Rashid Smart Learning Program (MBRSLP)—in 2012, which aims to reshape the learning environment and school culture into technology-based, interactive, and collaborative smart classes [8]. Schools in China have developed smart systems, focusing on the ICT infrastructure, digital resources, ICT applications, information literacy, and safeguard mechanisms [9].

We can infer that smart school concepts build on teacher training, reliable information, communications technology (ICT) infrastructures, modern curriculum designs, application of interactive and collaborative technologies, tools and devices, user-friendly, personalized learning environments, and intelligent school management systems. Therefore, the main objectives of a smart school—which characterize the advantages of a smart school over conventional schools—include the following:

- To achieve digital literacy and an ICT-literate future workforce.
- To achieve an interactive, collaborative learning experience and an enhanced quality of education
- To achieve inclusive education by providing virtual education to far-removed areas without setting up physical school infrastructures.
- To equip teachers with modern teaching tools and applications to harness ease of work and quality of delivery in their daily work routine.
- To achieve sustainable management of resources in providing quality education.
- To achieve sustainable development goals by supporting and building sustainable communities [10].

3.2. What Does Sustainable Education Mean?

Sustainability refers to persistence, sustenance, or endurance. It can also refer to preservation of environments, facilities, or cultures. Sustainability can also be defined as the maintenance of a certain system at a certain level without depleting the available resources and avoiding the fear of system breakage. We can also explain sustainability in terms of the reliability and continuity of a system.

The United Nation World Commission on Environment and Development defines sustainability development as the following: “the sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [11].

The University of California, Los Angeles (UCLA), Sustainability Committee Charter defined sustainability as the following: “the integration of environmental health, social equity and economic vitality in order to create thriving, healthy, diverse and resilient communities for this generation and generations to come. The practice of sustainability recognizes how these issues are interconnected and requires a systems approach and an acknowledgement of complexity” [12].

In the scenario of sustainable development, sustainable education (SE) is explained in many ways. Australian researcher, Reynolds, in 2009 [13], introduced sustainable education in terms of “sustainability quotients” that can be applied to many forms of sustainability, and which point to the balance between the availability of resources and consumption. According to Reynolds, education as a social institution has the responsibility to make a meaningful contribution to ensuring sustainability at local, societal, and international levels. According to another study, sustainable education (SE) comprises four descriptors [14], as follows: Sustaining: It helps to sustain people, communities, and ecosystems; Tenable: It

provides equity, integrity, justice, and inclusiveness; Healthy: It nurtures systems, leading to healthy life styles; Durable: It is lasting and affordable so that the systems are not interrupted and are available to all.

Sustainable education plays an important role in society by empowering learners with responsible social and economical thinking. The 2018 UNESCO report emphasized the importance of education for sustainable development, and called for reforms in educational systems for all countries to transform education systems, focusing on innovative pedagogies, characterized by technology-driven, efficient, and intelligent learning environments, available to all with equity, justice, and equality. UNESCO has asserted sustainable education for sustainable development (environmental, social, and economical) as a key target to achieve before 2030 [15].

3.3. Main Features of a Sustainable Smart School

What features characterize a sustainable smart school? This is an important question, and so far, no perfect definition or benchmark has been set. However, on the basis of recent research, we can say that a very basic smart school can be a school which offers its learners computers, tablets, multimedia screens, projectors, and a free internet availability, in a reliable and sustainable way [10]. Reliability here suggests that applications should be secure and available without any service breakdown, and sustainability can be achieved when the application is secure, easily available, cost effective, and environmentally friendly.

A school can enhance its smart features by embracing advanced devices and technologies, such as sensors, cameras, smart and interactive white boards, virtual reality, augmented reality tools and applications, interactive learning games and learning environments, and technology-based assessment and feedback tools in sustainable ways. Therefore, a school which comprises secure and reliable ICT infrastructure, technology-driven physical and virtual classrooms, sustainable resource management systems, and advanced pedagogies, with personalized learning management systems (LMS), can be termed as a smart school [10].

Similarly, when we talk about e-learning, a virtual classroom set up comes in our mind, which utilizes distance learning. E-schools provide learning online, offline, or in virtual classrooms, where the student can learn at home without going into campus. This kind of virtual or distance learning education has so many advantages in terms of providing education to far-removed areas as well. In a COVID-19—and post-COVID-19—era, the world has experienced the power and convenience of distance learning. Therefore, a school capable of providing education online to those students who live in far-away places is a smart school. Distance learning is cheaper and more convenient than travelling every day, or building a physical school setup in far-removed areas.

We suggest that a smart school concept, driven by ICT and modern technologies, would help in achieving the United Nation's goals for sustainable development. United Nation has 17 goals for sustainable development as shown in Figure 1 [4]. By applying a smart school concept, the goal for quality education (Goal 4), the goal for reducing discrimination (Goal 10), and the goal for sustainable societies (Goal 11) can be achieved on a wider spectrum [4]. Sustainable development Goal 4 [4], as explained by the United Nations, is to bring inclusion and provide quality education for all without any inequality. Sustainability garners the idea of developing the masses, not only for facing present challenges, but also for nurturing the ability of future generations to address future challenges and meet their own needs. Educational progress, enabled by advanced technologies, seems to pave the way to sustainability. We need a quality of education which would make our present better and our future brighter. Therefore, smart schools, enabled with advanced technologies, utilizing information and communication technology, will produce a skilled future workforce and a quality education for sustainable development. We summed up main features of Smart and Sustainable School at Figure 2.



Figure 1. UN sustainable development goals.

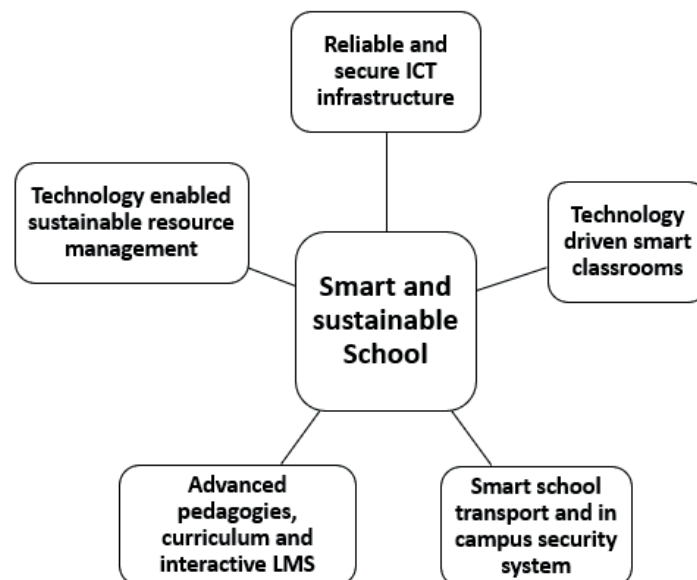


Figure 2. Smart and sustainable school.

4. Internet of Things: A Brief Introduction

Kevin Ashton, the co-founder of the Auto-ID Center, first introduced the term Internet of Things (IoT) in 1999 [16]. Later, International Telecommunications Union defined IoT as the following: “As enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” (International Telecommunications Union, 2012) [17]. The Internet of Things is a technology which gathers information in the form of data and transmits it to other devices, connected through internet. In this way, IoT interacts with its environment in close connection with other connected devices. A “thing” in IoT refers to a thing that should be capable of gathering and transmitting data to other connected devices. Multiple advanced technologies work as enablers of Internet of Things. For example, wireless communication and artificial intelligence are the key enablers technologies for the Internet of Things. In order to deliver IoT services, IoT works through the combination of different advanced technologies. Things in the Internet of Things do not include only electronic equipment, but also includes things such as art items, eatables, craft items, sports items, costumes, and garments [18]. IoT assures fast communication by collecting and transferring data, interacting with other devices, and receiving and transmitting information.

IoT Architecture

The architecture of IoT comprises of four layers, as shown in Figure 3. The first layer works as the physical layer. Sensors, wearable devices, actuators, and radio frequency identification tags (RFID) make up the physical layer. Therefore, we can say that the physical layer is made up of data collecting devices. Actuators are devices converting energy into motion. Basically, actuators are the motion producers. Motion can be linear, rotatory, or oscillatory [19].

Next to the physical layer is the network layer. The network layer acts as the backbone layer, which may constitute of wireless networks (3G, 4G, 5G), satellite networks, optical fibre networks, an ethernet network, or a cloud network. The network layer enables various functions, such as mobility management, accounting for IoT terminals, and the authentication and authorization of IoT applications [20].

After the network layer comes the software layer, commonly known as the data processing layer. The software layer behaves as a data processing engine. This layer consists of databases, data processing units, and high-power data processing servers to process the collected data. Therefore, the software layer enables the working by ensuring communication protocol for the data communication and management.

The last layer of an IoT architecture is the application layer. The application layer utilizes smart devices to make machine-to-machine (M-M) and machine-to-human (M-H) interactions possible. The application layer acts as an interface between the infrastructure and third party applications.

An Internet of Things system is characterized by three main features: (1) comprehensive perception, (2) reliable transmission, and (3) intelligent processing.

The Internet of Things has a vast range of applications, from smart industry to smart city concepts, which encapsulate smart health, smart commerce, smart education, and smart transport systems [20].

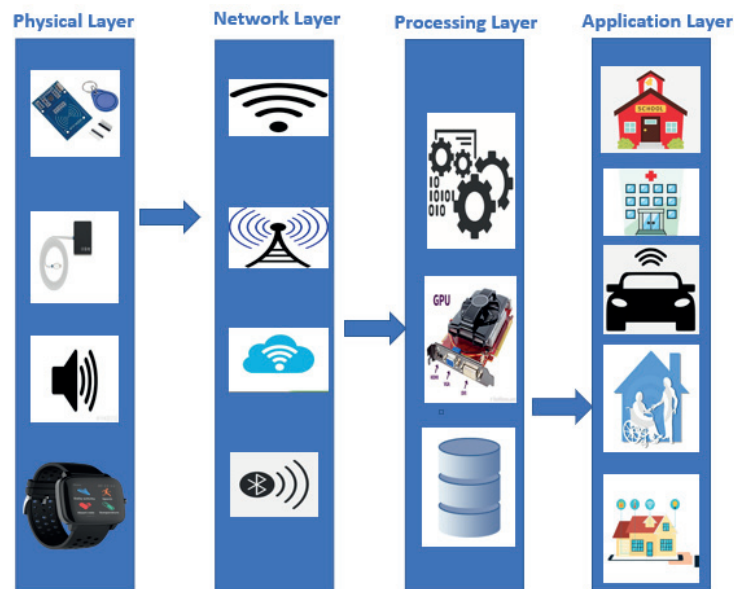


Figure 3. IoT architecture.

5. IoT as an Enabler for Sustainable and Smart Education

In this section, we explain the application of IoT from three different perspectives, i.e., from the school management perspective, from the teacher perspective, and from the learner perspective. The conceptualized IoT-driven Smart School is shown in the Figure 4.

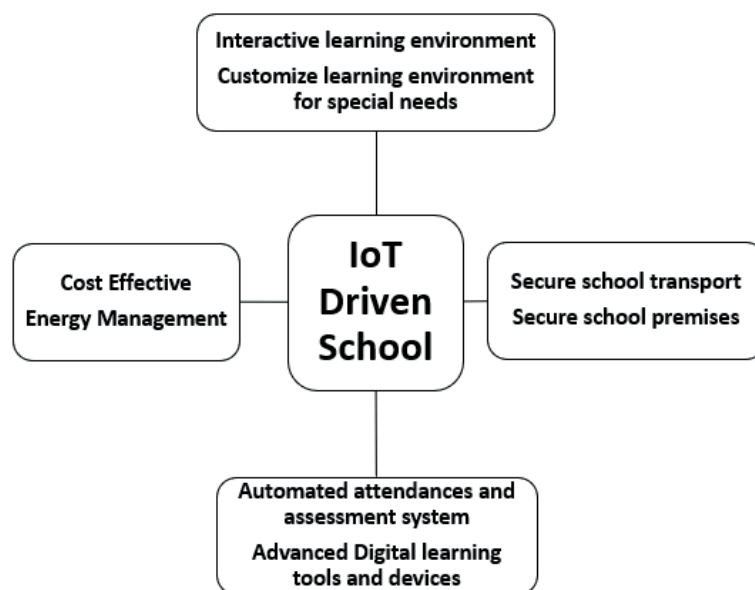


Figure 4. IoT-driven smart school.

5.1. IoT for Smart School Management

- **Energy management:** In the interests of sustainability, energy management demands interconnectivity and interoperability. Educational organizations could save millions of dollars using smart energy management. IoT sensors in school premises allow utility of only on demand energy and avoid unnecessary use of energy as in case of electricity. In this way, educational organizations can not only minimize their cost per unit of electricity but also their carbon footprint. An IoT-based communication framework can thus provide energy consumption information to the management system. An IoT-based energy-management platform has been developed to provide smart energy management for schools [21]; therefore, it provides a system based on demand resource energy management (DR). Another noteworthy solution for smart school building management is presented in [22], where a low-cost solution is designed for implementing energy consumption and environmental monitoring using an open-source IoT infrastructure. The solution is installed in many school buildings in Germany.
- **On-campus security:** School premises security is a challenge, especially in cases of large institutions. Most school buildings have insufficiently secured infrastructure. Therefore, it is almost impossible to detect incidents, such as physical abuse, fire, theft, or sexual abuse, on campuses. School management can enhance their in campus security by using real-time cameras in combination with devices. In this way, school management can reach the place of the incident quickly and initiate an action plan immediately. IoT-based security systems comprise sensing technologies, sensitive cameras, advanced cellular technologies, wireless communication, and cloud-based networks [23].
- **Student monitoring system:** In another work, researchers developed an IoT-based student monitoring system which utilizes Bluetooth low-energy technology (BLE) cards along with IP-based, closed-circuit television (CCTV) system. Here, the beacon chips are used for fingerprinting technology to determine the position of the object and face recognition is used to identify the student. In this way, it would be easier to monitor and identify the students carrying the BLE cards [24].
- **Management of students requiring extra support:** Facilitating learners with special needs is a challenge for education providers. Learners with physical and mental disabilities require holistic solutions to help them in learning. IoT has the ability to develop learner-

friendly personalized learning environments. Recent research work has presented the scope of IoT for students with special needs [25–27]. A useful example is that of gloves connected with sensors and a tablet for generating speech, which can help a deaf and mute learner for in class communication and interaction. Screen readers are one of the learning technologies which help in text-to-speech recognition for visually impaired students. Other features of screen readers include the following: on-screen keyboards, which help learners with mobility impairments to type; screen magnifiers, which enlarge screen content; and on-screen alerts, which send visual messages to assist deaf or hearing-impaired learners [28]. The research in [29] presents a wearable IoT device for early-stage detection of autism and management of related data.

- Smart transport for schools: School management can leverage IoT for the provision of secure transport for its learners. An IoT-based vehicle-monitoring system is presented in [30]. The presented idea explains a mechanism comprising a cellular device application and a microcontroller. Global positioning system (GPS) is used to find the position of the school transport using a cellular device. The mechanism uses an alcohol sensor and a panic switch for the security of the students. The real-time status of the vehicle can be observed by parents and school managers. Another proposed IoT-based bus-tracking system introduces a tracking website and an android application for the school administration, parents, and drivers of the buses to track the school transport [31].
- Student health monitoring system: A learner's health influences their educational performance. If a student is suffering from health-related problems, it would be extremely hard for them to focus on their studies, and thus their academic performance will decline. IoT in this case plays a vital role. IoT sensors gather health-related data through wearable devices. The collected data is then processed and gives precise measurements of student's health parameters. Research in [32] proposed a students health monitoring system presents an ambient intelligence-assisted health monitoring system (AmIHMS) based on IoT devices. Researchers in [33] suggested a cloud-centric IoT-based health monitoring framework. Research work in [34] presents an emotion detection system using long short-term memory (LSTM) and physiological signals. Researchers focused on distance learning in the pandemic era have presented an IoT-based framework for healthcare. A data-driven air quality prediction system in learning institutions is proposed in [35].

5.2. IoT for Teachers

- Autonomous attendance system: Taking attendance of each student is a strenuous daily task for educators. The main task of teachers is to teach and facilitate learners in learning. Biometric attendance system provides an automatic attendance system where each student has an ID card with a barcode to identify the student. This system is connected to face recognition, so that each student is recognised as well. Both teachers and parents will be aware of the presence or absence of the student [36–38].
- Advanced pedagogies: Learning spaces are not limited to physical classrooms these days. Now, learning is happening in physical modes, online modes, and hybrid modes. Classrooms can be real or virtual. Mobile learning, e-learning, online learning, digital learning, and distance learning are different names for the same concept. In that scenario, teachers need new pedagogies that support digital learning environments. For teachers, its vital to meaningfully use the advanced concepts and pedagogies for learning facilitation and teaching. The flipped classroom is a good example, where the teacher facilitates the students. Here, the flipped classroom worked as an IoT element during a computer network course [39].
- Assessment, evaluation, and feedback system: IoT can be used as an embedded technology to assess, evaluate, and provide feedback to students. Teachers can use such automated assessment tools for quick and easy working with in-depth insight into student performances. Research work presented in [40] proposed a framework for student interactions using attention scoring assessment in e-learning. Another

study proposed a real-time data mining approach based on IoT for students assessment [41]. Research work in [42] proposed student's engagement assessment based on IoT designed with Raspberry pie.

- IoT-based STEM education: IoT devices can be used in STEM (Science, technology, engineering, and mathematics) classes to have hands-on experiments and learning experience. Moreover, the learners can analyse the data collected through sensors or devices. Students can use IoT kits for design-based learning and can develop design thinking, which is one of the STEM skills [43]. IoT tools can be used in physics education and performing laboratory experiments [44]. A research study in [45] proposed methods to integrate IoT in STEM learning. Multimodal data collected through IoT devices can be used for developing analytical skills [46]. Research work in [47] shows IoT-based smart learning environments help learners to develop critical thinking and problem solving skills.

5.3. IoT for Students

- Distance learning: Distance learning has emerged as a solution in the pandemic era, when contact learning was impossible. Distance learning or online learning can be enhanced effectively by IoT [48]. IoT tools can benefit distance learning and help in uplifting student performance and efficiency by up to 20 percent, as reported in [49]. IoT sensors measured the brain activity during learning sessions and recorded the feedback. In this research [49], IoT sensors measured level of tiredness and keep brain active by sending signals.
- Enhanced productivity and interaction: Smartphone-based online classes, virtual classes, or e-classes develop more interactivity in students. This interaction-based learning develops students' interest in being involved in different tasks and participating actively in the feedback and assessment processes. Therefore, IoT-based learning environments enhance students productivity and interaction. For example, e-books with barcodes help students to read in an interactive environment. Scanmaker is an IoT device which can quickly scan editable text from books, papers, and other documents directly into a phone, tablet, or computer. The device has the ability to translate text in 40 languages [50].
- Customized learning environments: Customized digital learning environments are targeted to personal needs of the learner. Blackboard [51] is a digital learning environment, which has emerged as a convenient online learning solution for teachers and students. Blackboard is a virtual classroom technology which facilitates learning with enhanced collaboration, using an interactive learning management system (LMS). Such customized digital learning environments keep parents and students updated with daily school schedule, student grades, events, school news, and the attendance of the student. Additionally, IoT wearable technology provides the development of seamless learning. IoT wearable technologies can integrate the user location information, exercise log, and social media interaction into the learning and tailor the learning environment person-to-person in a personalized way. A good example is the IoT-ready platform from the MaTHiSiS H2020 EU project [52]. IoT sensing devices are used to capture the affect of learners during their interaction with learning material, which is in the form of games. This IoT platform utilised mobile devices, such as smart mobile phones and tablets, and robots for interaction [52]. The wearable IoT devices gather data from the learners and then, after processing the data, help in customising the learning environment according to the needs of the learner.
- School and home management: IoT can be used as a school and home management tool for students and parents. IoT-enabled smart school bag is one of the examples for home and school management. The research in [53] proposed a smart bag designed with IoT for students, which provides them with a quick timetable management tool and provides alerts for parents with notifications about any missed books or other school-related items which should be in the bag.

6. Challenges in IoT Adaptation in Education

Although application of IoT in education has tremendous benefits, there are many challenges posed by IoT adaptation in education [54]. This section aims to discuss bottlenecks in way of IoT applications in education.

6.1. Security and Privacy

We all know that there is a greater threat of cyberattacks when we have systems connected to the internet. The school system can be under direct threat if any of its system attacked, either by students or outsiders. The institutions can be made nonfunctional by such attempts. There can be a case of internet failure, which can paralyse the whole school system. Another great concern is data theft. Because a large amount of data would be collected by IoT devices, if such data is been stolen, then this poses a huge security threat. Among other security and privacy challenges are integrity-related issues, end-to-end security, authentication, and data confidentiality [55]. The IoT application in educational settings can be applied only when they are secure and reliable. IoT tools and applications gather huge data through devices such as RIFD, and technologies, such as NFC, 4G, and 5G. Therefore, data security is a great challenge. We need to think of the answers for the questions which arise in this context; for example, the following: who owns the data and who will benefit from it? Therefore, data management, control, and security is of the utmost priority. Data confidentiality and authenticity is another important factor. Data collected should be safe and can only be available to authenticated users either machines or humans. Data should be managed safely, and a secure and reliable system is required, so that there should not be any data breach, tampering, or theft occurring during data collection and data processing.

6.2. Scalability and Reliability

In the education sector, scalability is required for IoT applications. IoT collects huge data, so data analysis is the key to seek deep insight into the collected data. That is why data scalability is a challenge in IoT adaptation in educational settings. Research work in [56] discussed scalability, and proposed a social recommender system based on parallel computing and Hadoop, which provides students with customized learning content on the basis of large data analysis. Research work [57] proposed a secret sharing scheme for secured and scalable IoT systems. This research also discussed that the reliability and scalability of IoT applications can be achieved by deploying distributed IoT infrastructure.

IoT-based solutions should be sustainable and should be provided equally to all. Therefore, it should be accessible and available to its users without any delay. Schools and educational institutions should have enough money to acquire these services/applications so that their systems would be running in a sustainable way.

6.3. Dehumanization and Ethical Concerns

Dehumanization, in this context, refers to minimizing the role of humans. Dehumanization arises when we have autonomous systems with minimal human intervention. Dehumanization is one main issue which would arise when systems will work on their own, and there will be less human involvement, thus shifting control and power to the service providers [58]. Advanced technologies have great role to play in our daily lives, but concerns related to dehumanization and ethics should be taken into account. There should be an operating protocol for services and applications based on IoT.

User awareness is a crucial factor when it comes to the use of advanced technologies, tools, and devices. Customers/users must be educated on how to use internet technologies safely and how they can protect themselves from different kinds of cyber threats. It is a great responsibility of global governments, before rolling out any new technology, to organise mass awareness and education about those technologies, so that the users are well aware of all the aspects of a certain technology and can benefit from it in the safest way.

7. Discussion

With the advancements in technology, the world around us has changed a lot and it will keep on changing. Along with these advancements, on the one hand we have benefits, and on the other hand we have challenges. Education is one of the fields which is continuously reforming and evolving. The COVID-19 era has turned conventional educational means into digital means.

Similarly, the fourth industrial revolution is heading towards more advanced and digital technologies, which will demand a skilled workforce. The future workforce needs 21st century skills to meet the challenges of the future. For economical development, countries will require such a skilled workforce. Therefore, educational systems which can produce a skilled workforce are required. We argue that a sustainable smart education system can develop this future workforce. We need education which takes into account the economic, social, and environmental factors of sustainable development. In our point of view, a technology-driven education system which enhances sustainability in terms sustenance, equity, equality, justice, and quality is a sustainable smart education, and can deliver the skilled workforce of the future.

Emerging technologies are playing a vital role in the educational field. We focused on the Internet of Things in our research work. We presented an overview of how the Internet of Things can enable sustainable smart schools and we identified the challenges. We emphasize the utility of technology with sustainability. If a technology is expensive, unhealthy, or environment unfriendly, then its no longer sustainable. We argue for the application of technology which holds sustainability as a priority.

In our research work, we showcased that the Internet of Things is cutting-edge technology for educational settings. We discussed the ways in which the Internet of Things can be used in educational settings from the perspectives of school managers, teachers, and learners. IoT sensor technology plays a role in solving many problems. The Internet of Things can provide school management with energy management solutions, school transport management, student health management, on-campus security, and student monitoring systems. In all such applications, IoT makes use of sensors, data collection devices, cameras, cloud computing, and machine learning. From the perspective of teachers, IoT can play a key role in managing student attendances, assessment and feedback systems, STEM classes, smart teaching environments, and interactive tools for teaching. From the perspective of students, IoT can enable smart learning environments, personalized learning management systems, smart devices for students with special needs, and interactive and collaborative tools for immersive learning, both on the campus and outside of the campus. There is more research needed to explore the capabilities of IoT applications in schools. Similarly, more work is needed to discover sustainable methods of technology integration.

The present paper presents a view for our readers and educators which presents ways in which IoT can enable smart education. IoT applications have challenges also. The main challenges in IoT applications in educational settings are security and privacy, scalability and reliability, and dehumanization. We can make IoT solutions more sustainable by overcoming these challenges.

Similarly, more work is needed to discover sustainable methods of technology integration. Quality education with equity and inclusion is one of the United Nations' sustainable development goals. Therefore, there is a dire need for research bringing sustainability into technology applications. Smart education driven by technology can be sustainable if it is affordable, available, environmentally friendly, and healthy.

8. Conclusions

In the present study, we aimed to present a holistic view of the capability of the Internet of Things to enable smart school features in educational settings. In the realm of digitization, the provision of a sustainable, high-quality education is the goal. However, there are many constraints in this regard. We have summarized the focus of the recent research work on IoT as an enabler of the smart school concept. IoT is an opportunity to implement key smart

school features focusing on school management, teachers, and learners as summarised in Table 2. Education and workforce policies which develop superior talent is one of the five policies identified by the World Economic Forum [4]. Therefore, for a sustainable, high-quality education, the conventional ways need to be replaced with advanced technology.

Table 2. IoT enabling smart school features.

IoT for School Management	IoT for Teachers	IoT for Learners
Energy Management	Autonomous attendance system	Distance learning
School Premises security	New Pedagogies	Virtual classrooms, distance learning
Special need management	Feedback system	Enhanced productivity
Smart school transport	Assessment and evaluation system	Enhanced interaction, learning efficiency
Health management system	STEM education	Personalized learning environments

We conclude that the Internet of Things could prove to be a paradigm shift as an enabler of sustainable smart schools. We emphasize sustainable education methods promoting smart learning environments. IoT plays a vital role to optimize the needs of educational settings. We showcased in detail how IoT could be used for smart school management, smart school teaching, and smart school learning. We also discussed challenges in the application of IoT for education and addressed the security and privacy issues related to the Internet of Things. Security, privacy, scalability, reliability, dehumanisation, and ethical issues are the major bottlenecks in IoT applications. More research is needed to explore ways of making the Internet of Things more safe and secure. In our future research, we will focus on how we can use the Internet of Things in STEM (science, technology, engineering, and mathematics) education in secondary school settings to develop critical and analytical thinking in pupils.

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IV

CHATGPT FOR STEM EDUCATION: A WORKING FRAMEWORK

by

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki 2024

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ChatGPT for STEM Education: A Working Framework

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Abstract—This paper sheds light on the possible use of most recent technology, ChatGPT in STEM (Science, Technology, Engineering, and Mathematics) education. Here we used the ChatGPT tool and explored how it can help teachers in STEM class. Our work first presented a literature work related to Chat GPT in terms of its use in education, explained generative AI (Artificial Intelligence) and ChatGPT. ChatGPT tool is used to generate responses to prompts given. We ask ChatGPT that how it can be used in class for teaching science, mathematics, and coding. After detailed analysis of the responses by ChatGPT we presented a theoretical framework for guiding the use of ChatGPT in STEM educational settings. Next, we presented limitations of using ChatGPT in educational context and highlighted the bottlenecks and ethical issues in using technologies like ChatGPT. Finally, we presented our future research directions and concluded that ChatGPT has a great potential in STEM education and can be used as an effective tool for STEM teachers. We also emphasized on the concerning ethical issues related to the technology.

Keywords—ChatGPT, STEM education, skill development, artificial intelligence, science education, active learning

I. INTRODUCTION

New trends and technologies are opening new doors for educational reforms and support. On the other hand, the newfangled technologies offer big challenges too both for the teachers and students. A neutral take on the new technology adaptation should be to see both sides of the technology use to anticipate its pros and cons realistically. The last decade has shown a tremendous progress in the technology development and its adaptation in general and specifically in the field of education. Digital transformation of education has seen new heights during and post covid 19 eras.

Online learning tools, mobiles, digital learning applications, IoT, and AI tools are already in daily practice in educational systems. The most recent technology in market for education is AI chatbot ChatGPT. AI in general is making its place in every field of life and has become an important part of daily life in many ways from searching suitable routs on google maps to watching movies on Netflix.

A. What Is Generative AI (Gen AI)?

Generative AI can be defined as a technology that (i) leverages deep learning models to (ii) generate human-like content (e.g., images, words) in response to (iii) complex and varied prompts (e.g., languages, instructions, questions).

The last decade has shown enormous progress towards AI development and release of AI tools such as ChatGPT, GitHub Copilot, and DALL-E which have attracted widespread attention, optimism, and skepticism [1]. These technologies are all examples of “generative AI”, a class of machine learning technologies that can generate new content—such as text, images, music, video, poems, interesting phrases, or idea creation by analyzing patterns in existing data. Generative AI uses large language models to generate content. In 2017, the Transformer network made progress in generative models, leading to the first Generative Pre-trained Transformer (GPT), known as GPT-1 in 2018, this progress was followed in 2019 by GPT-2 which demonstrated the ability to generalize many different tasks as a Foundation model. In 2021, the release of DALL-E, a transformer-based pixel generative model, marked the emergence of practical high-quality artificial intelligence art from natural language prompts. GPT-4 was released in March 2023 [2].

Our conceptual paper has the following objectives: (1) to propose a theoretical framework for guiding the use of ChatGPT in STEM education (or “educative AI”, which refers to the use of AI in educational settings to enhance teaching and learning outcomes) and (2) to illustrate ChatGPT’s potential benefits and challenges for use in the field of education. This study also provides recommendations for future research, policy, and practice in educative AI [3].

B. What Is ChatGPT?

Open AI developed a natural language processing model to generate human conversation like texts called ChatGPT, stands for Chat Generative Pre-Trained Transformer, launched on 30 November 2022. ChatGPT is versatile in its functionality as compared to a normal chatbot. From writing poetry and essays, composing music, teleplays, generating business ideas, translating, and explaining texts to writing and debugging the computer programs ChatGPT is proving to be a master of all trades [4, 5].

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Ability to understand the context, generating coherent responses and adapting its language style based on the input it receives are some of the key features of Chat GPT. Therefore, Chat GPT can be used for answering questions, writing content, creating ideas, having conversations, planning discussions and many more.

Chat GPT is undoubtedly a versatile AI tool, but it is important for users to keep in mind that its responses are based on patterns learned during training and may not always be contextually accurate and perfect. Therefore, for users, it's important to verify information gathered from Chat GPT. It is important for STEM (Science, Technology, Engineering, and Mathematics) educators to understand the implications of this technology and to study how to adapt this technology in STEM ecosystem. This would ensure that the next generation of STEM professionals can take optimal advantages as offered by generative AI while minimizing any negative consequences.

II. CHATGPT FOR STEM EDUCATION

A. How Can a Science Teacher Use ChatGPT?

A science teacher can use ChatGPT in many ways to support, enhance and effectively deliver the learning tasks to the learners. From the last decade we have observed that artificial intelligence is playing a vital role in teaching and learning [6, 7]. Following are some suggestions for the science teachers that how they can use Chat GPT to support their teaching process.

Teachers can brainstorm ideas, can answer student's questions, can create interactive learning environment and interactive lessons where students are engaged in a conversation with ChatGPT to reinforce concepts. For instance, a teacher can set up a scenario where students must solve a scientific problem by asking ChatGPT for hints and guidance. ChatGPT can be used as a personal teacher assistant to look for references and data for the topics and can provide research material to investigate for the preparation of teaching materials. ChatGPT can be used by teachers for idea creation as how to plan a class lesson.

Teachers can use ChatGPT to stimulate debates or discussions in the classroom. Students can ask ChatGPT for arguments related to a scientific topic and then use this information in a structured debate.

At this point of discussion, we are interested to know that what Chat GPT itself says about its usage in STEM classes both by students and teachers. So, we gave a prompt to Chat GPT as follows:

Response of Chat GPT was as follows:

A science teacher can integrate ChatGPT into the classroom in various ways to enhance science teaching and engage students. Here are some ideas:

- **Answering Questions:** Use ChatGPT to quickly answer students' questions related to science topics. This can be particularly helpful for clarifying doubts, providing additional information, or exploring related concepts beyond the textbook.

- **Virtual Science Assistant:** Treat ChatGPT as a virtual science assistant. Students can interact with it to get explanations, summaries, or elaborations on science concepts. This can be especially useful for students who may need extra help or clarification.
- **Discussion Starter:** Use ChatGPT-generated prompts to initiate class discussions. Ask the model to generate questions or statements related to the current science topic, and then discuss the responses as a class. This can encourage critical thinking and diverse perspectives.
- **Writing Prompts:** Ask ChatGPT to generate writing prompts related to science topics. Students can use these prompts for essays, research papers, or creative writing exercises. It encourages students to think deeply about the subject matter.
- **Interactive Learning:** Integrate ChatGPT into interactive learning activities. For example, create a scenario where students have to ask the model questions to solve a science-related problem or simulate a scientific inquiry.
- **Homework Assistance:** Students can use ChatGPT as a resource for homework help. They can ask for explanations, examples, or additional resources related to the topics covered in class.
- **Concept Reinforcement:** After teaching a concept, the students would be able to summarize what they've learnt by interacting with ChatGPT? This can help reinforce the understanding of the material and identify any misconceptions.
- **Science Project Ideas:** Ask ChatGPT for creative and innovative science project ideas. This can inspire students and provide a starting point for them to explore their scientific interests further.
- **Language Skill Development:** Incorporate ChatGPT to help students develop their **language skills:** They can ask the model to explain scientific concepts in their own words, improving both their understanding of the material and their ability to communicate effectively.
- **Ethical Discussions:** Utilize ChatGPT to explore ethical considerations in science. Generate questions or scenarios related to the ethical implications of scientific advancements and engage students in thoughtful discussions.

It's important to note that while ChatGPT can be a valuable tool, it's not a replacement for the teacher's expertise. Teachers should guide the use of ChatGPT, ensuring that it complements their teaching methods and enhances the learning experience for students. Additionally, it's crucial to critically evaluate the information generated by ChatGPT, as it may not always be entirely accurate or up to date.

B. How Can a Math's Teacher Use ChatGPT in Class?

Response of Chat GPT was as follows:

While ChatGPT is primarily a text-based model and may not have specific knowledge about being a "math

teacher”, you can still integrate it into your science or math class in various ways. Here are some ideas on how a math teacher can use ChatGPT in the classroom:

- **Answering Math Questions:** Use ChatGPT to answer students’ math questions. It can help provide additional explanations, step-by-step solutions, or alternative approaches to solving problems.
- **Problem-Solving Practice:** Create math problems or equations and ask students to solve them. Students can then use ChatGPT to check their answers, get hints, or explore different methods of solving the problems.
- **Math Concepts Explained:** Have ChatGPT explain specific math concepts. This can be especially useful for students who may need extra support or for introducing advanced topics beyond the curriculum.
- **Math Puzzles and Challenges:** Generate math puzzles or challenges using ChatGPT and use them as engaging activities in the classroom. Students can work individually or in groups to solve these puzzles, promoting critical thinking and problem-solving skills.
- **Interactive Quizzes:** Use ChatGPT to create interactive quizzes where students can ask questions related to the quiz content. This can be a fun and interactive way for students to review and reinforce their understanding of math concepts.
- **Math Project Ideas:** Ask ChatGPT for creative math project ideas. Students can use these ideas as a starting point for independent or group projects, fostering creativity and exploration in mathematics.
- **Historical Math Context:** Explore the historical context of mathematical concepts. Ask ChatGPT to provide information on the historical development of specific mathematical ideas, helping students understand the evolution of mathematical thought.
- **Math Vocabulary and Definitions:** Use ChatGPT to reinforce math vocabulary and provide clear definitions of mathematical terms. This can be particularly helpful for students who may struggle with the language of mathematics.
- **Coding and Mathematics Integration:** If applicable, explore the intersection of mathematics and coding. Ask ChatGPT to provide coding examples related to mathematical concepts, promoting interdisciplinary learning.
- **Real-World Applications:** Discuss real-world applications of mathematical concepts with the help of ChatGPT. This can make math more relevant and interesting to students by showing how it is used in various fields.

We should always remember to guide students on how to use ChatGPT effectively and to emphasize that it’s a supplementary tool rather than a replacement for the teacher’s guidance. Additionally, it is to be ensured that

the information provided by ChatGPT is not only aligned with the curriculum but also is accurately delivered and applied in the said educational context.

C. How ChatGPT Can Help in Teaching Coding to Kids?

Response of Chat GPT was as follows:

ChatGPT can be a valuable tool in teaching coding to kids in various ways. Here are some ways you can leverage ChatGPT to enhance the coding learning experience:

- **Coding Assistance:** Kids can use ChatGPT to seek help with coding problems. They can ask questions about syntax, logic errors, or general programming concepts. ChatGPT can provide explanations and solutions, acting as a virtual coding tutor [8].
- **Code Writing Assistance:** Encourage kids to write code snippets or even full programs with ChatGPT’s assistance. The model can help them with code structure, suggest improvements, and provide examples to illustrate coding principles.
- **Concept Explanation:** Use ChatGPT to explain coding concepts in a kid-friendly manner. It can break down complex ideas into simpler terms, making it easier for children to understand fundamental programming concepts.
- **Creative Coding Ideas:** Ask ChatGPT for creative coding project ideas that align with the kids’ interests. This can inspire them to work on projects that are not only educational but also personally engaging and enjoyable.
- **Debugging Practice:** Kids can use ChatGPT to practice debugging. They can share their code with the model, describe the issue they are facing, and receive suggestions on how to identify and fix bugs.
- **Coding Challenges:** Generate coding challenges or puzzles using ChatGPT. Kids can then attempt to solve these challenges, promoting problem-solving skills and critical thinking in a fun and interactive way.
- **Learning Resources:** Ask ChatGPT to recommend age-appropriate coding resources, tutorials, or games. This can supplement the formal learning process and expose kids to a variety of coding tools and languages.
- **Storytelling with Code:** Kids can use ChatGPT to explore coding in a creative context. Encourage them to tell stories using code, where they create interactive narratives or games by applying coding concepts they’ve learned.
- **Coding Language Exploration:** If your curriculum includes multiple coding languages, kids can use ChatGPT to explore the differences between them. They can ask for comparisons, advantages, and use cases for various programming languages.
- **Coding History Exploration:** ChatGPT can provide information about the history and evolution of coding languages. This historical

context can make coding more interesting and help kids appreciate the development of the tools they are using.

It's important to note that while ChatGPT as an AI chat bot [8] can offer valuable assistance, hands-on coding practice, real-world projects, and interactive activities should remain central to the learning experience. Additionally, ensure that the coding concepts introduced align with the age and skill level of the students. Always encourage kids to think creatively, employ problem-solving techniques independently, and enjoy the process of learning to code. ChatGPT has a greater capability to provide personalized and efficient learning experiences [9].

The above prompt questions and the responses of the ChatGPT, explain a vast application of Chat GPT in STEM education. STEM education focusses on phenomenon or project-based learning and development of critical thinking [10]. Following features are the main ingredients of STEM education:

Asking questions, thinking, understanding problem, creating ideas, interaction, communication, collaboration, taking challenges and solving problems, language exploration, looking for authentic resources, debugging and recreating solutions, validating, testing and researching [11].

Research conducted [3] in pharmacy education concluded that ChatGPT has a great potential of enhancing process driven phenomenon or project-based learning [7]. As, we can clearly see from the above Chat GPT responses that it justifies its usage in STEM education.

D. Framework for Using ChatGPT in STEM Education

With an immense progress in technology and with growing number of tools and applications which can assist teachers and students digitally, there is a dire need of a working framework, which adheres to the needs and provides a clear instruction on the application of AI assisted tools in education. In our case here we propose a working framework for using ChatGPT in STEM education.

The application of AI technologies in STEM education is a burgeoning trend, capable of providing personalized and efficient learning experience with the challenge of integrating AI techniques in the complex STEM educational system.

1) Technology knowhow and ethical awareness

A very first step in implementing ChatGPT in enhancement of STEM education is to get awareness of the technology and after training teachers, the students should be provided with the complete awareness of the technology. Technology awareness includes:

- What is this technology?
- How technology works?
- What are the ethical issues?
- What are the benefits and limitations of this technology?
- To what extent this technology can be used in STEM education scenario?

- 2) Lesson explanation and reinforcement
 - ChatGPT integration into learning platforms or websites to provide instant explanations and clarification of STEM concepts.
 - Students can ask real time questions during or after lessons, receiving immediate responses to get better understanding of a certain topic.
- 3) Experimentations and simulations
 - Students can use virtual lab assistance to design experiments or simulations, offering guidance and explanations throughout the process.
 - ChatGPT can be used for interactive demonstrations to trigger scientific processes and visualize the concepts that are otherwise hard to grasp.
- 4) Project assistance and idea creation
 - Equip students in brainstorming and creating ideas for STEM projects or assignments.
 - Assist students and help them in rethinking and interacting in projects.
- 5) Collaborative and interactive learning
 - ChatGPT facilitates group discussions by providing explanations, resources, and guidance during collaborative projects and produces an interactive learning environment.
- 6) Problem solving techniques
 - A step-by-step guidance to the problem and finding its solution by breaking problem into pieces. Problem solving skill is an important part of STEM education [11].
- 7) Personalized teaching
 - ChatGPT can offer personalized tutoring sessions where students can ask specific questions or can receive additional support in understanding challenging topics. Personalized learning is an important part of STEM teaching as not all students are at the same pace and in that case personalized tutoring helps in understanding complex STEM concepts.
- 8) Adaptive Learning Methods
 - Adaptive learning Paths can be tailored based on students' individual strengths and weaknesses by providing targeted explanations and resources. In this way a student gets flexible and adaptive learning assistance according to his/her needs.
- 9) Assessments and feedback
 - Continuous assessments and feedback are necessary for improved learning. ChatGPT help students prepare for exams by offering practice questions, explanations, and clarifications.
 - Provides students with detailed feedback so that they can learn from it and improve their shortcomings in future.
 - Also helps teacher to generate personalized feedback for students from their tasks and write assessments on individual student performances.
- 10) Accuracy, authenticity, and safety
 - Ensures that the information generated from the ChatGPT, must be reliable. Students should check

the authenticity of the information from other sources as well. In the learning process students must take safety, accuracy, and authenticity into consideration.

11) Ethics and privacy

- Teachers and students must maintain privacy standards and ethical considerations when interacting with students, especially considering the age group and educational setting.

III. LIMITATIONS

Integration of AI tools in STEM education is a new trend in educational research [7]. Educational institutions can mitigate the disruptive effects of this technology and can promote academic integrity by developing clear policies and guidelines. Designing assessments that include limited AI-generated text would also prove beneficial. The main shortcomings faced on different levels of use of ChatGPT in different scenarios are lack of reliability that is the information generated can be biased or false or not updated. Limited knowledge is another important limitation. ChatGPT can give biased responses [5]. There can be accuracy problems and grammatical issues. Computational cost and power, academic integrity and safety issues are also some of the bottlenecks [12]. Language limitation is another drawback of ChatGPT. For example, ChatGPT3 is trained on English language. Therefore, there is language constraints which should be overcome [13].

IV. FUTURE WORK AND CONCLUSION

In future we will collect data from teachers in the form of interviews to find that how teachers are using ChatGPT for the benefit of teaching and learning in classrooms and what are the problems they are facing. We asked ChatGPT that how a science teacher can use ChatGPT and included the responses of Chat GPT, which are interesting to know. We presented a detailed framework for use of ChatGPT in STEM education. The ChatGPT as objects-to-think-with offer promising avenues to revolutionize STEM education through a fostering engagement in inclusive and accessible learning environments. Chat GPT is a new technology and making its place in everyday life. It is concluded from the above explanations and research that ChatGPT had a great potential in STEM education. 21st century skill development through STEM education enhanced with Artificial intelligence technologies is a new focus area. Therefore, we need to explore the AI technologies like ChatGPT. We should consider its limitations and see how we can minimize the challenges and maximize the usefulness of the technology.

CONFLICT OF INTEREST

The authors declare that they have no known competing interests or personal relationships that influence the work reported in this paper. Therefore, there is no conflict of interest.

AUTHOR CONTRIBUTION

KZ conducted the research, analyzed the data, and wrote the paper; TH and PN supervised the work and gave feedback; all authors had approved the final version.

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**COMPUTATIONAL THINKING AND AI CODING FOR KIDS
TO DEVELOP DIGITAL LITERACY**

by

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki 2024

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COMPUTATIONAL THINKING AND AI CODING FOR KIDS TO DEVELOP DIGITAL LITERACY

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ABSTRACT

21st century skill development is a challenge to today's educational system. There is a dire need to integrate Information and communication technology (ICT) skills in early school education along and science, technology, engineering, and mathematics education (STEM). In this research work, we have investigated how coding and computational thinking can be developed at an early school age by presenting a case study of an online course for kids aged 9-15. Additionally, we presented a detailed study focusing on the significance and need of coding and ICT education and initiatives taken by different countries at the K-12 level mentioned in the literature. The main goal of the study is to encourage educators and managers of education to take holistic initiatives to promote ICT skill development at the K-12 level to prepare a skilled future workforce.

KEYWORDS

Digital literacy, Computational thinking, Coding, 21st-century skills, digital learning process, analytical thinking, ICT education

1. INTRODUCTION

With the advent of 21st-century, the world is seeing a new revolution of technology embracing automation and digitalization. Artificial intelligence, advanced wireless technologies, and the Internet of Things have already transformed our world. Our future will be autonomous based on smart environments and intelligent machines. When we talk about smart and intelligent systems, on the one hand we think of machines replacing humans and on the other hand, we see the shortage of an advanced skilful workforce. In that scenario, we see a gap between fast-paced technology development and the scarcity of a skilled workforce capable of working with advanced technologies. This gap would be widened if the educational system failed to embrace digital literacy and the development of 21st-century skills in ICT/coding education as regular along with reading, writing, and the mathematics skills.

The Organisation for Economic Co-operation and Development (OECD) has presented a framework for 21st-century skills [1] and identified three dimensions: information, communication and ethics, and social impact. The framework clearly emphasizes on ICT education under the communication dimension to deliver critical thinking, computational thinking, problem-solving approach, and innovation, and creation skills for the future (OECD Paper). Partnership of 21st-century learning (P21) as shown in Figure 1 in also published a framework for 21st century skills and identified ICT, technology, media, and communication education as one of the important set of competencies to deliver skills like creativity and innovation, critical thinking and problem-solving, communication and collaboration. European Union's digital competence framework for citizens stresses the digital literacy of its citizens to prepare themselves to meet the challenges of future digital economies and make themselves

proficient in technology use and digital innovation and creation. EU's DigComp 2.0 [2] identified the main digital competencies in its conceptual reference model. These competencies are information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving.

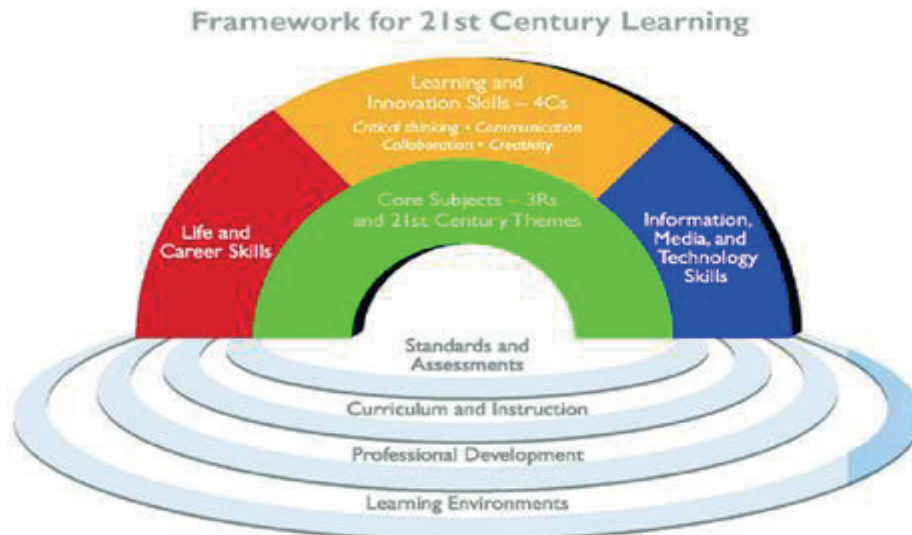


Figure 1. Framework for 21st Century Learning [1]

We need trained teachers and advanced pedagogies to achieve the goal of ICT literacy goa at the school education level. However, in this research work our focus is learners and we investigate the significance and need of coding and ICT education, pedagogical methods applied to develop ICT literacy at different levels, and initiatives taken at the K-12 level mentioned in literature. Additionally, our work presents a case study of online coding courses for learners aged 8-18. This research work is distributed in such a way that after introduction the paper presents an overview of ICT literacy and skills. The paper then sheds light on the ICT literacy initiatives at the K-12 education level. Our work then presents the case study of an online coding course for kids aged 8-18 years old learners. Finally, we concluded our paper.

2. DIGITAL LITERACY AND DIGITAL ENVIRONMENT 21ST CENTURY COMPETENCIES

ICT literacy or digital literacy is not just a capability of acquiring technical skills rather it's a whole educational process that encompasses a whole digital environment consisting of users, machines, tools, applications, technologies, and data. Therefore, we define ICT/ digital literacy as: "A capability of interacting within a digital environment to collect, use, create and secure information. Whereas a digital environment encompasses users, machines, tools, applications, technologies, and data." According to [3] Digital literacy is the ability to understand, analyse, and use information in various forms from varied sources that we can access through digital devices.

To achieve a capability of interaction in the digital environment, there are a set of skills or cognitive competencies that should be developed [4]. Digital literacy is the combination of cognitive and technical skills as shown in Table 1 (skills). Such cognitive skills or competencies are critical thinking, problem-solving skill, computational thinking, idea creation, collaboration, and communication. The set of these technical skills includes hardware knowledge, software

applications knowledge, networking, coding/programming, and knowledge from architecture design to software application development.

Table 1. Digital Literacy Skills.

Cognitive skills	Technical skills
Critical Thinking	Hardware Knowledge
Problem Solving Skill	Software Application Knowledge
Computational Thinking	Networking
Idea Creation	Coding and Programming
Collaboration	Architecture Design
Communication	Software Application Development
Ethics and Digital Awareness	Cybersecurity awareness, Skills to avoid cyber attacks

We foresee digital literacy skills will be the cornerstone of the 21st-century skills for a knowledge society where the industry will be run by automation and disruptive technologies. Thus, in future, there will be a high demand of a digitally literate workforce with outstanding aptitude for cognitive and technical skills. On the other hand, knowledge economies driven by a skilled workforce will improve life and uplift the development of society. In order to achieve a progressing economy, we need to turn our economies into knowledge economies based on digital literacy.

2.1. Digital environment (Dig Env.)

The Fourth industrial revolution is bringing autonomous systems based on a connected world with high-speed wireless communication and data-driven disruptive technologies. Computers have already made their place in our daily lives and mobiles are everywhere. In that scenario, we define a digital environment as, “A physical or virtual place encompasses users (machines or humans), machines, tools, applications, technologies, and data.” The Digital environment serves as a place for digital interaction that leads to the collection, usage, creation, and storage of information. Therefore, to operate in a digital environment, one must be digitally literate. In the future, the fourth-generation industrial revolution will roll out autonomous systems where humans will work with machines. To be eligible to work in such a mechanized digital environment, today’s learners should be well-prepared and digitally well-literate to be the part of the future workforce. 21st-century skills focus on the development of digital skills along with other skills.

2.2. 21st-century Competencies and digital literacy

Different frameworks for 21st-century skills are presented by different world-renowned organisations. The Partnership for 21st Century Skills (P21), the Organization of Economic Cooperation and Development (OECD), the European Union (EU), and the United Nations Educational, Scientific and Cultural Organisation (UNESCO) [5] have recommended ICT literacy as the core competence of 21st-century skills framework. These organisations have consistently emphasized on integration of ICT in the curriculum and the adoption of digital tools in teaching and assessment of these skills [6]. It is also noted that 21st-century skill development requires competent and well-prepared teachers to deliver the task, therefore teacher training must be part of the whole process [7]. 21st-century skill framework presented by P21 has three main groups of skills, one group of skills is “Life and career skills”, the second is “Learning and innovation skills”, and the third one is “Information, media and technology skills” as shown in figure 1. Digital literacy is a means to develop learning and innovation skills which finally leads to life and career skills. From literature, we find how different countries and

nations are preparing their future workforce by taking mathematical and digital learning initiatives to embrace next generation`s digital age [8].

Digital literacy can be seen as a learning process that finally yields to the development of 21st-century skill sets to address the job challenges of future workplaces [9]. Skills required for the 21st century encompasses competencies related to the development of a solution to a problem such as the collection of useful information, critical analysis of the information, solution development, testing and validation, communicating the results, and collaboration. Therefore, digital literacy is a whole process from collecting information to the creation of solutions for existing problems [10].

2.3. Digital Literacy Process

We see digital literacy as a learning process that enhances skills and competencies along the of learning. So, a learner is not only developing digital skills but at the same time developing his/her competencies. As explained earlier a digital literacy process has two paths, one can take both paths to achieve a high-level competency in digital literacy or can focus on the first path only. Our proposed digital learning process is shown in Figure 2 and explained below.

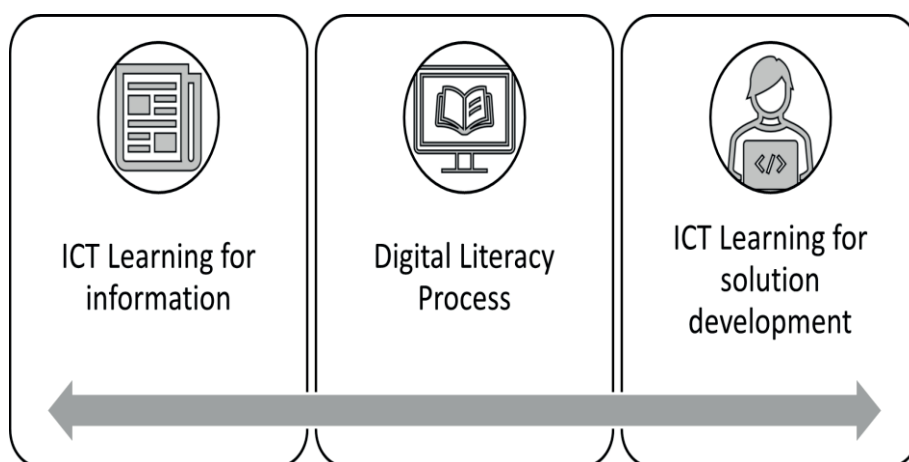


Figure 2. Digital Literacy Process.

ICT learning for information and communication: The First path of the digital literacy process leads to ICT learning for information. A learner can take this path to develop skills related to information seeking for understanding a problem, learner can identify fake and real information, can compare different sources of information, can critically analyze, and evaluate information, can deduce useful results/predictions from the collected information, can save and secure information, and can share and communicate information effectively and efficiently. Additionally, an individual will be capable of utilizing digital tools and applications in a friendly manner. Such a digitally literate individual will be capable of human-to-machine interaction and communication. During this process of learning a learner develops competencies including inquiry, analytical and critical thinking, collaboration, active interaction, communication, and ethical responsibility.

ICT learning for solution development: The second path of the digital literacy process is a more advanced path which leads to the idea creation and development for solving a problem. A

learner can take this path to develop the skills required for idea creation and development to solve a certain problem. Adhering to this path enables learners to be capable of idea creation, collection of useful information, teaming up, collaborating, critical analysis of information and assumptions, developing models, applications, tools, testing and validating solutions, redesigning, and retesting if needed, communicating the results, interacting efficiently with machines and humans. Therefore, developing a certain solution for a problem and showcasing the required competencies and skills learned during the whole process. During this process of learning a learner develops competencies including brainstorming, idea creation, inquiry and research, analytical and critical thinking, collaboration, active interaction, design and development, computational thinking testing and validation, communication, and ethical responsibility. Table 2 below shows a set of competencies developed during the digital literacy process.

Table 2. Competencies acquired during the digital literacy process

Competencies	ICT Learning for Information and Communication	ICT Learning for Solution Development
Research and Inquiry	✓	✓
Analytical Thinking	-	✓
Critical Thinking	✓	✓
Problem Solving Skill	✓	✓
Computational Thinking	✓	✓
Collaboration	✓	✓
Design Thinking	-	✓
Evaluation	✓	✓
Active Interaction both Human and Machine	✓	✓
Testing and Validation	-	✓
Redesigning and Troubleshooting	-	✓
Security and Privacy	✓	✓
Ethical Responsibility	✓	✓

3. COMPUTATIONAL THINKING (CT) DEFINITIONS

CT has no straightforward definition so far. Researchers of the field have defined CT in many ways to understanding and elaborate on its purpose. Voogt [11] argued that “we should not try

to give an ultimate definition of CT, but rather try to find similarities and relationships in the discussions about CT.”

Wing [12] in 2006 defined CT as an approach of designing systems, solving problems, and understanding human behaviour by drawing to the concepts fundamental to computer science.

Furber [13] conceptualized CT as a process of recognizing aspects of computation in the world that surrounds us and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes.

Yadav [14] pinned CT as a mental process for the abstraction of problems and the creation of solutions. Computational thinking (CT) is therefore broadly defined as the mental activity for abstracting problems and formulating solutions that can be automated.

Papert [15] first introduced the term computational thinking in a discussion of the potential impacts of computers on the way people think and learn. He suggested that interactions with technology may contribute to the development of new types of mental processes. Therefore, computational thinking is considered a cognitive process—not an application of knowledge or a technique [16] [17] [18]. In another research work, CT is defined as a process of utilizing computers to model ideas and develop programs, clearly connecting CT to programming skills in [19].

4. CODING AND COMPUTATIONAL THINKING FOR EARLY EDUCATION

Computational thinking in the computer science field has a core place and CT is not just programming and coding. While CT conceptualizes and brings all the science working behind different computer science tools and software. Therefore, CT provides a set of skills, where coding is one piece of the puzzle to complete the whole picture of computational thinking. We can develop CT skills in pupils by teaching them coding which is a form of writing to create solutions to certain problems. According to Wing, thinking as a computer scientist means more than being able to program a computer.

Coding/programming skills that is the ability to write a set of commands for a computer to solve a certain problem and computational thinking development have become a key need for early education. According to Gretter and Yadav [20] two approaches to 21st-century skills merge CT with UNESCO’s concept of Media and Information Literacy (MIL) in support of students’ 21st-century skills and citizenship. They explain how CT and MIL together can develop learners with the complementary skills to become active as well as reflective participants in their digital environment. They further argued that “the complementary relationship between computational thinking and media and information literacy can provide teachers with a comprehensive set of skills to allow students to both critically navigate and creatively produce digital content” (p.6). Therefore, writing programs is a means of developing new ways of thinking and creating digital content.

Computational thinking developing through coding skills enhances pupils’ skill of understanding a problem and then breaking problems into parts and finally creating a solution for that problem. Coding skills develop intelligent thinking while a coder tries to write a more efficient and simple code rather than lengthy and complex coding to solve the problem efficiently and create an efficient solution to a certain problem. However, computational thinking makes things understandable and helps in unveiling the things behind the curtain during problem-solving journey. For instance, Barr [21] concluded that in K-12 education, CT involves problem-solving skills and particular dispositions, such as confidence and persistence, when confronting problems.

A Policy report titled “Developing Computational Thinking in Compulsory Education” published by the European Union in 2016 presented detailed policy directions and adaptations for developing computational thinking in compulsory education. This report also presented opinions on different EU countries about CT. According to Norway, a distinctive element of CT that Norway puts forward is a focus on problem-solving processes and methods, and on creating solutions. The Czech Republic regarded CT as a competence, while a well-developed digital literacy is a precondition for thinking in a “computational” way. According to Hungary, by observing and understanding the algorithms of the functioning computer, an aptitude for computer usage can be developed. In Italy, CT is seen as key to digital and media literacy, an indispensable alphabet for student awareness of the digital environment and the capacity to proactively create and act in the digital world. According to Lithuania, developing CT can help to develop digital skills and collective intelligence. A similar view is expressed in Poland since the new CS curriculum addresses all students in compulsory education and, it is held, will also contribute to general digital literacy. In the Maltese primary cross-curriculum, CT is ingrained in the subject of Digital Literacy and ICT. Finally, Wales has included CT in their Digital Competence Framework (DCF) adopted in September 2016 [22].

5. ICT LITERACY INITIATIVES AT K- 12 LEVEL

Since the world is engulfed by the height of digitalization and technological progress, the education sector and governments around the world are more focused on developing digital citizenship than ever before. Countries around the globe initiating effective programs to amplify the efforts for digital skill development which is the burgeoning need of our times. It is noted that the European reference framework for the digital competence of citizens, DigComp in [22], includes programming as a core digital competence to develop at school levels. The recent update, DigComp 2.0 encompasses the main components of Information Literacy and parts of UNESCO’s Media and Information Literacy.

In this section, we shed light on some of the initiatives taken in different parts of the world in recent years to develop digital competencies at the K-12 level.

In August 2019, the United Nations International Children’s Emergency Fund published a report on digital literacy for children. The report presented a detailed discussion of different frameworks of digital literacy for children. The Report concluded that UNICEF must support the government and partners in embedding digital literacy within education and learning systems, throughout the life course, and for all children through multiple pathways [23].

In 2016, the Australian Council for Educational Research published a paper emphasizing on Digital and ICT literacy development for full participation in a knowledge economy and an information society. This research includes an appraisal of prospects for digital literacy development in [24].

European countries initiated many programs in the field of education to uplift digital learning and digital skill development. Some examples of such programs are the CoderDojo Foundation code activities; Digital Schools Award initiated by Ireland, Digital Schools Award; Ofcom; Future Learn and Childnet Digital Leaders Programs and Jisc by United Kingdom, MediaSmart Contest; Scratch Challenge; Initiation to Code at Primary School; Clubs of Code and Robotics by Portuguese, Connected Generations and Computer scientists without borders by Italy, and 5YeP4europe – Youth e-perspectives on migration. Finland included multiliteracies and ICT in its national core curriculum as an important skill to teach pupils and foster transversal competencies [25][26]. Above mentioned initiatives by different countries are just a few examples for understanding how different countries are developing digital competencies at the early education level.

The Korean government and its Ministry of Education (MoE) have made software education to be compulsory at K-12 schools by 2018. Korean Ministry of Education has already initiated pilot programs at 72 schools nationwide in 2015 [27]. Similarly different Asian countries like Singapore, China, and Japan steered their nations through different digital literacy programs to acquire digital competencies and computer literacy to enhance skills like computational thinking and problem-solving for better societal impact.

6. AI FOR KIDS: A CASE STUDY

In this section, we present a case study for Artificial learning for children from ages 9-15. The author participated in an online AI course for kids as an observer. The main objective of this study was to find answers to the following questions: What is the age group of the course participants? Why are they interested in learning coding? What are the occupations of their parents? What do they know about AI/CODING? What do they want to become in the future? What do they think about the course? (Language, convenience, usefulness, easy to understand) To find answers to these questions we prepared a Google form of 13 questions. Some questions are multiple choice questions, some are number scale questions and few of them needs answers in the form of small text. The total number of participants was n=9. As it was an online course, participants were participating from different countries like Pakistan, America, UAE, Finland, and Saudi Arabia.

6.1. Course Information

The coding course was online taught by using Zoom. The course was taught by two teachers in the English language. The course content was divided into theory and practical parts. There were ten hours of learning, one hour per day. The main tool applied to teach coding and AI concepts to young learners was mBlock (mBlock - One-Stop Coding Platform for Teaching and Learning) [28], as block coding is an easy way to start coding at the beginner's level. Kids learned about the basics of coding, the logic of coding, they learnt to create games in mblock using loops and conditional logic and learned to use computer vision in game making. At the end of the course, kids presented their final projects. Kids were given certificates at the completion of the course.

6.2. Observations about the course

The teachers were friendly, and they explained step by step the whole coding process. The kids were given small projects to build. For that purpose, first, they learn and practice in online sessions and then they create their own small projects and present them in the next class. We found a sense of achievement and satisfaction in young learners. We also found that kids faced problems but then they learned to solve the problems as well. It is noted that such courses play an important role in building interest in young learners for coding. Each kid was having their own computer or tablet with good internet connection availability. It was also observed during the sessions that learners were having great support from their parents as well. As, if sometimes some kid was facing any connection problem, the parents were there to help. This shows the interest of parents in building digital competencies in their kids.

6.3. Questionnaire Results

We collected data from the students of the course in the form of a google questionnaire. There were total of 9 responses that is the total number of participants were 9 (n=9). There were 13 questions. Questions and their results are discussed below.

Question 1: In which grade are you studying?

There were three students from 3rd grade, one from 4th grade, one student each from 5th, 6th, 7th and 8th grade and one student did not specify the grade, but grade range was 5-8. We can say that the student age ranges from 9-15 years. Responses for Q1 are shown below in figure 3.

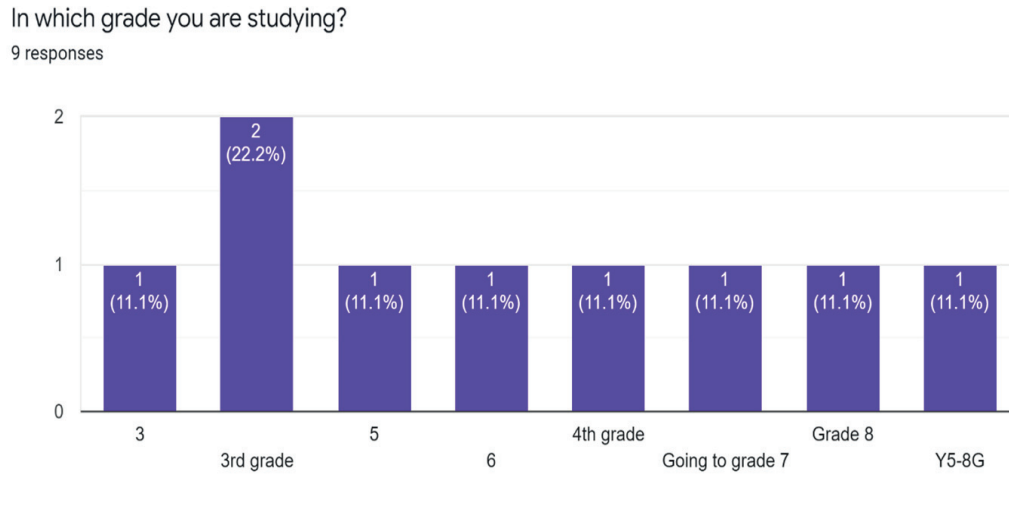


Figure 3. Grade level

Question 2: How old are you?

Responses shows that there were four students of 9 years old, two students of 10 years old, one of 11 years old and two students of 12 years old. So, the age of students ranges from 9-12 years. Responses for Q2 are shown below in figure 4.

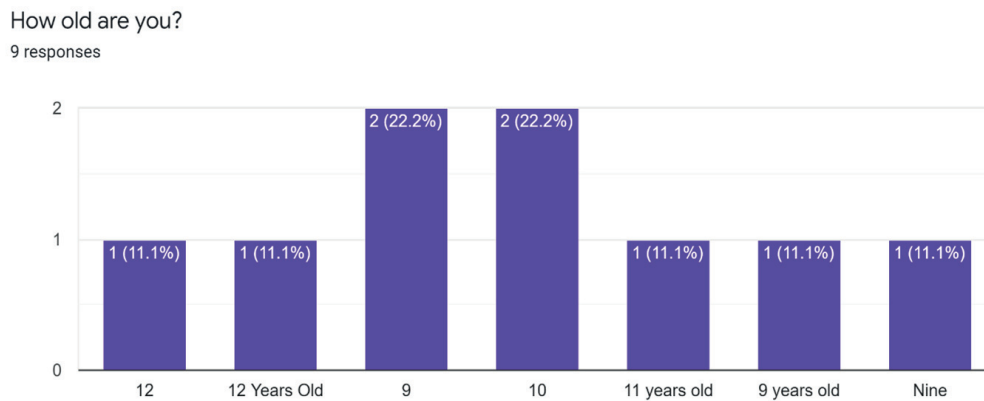


Figure 4. Age of the participants

Do you have any coding experience or have you studied coding earlier?
8 responses

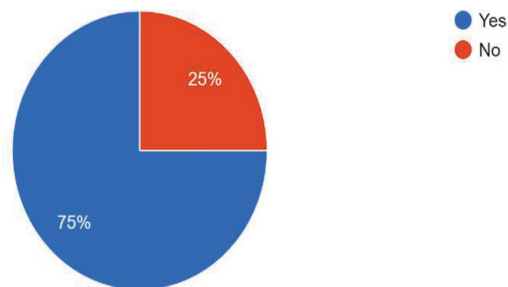


Figure 5. Coding experience

Question 3: Do you have any coding experience, or have you studied coding earlier?

There were 8 responses out of 9 participants. 75 percent of the responders say that they have earlier experience of coding, while 25 percent were learning coding first time in this course shown in figure 5.

Question 4: What is Artificial Intelligence (AI)?

We gave options to choose if its AI. The options were if self-driving cars, chat bots, robots, computer, google assistants are AI or not. Most of the kids understood well and opted for right options. Responses for the Q4 are shown in figure 6.

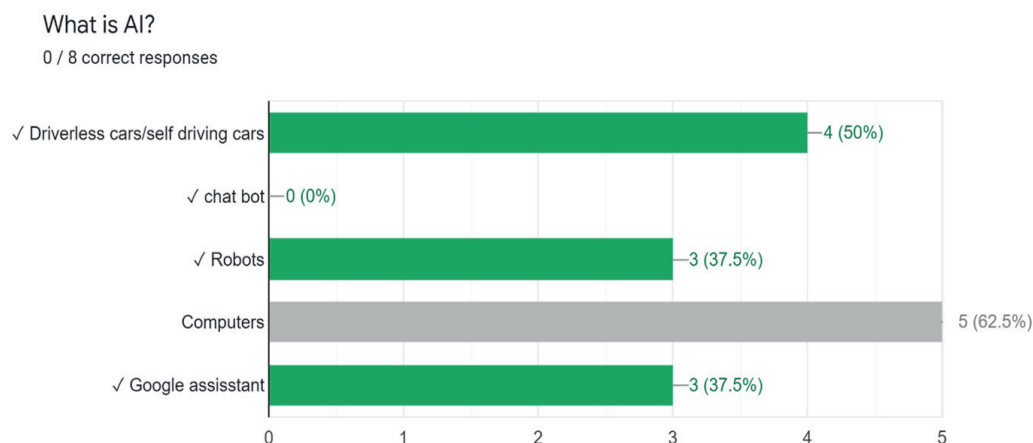


Figure 6. Knowledge about AI

Question 5: Coding is fun to learn.

We gave a number scale from 1-5. The answer can be selected in the form of numbers 1-5. 1 is the minimum value and 5 is the maximum value. There were eight responses. Out of which 2 respondents selected number 3 and 6 respondents selected number 5 from 1-5 scale. Therefore, 75 percent thinks that coding is fun with maximum number value. Responses to the Q5 is shown in figure 7.

AI course is easy to follow and understand
9 responses

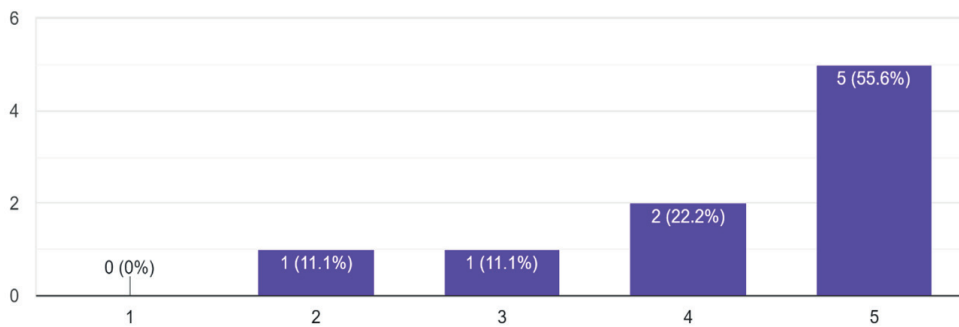


Figure 7. AI course is fun

Question 6: My parent's profession is:

The respondents specify their parent's profession in short text form. It is evident from the answers that participants of the course belonged to educated backgrounds. The professions specified by respondents were teaching, engineering, research, scientific job, army, consultancy, and office job. It is interesting to know that parents from different professions and fields are interested in developing digital and computational skills of their kids. It is also evident that parents understand the value of digital and computational literacy in this age of digitalisation.

Question 7: I have free access to (what kind of devices?):

We want to know here that what kind of devices and facilities kids have, to learn online coding course. We have given them options like computers, internet, tablets, mobile phones, all the mentioned facilities, none, and if the kid needs permission to use these devices. Results shows that 66 percent of the respondents have computers and mobile phones, 55.6 percent of them have tablets, 55.6 percent of respondents have an easy access to internet, 11.1 percent of them has every facility mentioned, and 11.1 percent has mentioned that his parent's permission is needed to use all facilities. We can see that overall, the participants of the course were having easy access to internet and internet devices to participate easily in the course. Responses for the Q7 are shown in the figure 8.

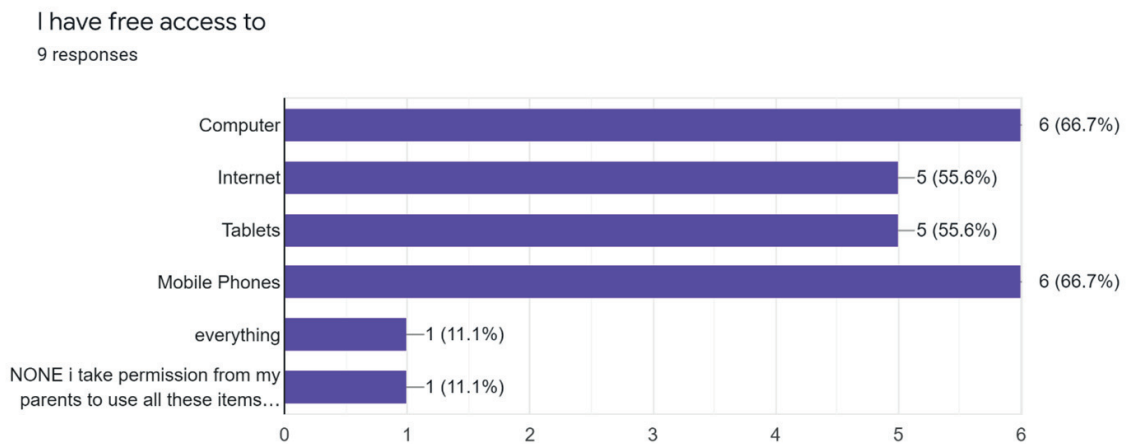


Figure 8. Available devices

Question 8: In the future I want to become (profession):

Respondents were asked to write answer in the form of a small text. We are providing here the answers of the eight responses we get from the participants. One of the participants did not give answer. The responses were as follows.

- I want to become an architect
- Soldier
- AI specialist and soldier
- Businessman of Ecommerce
- Artist or maybe an archaeologist
- Science teacher
- Software Engineer -Gymnast -Auto mobile engineer

We can observe that kids mentioned here a variety of occupations and it is evident from the choices of the professions that kids know well that what they would be requiring in future to pursue their careers.

Question 9: I am learning AI because I will use this knowledge in my future.

Responses were asked in the form of options (strongly disagree, disagree, neutral, agree, strongly agree).

We got 9 responses, out of which 55.6 percent strongly agree to the statement and 11.1 percent strongly disagree, 22.2 percent agree, and 11.1 percent remain neutral. One of the participants explained that he/she is learning because of the interest in coding and his/her friends and teachers taught coding to him/her. Responses to Q9 are shown in figure 9.

I am learning AI because I will use this knowledge in my future.

9 responses

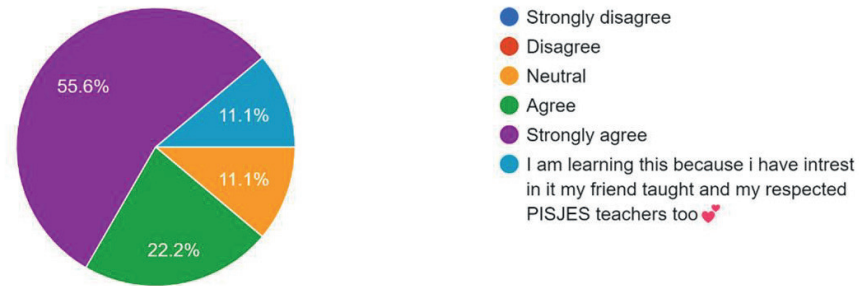


Figure 9. Knowledge for future

Question 10: I want to learn coding and programming in future too

44.4 percent of the respondents agreed while 33.3 percent strongly agreed that they want to learn coding and programming in future. While 22.2 percent remain neutral and did not clear yet about their future choice. This clearly shows that most of the participants have developed interest in learning coding as shown in figure 10.

I want to learn coding and programming in future too

9 responses

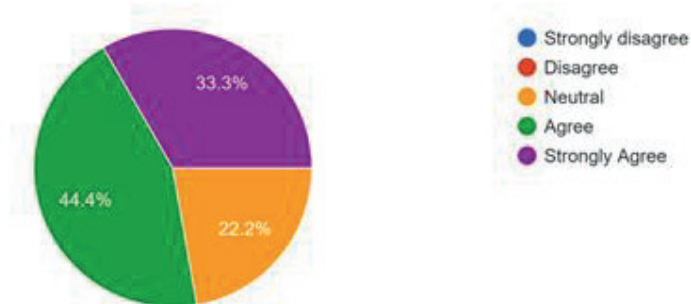


Figure 10. Learning coding in

Question 11: What was the most interesting thing to do in the course?

We get different answers for this question as participants of the course did many different coding activities and they mention here what they liked the most. Here are the responses of the respondents as shown in the figure 11. They mentioned that they liked to do the coding, the mask tests, the ping pong game, the video sensing extensions, the pop the

balloon.

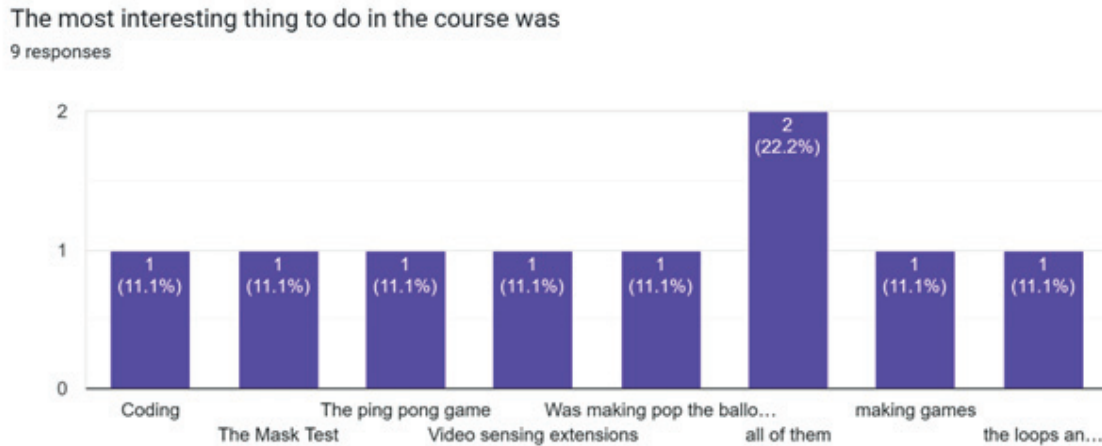


Figure 11. The most interesting part of the course

Question 12: I participated in the AI summer course by using the device:

Results in the figure 12 shows that 77.8 percent of the course participants used their own computer/laptop, and the remaining used their iPad or tablets.

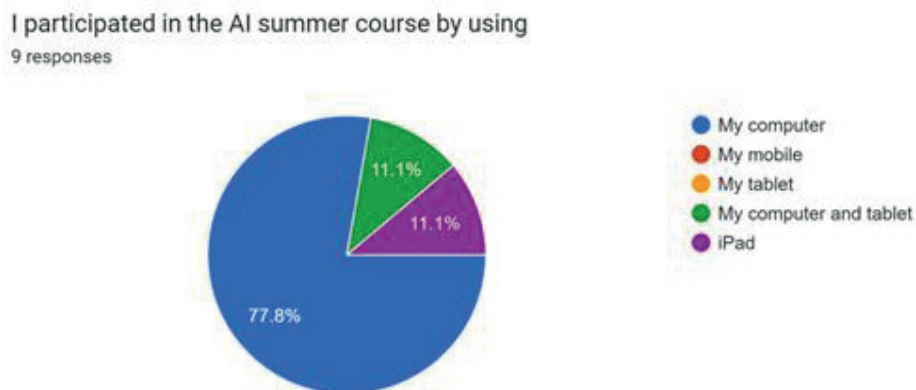


Figure 12. Devices used in the course

Question 13: What kinds of skills do you think you have developed during this course?

Response to this question was interesting and of great importance for us. As we argue that 21st century skill development is a challenge for today's education system. We should integrate skill development within the subjects taught. Programming and coding lessons are a good way to inculcate 21st century skills in future work force. As we have seen that participant of the coding course mention here that they developed different skills such as idea creation, creative thinking skills, designing skills, coding skills, digital/ICT skills, communication skills. Results are shown in figure 13.

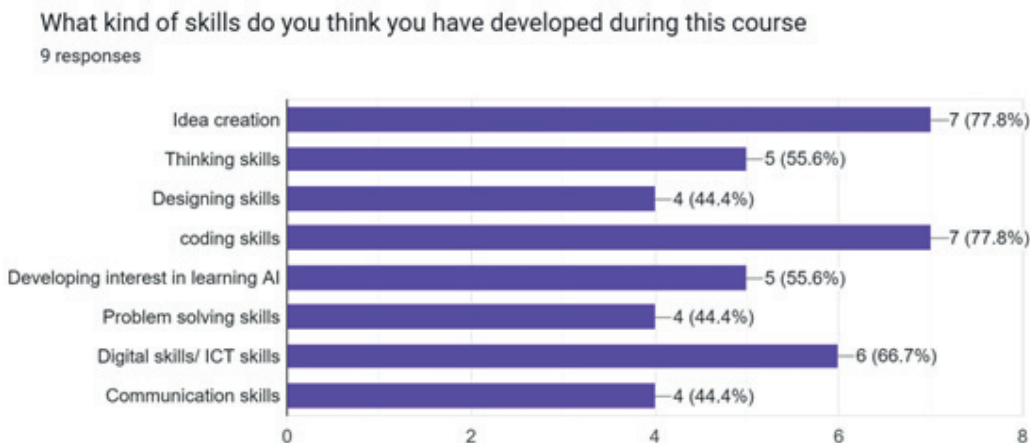


Figure 13. Skills developed during the course

7. RECOMMENDATIONS

In this section, we make some recommendations about how we can develop ICT skills by taking some initiatives at the K-12 level. As we discussed earlier today's educational system needs holistic approaches to adapt ICT literacy and skill development. We need to integrate ICT education in regular school studies as a regular subject for all pupils to develop CT skills and ICT proficiency.

Integrated ICT curriculum: There is a dire need to develop and integrate ICT curriculum in regular school studies. It would be even more beneficial if we take ICT and CT skill development as a subject in the regular school study curriculum. The use of technology in the form of laptops, media projectors, touchscreen writing boards, tablets, and mobile phones is already common in normal school classes. But our focus should not be to teach how to use technology but to teach how to develop and create technology, how to solve problems and how to develop solutions. Therefore, the next step in K-12 school setup should be to teach kids to think critically and inculcate coding skills in pupils. We can integrate the ICT curriculum in many ways. For example, in maths class, kids can learn to solve mathematical problems (addition, subtraction, division) by writing small programs. Kids of our age are more interested in online gaming. We can develop a game development course for small school classes where students can develop their own games. For theoretical awareness of ICT, schools can arrange classes for kids to know how a computer works? How a robot talk? How can we do artwork on a computer? ICT curriculum development and integration not only help develop a future skilled workforce but also help parents. As parents pay for expensive coding classes. Most parents cannot afford and therefore, many kids are deprived of ICT learning skills just because they cannot afford it. Therefore, schools must offer and integrate ICT and CT skill development in their regular school studies.

Availability of required tools and devices: Schools must make sure to provide computers and internet to the students. In Europe and other developed parts of the world students in schools have easy access to computers and the internet. However, developing countries are struggling to provide quality education to their students. These developing countries even cannot provide quality education to their pupils if they take computers and the internet out of their education system. Therefore, computers, internet, free learning applications, and software are important requirements for supporting ICT and CT skill development at schools.

Fun events: School and home plays an important role in building a child's educational path. It is also evident that learning in a playful manner is more effective (reference needed) than learning in conventional ways. To develop a child's interest and awareness in ICT learning and coding schools can organize events like coding parks, code day, code fairs, family day, etc. Such events bring liveliness to learning and more awareness to the parents and kids. Local universities can play a role in that regard. University students of IT background can volunteer to help schools in setting up such events.

Teacher training: Teacher training is the most important constituent of ICT and CT skill development path in schools. Only well-trained teachers can deliver the task. Therefore, there should be training offered to elementary school teachers to teach coding and ICT skills at schools. Sometimes technology fear hinders the performance of teachers. So, teachers should be provided with help and assistance in schools to overcome such difficulties. Local universities can play their role very actively here. University students of IT background can help schoolteachers in teaching things like coding and assist teachers at school. In return, they can get credits from their universities to complete their degrees. Government, city administrations, councils, and universities, Schools, must arrange ICT training courses and develop pedagogy for supporting ICT and CT skill development at K-12 schools.

Assessment: In any learning activity assessment and feedback is an important part of that learning. Most of the strategies assess ICT and CT skills by analyzing the artifacts (e.g., games, models, designs) that students develop as indications of their ICT capabilities. Students can also be assessed by giving them assignments to achieve different objectives by modifying their code or in other words making more complicated or sophisticated models or games. Assigning to simplify a program with efficient results is another way to assess the capability of the learner. Debugging and troubleshooting an existing program could also be an effective way to assess students' fluency in computer coding and problem-solving. The use of multiple-choice the assessments and attendant rubrics to assess the CT skills of middle school students is also mentioned in the literature. A study [20] summarizes what is known about assessment of student learning in high school Computer Science (CS) in the USA. Similarly, Simon Peyton Jones reports in the expert interviews that the Computing at School initiative has started a project called Quantum on assessing computing in primary and secondary schools [29].

8. DISCUSSION

Our research work in this article has focused on an important issue of developing ICT and computational literacy in young school kids. This challenge will have a profound impact on our future workforce if this challenge would not be handled at this point. The Future industrial revolution and digitization demand a fully digitally literate work force which can not only handle the digitized environment in the pretext of machine-machine and machine-human interaction but can also solve problems and create innovative solutions as well. In this research article, we presented a case study of an online coding class. We collected data in terms of student's codes, designs, and games they made. We also observed the class communication, the manner the classes were conducted, and the way students participated. We also collected student's responses about the course and their feedback. From the data presented above we have noticed many important things. We discuss the important takeaways here:

Availability of the courses: So far, we have observed a trend in many places that coding is taken as an extra hobby lesson organized by private organizations and institutes. It is observed that such coding courses are available online and on campus but there is always a cost related to the courses. Therefore, there is a need for free courses available to everyone. If schools take coding and computational skill development as a part of the curriculum in addition to mathematics, then it would be accessible and available for everyone.

Accessibility: A certain cost attached to a particular course hinders its accessibility to many kids who simply cannot afford such courses. We argue for accessible skill development for everyone. It would be worth providing such skills to kids free of cost. It can be done by adding coding and computational skill development in the regular school curriculum.

Language and communication: As, in the coding course presented here, the language of instruction is English. Therefore, language of instruction and ease of communication play a vital role in the learning process. All the participants of the course and the teachers speak English language as a language of instruction and the level of communication was well established. Course teachers communicated with participants online, through Zoom, by email, and in groups by chatting. **Interaction:** A strong interactive environment is needed in coding classes. Interaction is a challenge when the class is online. We observed that during online sessions students require more motivation and interaction as compared to face-to-face teaching. Plenty of interactive tools such as jam board [30], kahoot [31], and mentimeter [32] are available for interactive learning.

Tasks and assessment: In any learning activity assessment and feedback is an important part of that learning. ICT and CT skills can be assessed by the artifacts (e.g., games, models, designs) that students develop, which portray student's ICT capabilities. Students can also be assessed by giving them assignments to achieve different objectives by modifying their code or in other words making more complicated or sophisticated models or games. In the studied case, the instructor of the course gave tasks of developing small games to his pupils by using the m-block. Many interesting games were developed by the participants.

Family background of pupils: It is worth to discussing here that we observed during our study that parent's background also affects kid's choice of future profession and eagerness to seek more knowledge. Kids with educated backgrounds show more interest in learning and future career path development.

9. CONCLUSIONS

In this article, we emphasized on coding and computational skill development. We argued that computational skill development is an important skill to foster in future workforce. Along with computational skill development, coding skills are equally important. Schools should adopt coding as a regular subject so that it can be available and accessible to all students. Future work requirements demand a skilled workforce with digital literacy to solve problems and create innovative solutions. We discussed the initiatives taken by different countries around the world to enhance computational thinking and digital literacy among young learners. In this research, we showcased that how an online coding course developed coding and computational thinking skills in the kids aged 9-17. Therefore, this is high time to create such kind of curriculum which focuses on the development of digital literacy skills including coding and computational thinking. We encourage and recommend educators and managers of education to take holistic initiatives to promote ICT skill development at k-12 level to prepare skilled future workforce.

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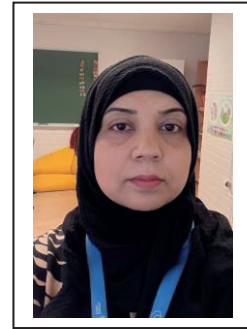
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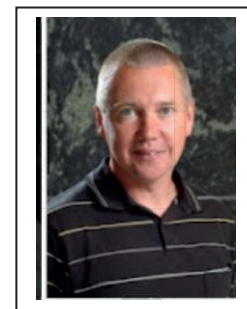
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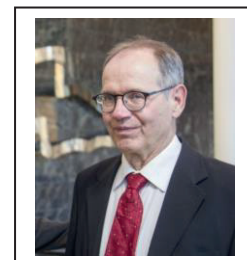


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VI

PROJECT BASED LEARNING AND INTEGRATED STEM-IT EDUCATION FOR 21ST-CENTURY SKILL DEVELOPMENT

by

Khaula Zeeshan, Timo Hämäläinen, and Pekka Neittaanmäki 2024

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Project-Based Learning and Integrated STEM-IT Education for 21ST-Century Skill Development

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Abstract—We are living in an era of digital transformation, where newfangled technologies are continuously changing the ways of life around us. The next generation industrial revolution is driven by the disruptive technologies such as Artificial Intelligence, Internet of Things, 3D printing, AR, VR, Blockchain, Big data etc. Therefore, the challenges posed by the next generation industry driven by these disruptive technologies are big. One of the greater challenges is to prepare workforce for the future digital economies encompasses Human-Machine and Machine-Machine working environments, where most of the jobs will be taken by the machines and new kind of skill-based jobs will be created. In that scenario, there is a great responsibility posed on the shoulders of today's educational setups to adapt holistic approaches to develop 21STCentury skills in pupils to get them ready for future. This research article sheds light on the challenges posed by digital industrial revolution and the importance of STEM and digital literacy at basic education level. The article also showcases that how educational technologies supports the Project-Based Learning approaches and thus deliver the purpose of skill development in young learners. Finally, the article provides a framework for Project-Based Integrated STEM and ICT education Learning to inculcate required skills in young learners at K-12 educational levels.

Index Terms—Project based learning, STEM education, ICT Learning, 21st Century skill development, fFourth Industrial Revolution

I. INTRODUCTION

The Digital Economy (DE) is an economy which involves digital technologies and electronic communication for its economic and commercial activities [1]. The component of the Digital Economy includes Internet, digital data, electronic devices, disruptive technologies such as AI, E-Commerce, Digital platforms, and social media. Whereas, the characteristics of DE are internet availability and connectivity,

personalization, mobility, automation, networking, mobility, and ubiquity as shown in Table 1.

We argue here that in future the DE will be more adhered to automation. As a result, the traditional jobs will be taken away by machines and new jobs with new skill requirements will be created. As, today we are experiencing already this phenomenon. About 1.7 million manufacturing jobs have already been taken up by robots since 2000, including 400,000 in Europe, 260,000 in the US, and 550,000 in China [2]. We can say skill-based jobs will be created. Therefore, to address this challenge, a skillful human resource would be needed with minds to think and create.

The next generation industrial revolution requires skilled workforce filling the jobs related to cybersecurity, digital content creation, product management, digital marketing and E-Commerce, artificial intelligence and IoT related, Fintech and digital Finance, remote work solutions and digital tools, cloud computing, smart city solution creation and infrastructure, and educational technology. All such above mentioned fields demand knowledge-based skills [3]. Therefore, in this research article, we propose that Integrated STEM and ICT education based on project-based learning is the way to develop such skills in young learner.

This article is divided into four sections, first section presents the introduction. The second section discusses the challenges posed by the digital industrial revolution. Third section explains the PBL approach and integrated STEM and ICT learning for young learners at K-12 level. Fourth section proposes the framework for PBL based integrated STEM-IT learning. Fifth section concludes the paper and provide the future research directions.

TABLE I. COMPONENTS AND CHARACTERISTICS OF DE

Components of DE	Characteristics of DE
Internet	Connectivity / Availability
Electric Devices	Mobility
Social media	Personalization
Disruptive Technologies	Networking
Digital Data	Automation
Digital Platforms	Ubiquity

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I. 21ST-CENTURY SKILL DEVELOPMENT

A. Fourth Industry Revolution and its Challenges

The fourth industrial revolution is a term coined by Klaus Schwab, founder and executive chairman of the World Economic Forum, explains a world where individuals move between digital domains and offline reality with the use of connected technology to enable and manage their lives [4]. The first industrial revolution brought a change in the world from an agricultural and handicraft economy to one dominated by industry and machine manufacturing. Second Industrial revolution was triggered by oil and electricity. In the third industrial revolution, information technology was used to automate production. Now we are experiencing the fourth industrial revolution which is driven by the disruptive technologies, digitalization and sustainability.

The automation, and AI has already transformed our world drastically. New kind of jobs such as application development, digital media and marketing, cloud computing, smart city solution development and infrastructure, blockchain and bitcoin, gamification and AR/VR platform development, and many such jobs. The traditional jobs will be taken away by machines and new jobs with new skill requirement will be created. The next generation workforce will face huge challenge of new skill requirements if this problem is not addressed now.

B. Skills for 4IR

The Skill development for 21st-century is taken up automation, priority agenda by worlds prestigious organizations such as, organization of economic cooperation and development (OECD), Frameworks for 21st century skills, United Nations Educational, Scientific and Cultural Organization (UNESCO), and European Union (EU), and United Nations Educational [5] [6].and AI has already transformed our world drastically. These organizations have reported on the need of skill development and adoption of digital literacy and knowledge construction [7]. It is also noted that 21st century skill development requires competent and well-prepared teachers to deliver the task, therefore teacher training must be the part of the whole process.

21st-century Skills such as computational thinking, critical thinking, digital literacy, analyzing thinking, problem-solving skills, design thinking, idea creation and solution development, communication, collaboration and testing and validating are some of the important skills as shown in Fig. 1. Such skills are required by the digitally transformed work environment, where H-M, and M-M interaction will be of routine observation [8].

II. STEM AND ICT LEARNING FOR 21ST-CENTURY SKILL DEVELOPMENT

A. Integrated STEM-IT and Skill Development

Integrated STEM-IT is teaching Science, technology, engineering and mathematics education, and ICT in one lesson form with project-based learning approach. In such an integrated way we can develop skills in young learners for real life problems. This form of interdisciplinary education with PBL approach is called as Integrated STEM-IT. In this era of digital transformation, scientific knowledge creation and digital literacy development is need of the time. We argue here that mathematical education must include coding and programming as basic subject to teach [9].

Multidisciplinary Integrated STEM-IT approach with PBL methods, focuses on construction of scientific knowledge from different disciplines. In STEM-IT class, learners can work on a problem to solve and create a solution that requires them to design a solution by thinking all the technical, scientific, ethical and environmental aspects. Such a kind of learning approach facilitates learners to foster creative, analytical, critical thinking, and ethical skills that are essential for addressing the challenges and embracing the opportunities in continuously transforming world [10].

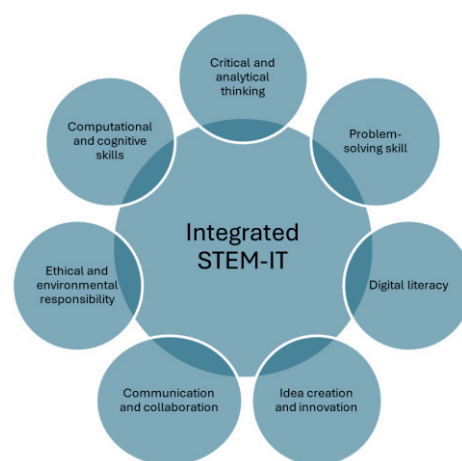


Figure1. STEM-IT Skills

B. Project- Based Learning

PBL is student centric inquiry-based learning, were students start with a question or problem, often an open-ended or complex issue, that requires critical thinking and research to solve. PBL is focused on student's choice and voice, real world relevance, and collaboration and

interaction. Students feel freedom to think and create with critical and analytical thinking [11]. With integrated STEM-IT approach shown in Fig. 3, based on Scenario-based learning (SBL) / (PBL), learners can immerse themselves in realistic scenarios where they apply their knowledge to solve complex problems involving [12].

It is evident that educational technologies support PBL. There is research done [13] shows that how Gen AI can help in STEM learning class. Students can use research and information tools such as web browsers, search engines. They can collaborate by using collaborative tools, interact with multimedia tools, can create innovative designs, presentations, and videos by using interactive design tools, can present and communicate their work with communication and presentation tools. Learners can do self-assessments by using different digital assessment and feedback tools. They can connect the world through social media platforms and share their results and get feedback and comments from real life audience.

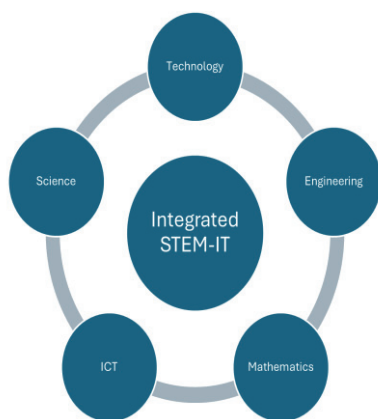


Figure. 2 Integrated STEM-IT Learning

III. FRAMEWORK FOR STEM AND ICT LEARNING

A. PBL-Based Integrated STEM-IT Framework

We propose here a framework for integrated STEM and ICT education called STEM-IT framework as shown in figure Fig. 4. The STEM-IT framework is based on the integrated approach as the STEM and ICT subjects include as the topics and after crafting the problem, the learners need to develop a project to solve the problem and create the solution. During this process, the learners need to explore all the aspects of STEM and ICT, they collect the scientific knowledge, they think and create the solution, they analyze, they test and validate, they use the digital tools and hence practice the digital literacy process [14]. Therefore, this whole process does not involve one or two subjects rather it involves the topics from different

disciplines in integrated form. we see here that how we can develop a certain skill set in young learners by applying PBL approach in integrating STEM and ICT lesson.

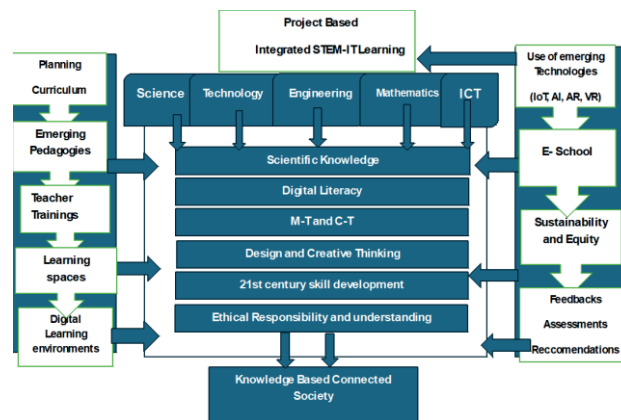


Figure. 3 STEM-IT Framework

The features of the framework are as follows:

- **Interdisciplinary Curriculum development:** An **interdisciplinary approach** for curriculum development is needed to teach science, technology, engineering, mathematics, and ICT subjects in such a way that the pupils gain knowledge and at the same time develop related skills. Therefore, there is a dire need of developing an interdisciplinary curriculum which focuses the skill development and knowledge creation, which would focus all these subjects, and the aim would be to develop the skills required for progressing in life and work situations. For example, in mathematic class teacher can help learners in developing computational and analytical thinking skills by giving them small coding problems while teaching them basic mathematics. They don't need to learn how to write code at this point, but they can think and write simple equations to solve problems and develop logical and reasoning thinking [15] [16].
- **Learning Environments:** Fast paced digital transformation and advanced technologies are the enabling key drivers of new learning spaces. Learning spaces can be brick and wall space, online or hybrid. Schools can be e-schools/distance learning schools or physical schools, classroom can be online, offline, in premises, in virtual or real environment. We argue that availability and quality of education world be equal for all. We can benefit from the digital learning tools and applications to provide such an education which is not dependent on bricks and walls rather it should be available online in the form of e-schools. During the time of COVID-19, the world has experienced that how online learning benefitted the society. We see the success of different online learning one good example is

MOOC [17]. Additionally, gaming-based learning environments like Ekapeli [18][19], successfully serving the purpose of teaching, learning and skill development. Therefore, we explain learning environments/spaces as any form from physical to online, hybrid mode and equipped with digital tools and applications powered by internet and enabling technologies.

- **Internet Connectivity and availability of electronic devices:** A connected environment with the facilitation of fast and free internet connection is the backbone of Integrated STEM and ICT framework. The availability of free internet and electronic devices to the learners enable them to focus on their learning without any stress and pressures. We must say that in a highly connected environment of learning where the digital applications and platforms are dependent on internet, a free and stable internet and electronic devices like laptops/tablets is crucial to the STEM-IT class.
- **Skill Development:** The main purpose of STEM-IT education system is to develop 21st-century skill such as digital literacy, mathematical and computational thinking, analytical thinking scientific knowledge, design and creative thinking, ethical responsibility and understanding etc. [20]. These skills are crucial to develop in young learners as they are growing in this digital age and will work in digitally transformed and automated environments with machines. STEM education along with ICT literacy integrates different disciplines to instill 21st-century skills especially 4C's of STEM education (creativity, critical thinking, collaboration and communication). This digitally transforming world needs skilled workforce and STEM [21] and ICT education is a solid solution to this problem [22].
- **New Pedagogical Approaches:** With advancement of educational technology, the approaches to teach and facilitate learning has also transformed and continuously transforming. The emerging pedagogies are based on different constructs such as textual, visual, audio, gaming, reading and writing, and immersive experiences using AR/VR. The emerging approaches to guide and facilitate learners must be applied for skill development and knowledge to meet the needs of digitally transformed and automated society in which H-M, and M-M interaction would be the key element. We argue here that Project-based learning with student centric approach with the twinning of other approaches can serve the purpose well [23]. Additionally, design-based learning, and scientific method-based learning are the approaches which develop problem-solving thinking, design thinking and creativity, and innovation thinking in young learners at K-12 level [24].
- **Educational Technologies:** Educational Technologies based on disruptive technologies such as AI, IoT, AR, VR, and robotics. Digital tools and applications based on these technologies such as collaborative and interactive learning platforms, gamified learning platforms, virtual classrooms, educational robotics, e-learning platforms, online courses, and digital tools for assessments and feedback, are driving the educational set ups of this digitally transformed world[25].
- **Teacher training:** Teacher training is crucial for adapting integrated STEM and ICT learning as in most cases teachers failed to understand the meaning of integrated approach. Therefore, a special training for science and ICT teachers is required to train them as the facilitators of integrated STEM and ICT learning in a student centric way. Content knowledge, quality pedagogy and self-efficacy are the important skills for STEM teachers to develop [26].
- **Sustainability and Equity:** There should be sustainability and equity factor. Any solution which is sustainable and available to all is going to deliver the purpose. Therefore, STEM-IT relies on sustainability and equity [27]. Quality education for all is the key to success in life and sustainable quality education for all opens the ways for success and sustainable development. Therefore, it is necessary to provide equal and quality education to all, keeping in mind millions of children in developing countries out of school or incapable to afford education due to poverty. Therefore, we should provide such solutions which are easily available to all and of same quality for sustainable development according to UN's sustainable development goal 4, which promotes the inclusive and equitable quality education and promote lifelong learning opportunities for all [28].
- **Bridging the gap:** Millions of children are unable to join schools and learn. We can bridge the gap by taking advantage of distance learning and setting up E-school, so the governments with minimum resources can also provide good quality education to the children [29] as required by the Sustainable development goals of United Nations [30]. Bridging the gap is crucial, otherwise we will be having one part of the world with all the facilities and skilled education to prosper and progress, while the rest of the world will be struggling for basic education. This situation of course will lead to no sustainability.
- **Knowledge based Connected Society: Project-based Integrated STEM-IT education** is focused on skilled based knowledge oriented connected society. A society which is knowledgeable, skilled, sustainable, inclusive and adheres to the ethical responsibility. A society, where humans and machines work together with humans in the central role. Digital economies based on

knowledge based, skilled and connected society would be sustainable and prosperous [31].

I. CONCLUSION

We conclude that STEM and ICT education at early education level is crucial for the development of next generation skilled workforce. We argued that integrated form of STEM and ICT learning is effective and helps in developing 21st- Century skills in pupils. Project-Based learning approach is well suited approach for integrated STEM and ICT learning. We discussed in this article that emerging technologies support PBL approach in many good ways. For bridging the gap between developed and developing countries, we can take advantage of online learning and E-school concept. Finally, we proposed a framework for Integrated STEM and ICT learning for K-12 educational settings to develop a skilled and knowledge based connected society.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The author KZ contributed as the first author of the article. KZ conducted the research and wrote the paper. TH and PN supervised the research work, provided their valuable feedback, and arranged funding to support the work. All authors had approved the final version.

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