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Article

Exploring the enablers of IOT in education: A qualitative analysis of expert tweets

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Abstract: The technology known as Internet of Things, or IoT, has started to permeate many facets of our lives and offers a plethora of options and empowerment, expanding the potentials of integrating it in education. Considering how new IoT is and how it may affect education, it is now essential to investigate its potential in order to choose where to begin using it in the classroom. Examining the possible applications of IoT in education may be strongly aided by the knowledge and perspectives of professionals and experts. As a result, the present research concentrated on looking at and evaluating the viewpoints that relevant experts shared on platform (X) via a variety of tweets. The present study takes a qualitative approach, analyzing a collection of expert tweets on IoT in education on platform X using qualitative content analysis. The primary themes of the study findings, the software-based and material-based enablers of IoT in education, indicate the key potentials of IoT in education. These consist of data, sensors, interactive devices, e-learning tools, network accessibility and communications, integrating developing technologies, and system administration. The enormous individual enablers of IoT in education also include sustainability, professional growth, planning, preparing the next generation, and upholding the safety of the learning environment. The study suggested that in order to handle the IoT, classrooms and the educational environment needed to be restructured. Additionally, human resources needed to be developed in order to keep up with the educational environment's progress.

Keywords: Internet of Things (IoT); enablers; qualitative analysis of tweets

1. Introduction

The IoT is a very prevalent technology in our everyday life (Hwang and Chen, 2017). The phrase IoT was first introduced by Kevin Ashton in 1999 at the Massachusetts Institute of Technology. Ashton used the RFID radio frequency tracking technology to develop this concept (Ashton, 2009). IoT can be described as an interface that facilitates the connection between the physical and digital domains. It does this by using a range of communication and detecting devices, enabling communication between the digital and actual worlds (Hussain and Di Sia, 2022). IoT refers to the connectivity of many products and gadgets used in our everyday lives, allowing them to be controlled and managed via a smartphone application, computer, or other web-connected control devices (Al-Taai et al., 2023).

The IoT has emerged as a significant technological advancement, attracting considerable attention from researchers, experts, and academics alike, who are keen on investigating its potential and diverse applications across various domains (Alhasan et al., 2023). Anticipating the advancement of IoT technology, the price of sensing technology will decline, and the enhancement of networking and communications

technologies will amplify the potential for its versatility and application implementation in the future (Ramlowat and Pattanayak, 2019). Experts consider the use of IoT in education as a crucial area for utilizing the potential of these innovative technologies. This helps shift the learning process from a traditional model of knowledge transfer to a model that emphasizes interaction, cooperation, and engaged participation (Kiryakova et al., 2017). This technology enhances classroom learning efficiency by enabling students to engage with tangible devices, delivering tailored educational content based on their interaction, and collecting and analyzing data through sensors and IoT devices (Kim, 2018). IoT may be used by merging its functionalities with complementary technologies such as artificial intelligence, cloud computing, data analysis, and other related technologies. As an example, the instructor has the ability to remotely issue instructions to either the textbook or the assistant robot inside the classroom. This assists the student in a particular task and aids in the organization of the educational setting (Al-Taai et al., 2023; Hwang and Chen, 2017). One can also take advantage of the wide range of devices supported by IoT technology, including interactive boards, highlighters, digital scanners, air conditioning and lighting sensors, and smart vision cameras (Bucea-Manea-Țoniș et al., 2022; Mershad and Wakim, 2018).

In the context of scholarly investigations pertaining to IoT within the educational domain, a notable study conducted by Ramlowat and Pattanayak (2019) delved into the significance of IoT technology in the field of education, emphasizing its potential to enhance the efficacy of pedagogical practices and the acquisition of knowledge. In a study conducted by Kiryakova et al. (2017), it was determined that IoT has the potential to enhance the creation of interactive and efficient teaching and learning environments. These environments are characterized by dynamic activities that appeal to the individual needs of learners, thereby offering a personalized learning experience for all students. However, numerous inquiries persist concerning the manner and route in which IoT will precipitate alterations in educational practices, activities, processes, and environments. Numerous scholarly investigations have also put forth conceptual frameworks that outline the potential transformation of educational institutions through the utilization of IoT services. These frameworks aim to enhance the educational process and foster intelligent, interactive, and sustainable educational environments (Curralo et al., 2022; Kiryakova et al., 2017; Sneesl et al., 2022). In recent years, several studies have explored the integration of IoT technology with various advancements and emerging trends in the field of education. Particularly, these studies have investigated the integration of IoT with big data analysis, learning management systems, STEM education, gamification, and other related areas. The works of Chen et al. (2020), Jin et al. (2022), Li and Wang (2023), Mershad and Wakim (2018), and Pappas et al. (2022) have contributed significantly to this body of research.

The X Platform is a fertile environment for the convergence of ideas related to developments in various fields, including IoT. Digging into this data and analysing it in depth can lead to scientific ideas that can be built upon. This is related to the research team's discovery that there is a huge amount of information about the IoT on the X platform. This information comes in the form of tweets from figures with scientific and practical weight, which means that their opinions can be listened to and analysed

to come up with ideas that can lead to tangible implications regarding the use of IoT in education.

Accordingly, a qualitative approach was followed using a content analysis approach in order to conduct in-depth analyses of the experts' tweets and thereby build common concepts that can be used to improve IoT in education. The qualitative approach helps to carefully analyse the tweets and exclude unnecessary content and focus on essential content that can lead to new knowledge. Qualitative analysis helps to highlight key ideas by identifying commonalities between the tweets of carefully selected experts in order to maximise the reliability of the analysed data.

IoT technology has emerged as a novel and promising technology that educational institutions are increasingly adopting in their educational processes (Al-Taai et al., 2023; Alhasan et al., 2023; Kadhim et al., 2023). The present study is situated within the broader context of the attempt to explore the potential and capacities associated with the utilization of IoT in the field of education. The present study is grounded in the recognition of a research void pertaining to the limited number of investigations that have endeavored to ascertain the potential advantages and obstacles associated with the utilization of IoT within the realm of education. Consequently, there exists a pressing and indispensable requirement to broaden the scope of research endeavors that specifically focus on the application of IoT in educational settings (Al-Emran et al., 2020).

The significance of IoT in the field of education cannot be overstated. However, it is worth noting that the current situation in Saudi Arabia falls short of fully embracing IoT-based initiatives that can effectively enhance educational opportunities. The limited number of research studies investigating the potential applications of IoT in the field of education may account for this phenomenon. The present discourse highlights the imperative nature of conducting comprehensive studies that elucidate the practical implementation of IoT in educational institutions within the specific context of Saudi Arabia. Given the limited availability of experts specializing in the field of IoT, the researcher sought to engage a diverse group of distinguished individuals with varying cultural backgrounds. This selection was not confined solely to those with a scientific research background, but also included executives and experts from various sectors associated with IoT. To facilitate this process, the researcher utilized the X platform. The convergence of experts in the field of IoT within a conducive environment is crucial for the generation and implementation of innovative ideas. By analyzing the tweets of these experts, which serve as a means to define the capabilities of IoT, a fertile ground can be established for the development of novel approaches in leveraging IoT technologies.

This paper aims to explore the potential of such an environment, where experts can collaborate and initiate a set of ideas that are grounded in the principles of IoT, thereby fostering innovative thinking and application of IoT in various domains. In consideration of the aforementioned, it is imperative to note that the selection of experts for the purpose of advancing the utilization of the IoT within educational institutions in the Kingdom of Saudi Arabia will be conducted based on stringent criteria. These criteria have been designed to ensure that only highly competent individuals are chosen, thereby maximizing the potential for accessing capabilities that can effectively enhance the opportunities associated with IoT implementation in the

aforementioned context. The utilization of novel technologies necessitates a comprehensive examination of various studies that elucidate the potentialities, advantages, and limitations that may impact the implementation of said technology.

Henceforth, the present investigation has undertaken the approach of commencing with a qualitative inquiry, the results of which can be predicated upon the identification and elucidation of the underlying mechanisms pertaining to the utilization of IoT technology within the realm of education. The present study conducted an extensive review of various research databases pertaining to the IoT. It was observed that there exists a dearth of studies that comprehensively define the capabilities of the IoT. Furthermore, a notable absence was identified in terms of research that specifically focuses on qualitative analysis of tweets, which could potentially offer an integrated framework elucidating the capabilities and challenges associated with the IoT. Henceforth, the ongoing investigation has been centered around the examination of the substance contained within these tweets, originating from esteemed authorities, with the objective of formulating a perspective that contextualizes the utilization of IoT within the realm of education.

In light of the aforementioned information, the researcher tries to investigate the possibilities of integrating IoT into education. This exploration is conducted by consulting experts and addressing the following primary research question:

- How can the educational enablers of IoT be revealed via tweets from experts?

The sub-questions that arise are as follows:

- What is the expert perspective on the physical and software enablers of IoT in education?
- What is the expert perspective on the Human enablers of IoT in education?

2. Literature review

According to Khan et al. (2012), the fundamental concept behind IoT is to facilitate independent and secure communication as well as data interchange among physical devices and software applications. The various modes of communication encompass a range of interactions between entities. These interactions include human-to-human (H to H), human-to-things (H to T), things-to-things (T to T), and machine-to-machine (M to M) communication (Hwang and Chen, 2017; Ramlowat and Pattanayak, 2019).The convergence of technologies and IoT has sparked significant interest among researchers and experts. They are actively investigating the immense possibilities presented by the IoT and striving to devise a comprehensive strategy for effectively harnessing these technological advancements. This exploration encompasses diverse domains, including education (Ahmad et al., 2022; Ali et al., 2023; Bucea-Manea-Ţoniş et al., 2022; Mozumder et al., 2023).

In the existing body of literature pertaining to IoT, previous research efforts have explored various aspects of this domain. Notably, Kadhim et al. (2023) put forth a novel proposition for the development of an automated system specifically designed to assess the performance of engineering students. The proposed system was developed utilizing the principles of IoT and wireless communication networks in order to enhance the virtual education process. In a recent study conducted by Pappas et al. (2022), the concept of merging gamification with the IoT was examined. The

researchers explored the potential impact of gamification and IoT on education, particularly focusing on how game engines can be utilized to create novel virtual laboratories and interactive experiences for students.

In their research, Mershad and Wakim (2018) introduced a conceptual framework that explores the potential integration of IoT enablers into a learning management system (LMS) for future educational settings. The study's findings revealed various aspects of the Learning Management System (LMS) that will be influenced by the IoT, along with the anticipated enhancements and modifications that the IoT will introduce to the LMS functionalities. According to Gul et al. (2017), the integration of IoT applications in the education sector offers numerous advantages. The authors argue that IoT technology has the potential to significantly influence the future of education by introducing a new wave of change. This wave brings forth various opportunities and possibilities to enhance both the teaching process and the overall infrastructure of educational institutions.

In a study conducted by Charlton and Avramides (2016), the authors explored the learning conditions and indicators of cooperation and production within the context of STEM-based learning. The study aimed to examine the impact of utilizing IoT in the learning process. The findings of the study revealed that the incorporation of IoT in learning fosters the development of collaborative, problem-based, as well as interdisciplinary learning conditions. These results suggest that the use of IoT technology has the potential to enhance the overall learning experience. The findings suggest that the integration of IoT has a positive impact on interdisciplinary learning opportunities and the overall value of collaboration and knowledge creation. In order to effectively implement IoT in educational institutions and harness its potential, it is imperative to consider the acceptance and attitudes of users towards its utilization.

In a recent study conducted by Suduc et al. (2018), a survey was administered to university students who were pursuing technical majors. The findings of this study revealed that IoT technologies present a significant potential for educational institutions to gather data, enhance school operations, and attain educational objectives. The findings of the study also indicate a substantial projected growth in this particular field in the coming years. Additionally, the research underscores the significance of adequately equipping younger generations to navigate and adapt to these anticipated transformations. In a recent study conducted by Ramlowat and Pattanayak (2019), the researchers explored the potential benefits of IoT in the field of education. The findings of their study indicated that the IoT holds promising implications for education, particularly in terms of enhancing teaching efficiency and optimizing the learning process. In a relevant context, the findings of the study conducted by Bagheri and Movahed (2016) demonstrated that the integration of IoT in the field of education can be categorized into four fundamental scopes. These scopes encompass: energy management and real time ecosystem monitoring, monitoring student's healthcare, classroom access control and improving teaching and learning.

IoT can increase the capacity of educational environments, making them smarter and more capable of providing learner access to educational materials, which can contribute to creating more optimal learning environments (Terzieva et al., 2022). Due to this great importance of IoT, it is necessary to pay attention to the development of educational programmes and courses that can contribute to improving students'

experiences in dealing with such environments (Rao and Elias-Medina, 2024). IoT can also play an important role in enhancing the abilities of people with special needs to improve their lifestyle, but this requires training in the mechanisms of using IoT technologies (Alqarni et al., 2024). IoT can simulate the classroom environment and provide real-time feedback, so that students can have a better learning experience and improve their skills more deeply (Rui, 2024).

The previously reviewed studies indicate that IoT holds significant potential for enhancing education within educational institutions. These studies aim to establish a framework that facilitates the integration of IoT technology in educational settings (Ahmad et al., 2022; Bucea-Manea-Țoniș et al., 2022; Mozumder et al., 2023). Several previous studies have examined a range of influential factors that can serve as a foundation for understanding the factors that impact the capabilities of IoT (Charlton and Avramides, 2016; Chweya et al., 2020; Essa et al., 2023; Sneesl et al., 2022; Suduc et al., 2018). Despite the great advantages of IoT, the use of IoT in education faces many challenges and obstacles, including the need for training and acquisition of skills that promote the use of IoT as a technology that has a significant role in the educational process (Pino et al., 2024). The technology of manufacturing IoT components itself is one of the most common barriers to the use of IoT in education (Rogdakis et al., 2024). There is a lack of awareness associated with the perceived benefits of IoT, which needs to be worked on and improved (Alqarni et al., 2024).Based on the existing body of research, it is evident that there is a pressing demand for further investigation employing a qualitative methodology to gain a more profound comprehension and a holistic overview of the potential applications of IoT in the field of education.

3. Methodology

3.1. Approach

The researcher conducted a study to investigate the potential of IoT in developing a system for the Kingdom of Saudi Arabia. The study is employing a qualitative content analysis approach, which is a systematic method for examining and validating texts and digital content (Leavy, 2022). The purpose is to get a more profound comprehension of the many potentialities that may be used by interested parties to implement IoT in education. This methodology will be used to address subsidiary inquiries focused on discerning infrastructural elements that augment scalability in IoT settings, as well as recognizing human elements. This technique involves using content analysis to examine a collection of tweets posted by experts on the X platform about the integration of IoT in the field of education. Professionals specializing in IoT will also be categorized based on a specific set of criteria and requirements.

3.2. Participants

According to Creswell and Clark (2017), the appropriate number of participants in qualitative research is decided based on the point of saturation in replies. This saturation point may typically be attained with a minimum of six participants or more. The investigation had a total of 12 participants. The number of participants in the study has been increased slightly due to the decision to not conduct direct interviews. Instead,

the data analysis will rely on the analysis of experts' tweets, which will provide a more comprehensive source of information. The research team established a series of criteria to decide the selection of persons participating in the study. The participants were required to meet at least some of these criteria, which are as follows:

- The selection process included choosing individuals with expertise in IoT and a minimum of 10,000 followers.
- Each expert in the area of IoT should aim to produce a minimum of 20 tweets in order to guarantee a wide range of thoughts pertaining to IoT.
- The selection process also considered the requirement for the tweeter to possess an academic or professional background. The research team assessed this background to ensure that the tweeter is affiliated with an academic institution or is employed by companies that offer IoT solutions. Alternatively, the tweeter may be recognized as an expert speaker at scientific conferences focused on the IoT.
- The participants were chosen based on their occupation in the area of IoT, rather than only their interest in it.

According to these criteria, the number of participants (12) was as follows: The proportion of male participants was 58%, whilst the proportion of females was 42%. The people involved in the project had diverse specialties, including computer science, information technology, engineering, networking, and communications as broad areas of expertise. Additionally, several individuals had specialized knowledge in artificial intelligence, IoT, and new technologies. **Table 1** displays the information on the people who are taking part.

Table 1. Data on the individuals involved in the study.

Participant	Gender	Domain	General Major	Sub-major in IoT	Number of Tweets	Number of Followers
A1	Female	Academic, CEO	Computer and Information sciences	Specializing in digital solutions, artificial intelligence, smart cities, and virtual and augmented reality	1009.1 thousand	53.1 thousand
B1	Male	Technician	Electrical Engineering	Cloud, security, IoT, big data, artificial intelligence, and other technologies	1.1 million	346.9 thousand
B2	Male	Director of a technology company	Psychology	Artificial intelligence, big data, #futureofwork, Cyber security, Digital transformation	54.8 thousand	152.6 thousand
B3	Male	Academic	Computer Science Engineering	Machine learning, big data analytics and IoT	76.2 thousand	142.2 thousand
A2	Female	Ph.D., Executive Vice President of a major telecommunications company	Computer Security	Artificial Intelligence	171.6 thousand	393.8 thousand
B4	Male	Academic, researcher, conference speaker	Astronomy and Physics	Data Analysis	172.6 thousand	393.8 thousand
B5	Male	Speaker and technical consultant	Law	AI | Blockchain | Fintech | Web3	89.6 thousand	121.1 thousand
A3	Female	Founder and CEO	undefined	IoT, sustainability and digital innovation	12.7 thousand	164.4 thousand
B6	Male	Founder and CEO	MA in Communications Engineering	Digital transformation, data analytics and artificial intelligence	21.2 thousand	52.4 thousand
B7	Male	IoT expert Technologist, author, and entrepreneur	Scandinavian Studies	IoT	14.7 thousand	10.6 thousand
A4	Female	Consultant, technology journalist, and technology blogger	Undefined	IoT, Artificial Intelligence, Mobile Technologies, Big Data, Cloud Computing and Machine Learning	197.7 thousand	139.7 thousand
A5	Female	Founder of a technology company	Undefined	Artificial intelligence, robot, Augmented and virtual reality, Web3	37.2 thousand	13 thousand

3.3. Procedures

The researcher prepared a list of Tweeters who possess specialized knowledge in the field of IoT by conducting thorough searches and investigations using many tools. A preliminary synthesis was conducted in several research databases including Web of Science and Scopus, as well as in the Google search engine. An inquiry was conducted to identify scientific conferences that focus on the topic of the IoT, as well as the experts that are present at these conferences. The research team employed an additional approach to locate authoritative testimonies, utilizing generative artificial intelligence software such as ChatGPT, Bard, and Bing. Their search targeted individuals in the fields of academics, researchers, CEOs, and managers in IoT. The team sought out these individuals' accounts on LinkedIn, a platform that frequently offers a comprehensive summary of their professional background. Regarding the members' professional paths and expertise in the field of IoT. To ensure scientific accuracy when discussing outcomes, specialists assemble an initial list from many sources and determine the accounts of the most popular or most referenced publications. By considering the criterion of tweet count per author and number of followers, the list was further refined to include 12 participants. A list of each individual that tweeted was created, followed by tweets pertaining to IoT. Excluded from the study were tweets that were unrelated to the use of IoT in the field of education. The tweets were analyzed over a span of five years, namely from 2019 to 2022. Prior to commencing the analysis process, the research team thoroughly examined the list of experts and their tweets. They collaborated with two artificial intelligence specialists to ensure the maximum level of dependability in identifying and scrutinizing the content of the tweets. A total of 240 tweets were evaluated.

3.4. Data analysis

The researcher performed an analysis on the tweets obtained in the present study, totaling 240 in number. The coding, grouping, and launching of subtopics for the content of the preceding tweets were conducted based on the total number of tweets, which was 240 as mentioned in the previous table. The procedure yielded a total of 86 codings, which were categorized into 10 subgroups. These subgroups consisted of 10 subtopics, which were further organized into two primary themes. **Figure 1** shows the results of the data analysis obtained after conducting the interviews.

As shown in **Figure 1**, the qualitative analysis of the experts' tweets identified the potential of IoT in education in two main themes: Hardware and software enablers for IoT in education and human enablers for IoT in education. The hardware and software enablers focused on Network and Communications, Sensors and System Management, Data as a Fundamental Cornerstone, Tools of Online Learning, and Interactive Devices. The individual enablers of the IoT are rooted in planning, preparing a Pioneering Future Generation, Training and Professional Development, and Ensuring the Security and Sustainability of the Educational Setting.

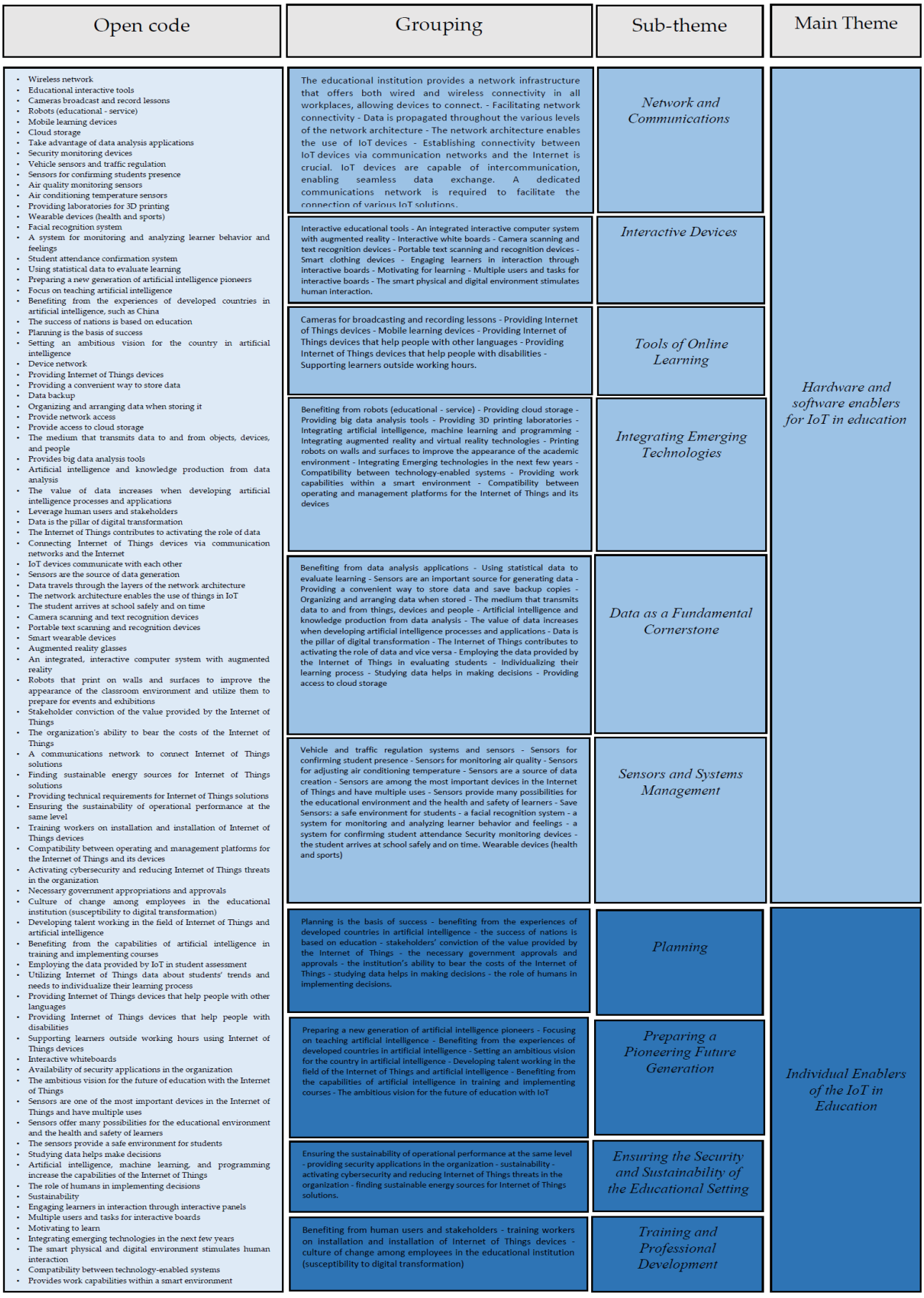

Figure 1. Outputs of the coding and topic identification processes.

3.5. Ethical issues in the study

In order to maintain professional ethical standards in the study, numerous procedures were implemented after careful consideration of the ethical concerns associated with the gathering and examination of tweets on the X platform. The issues of privacy have been addressed by obfuscating usernames and other personally identifiable information in the gathered data. The study took into consideration the potential for discrimination and prejudice arising from the choice of terms. To mitigate this issue, objective analytical approaches were used. The methodological processes used for data collection and analysis were well recorded, and the outcomes were disseminated in a clear and unbiased way to enhance scientific understanding. In conclusion, meticulous measures were taken to secure the well-being and prevent any form of prejudice or bias towards the individuals who participated in the study. Furthermore, explicit explanation was provided regarding the procedures and techniques employed throughout the research endeavor, with the explicit intention of upholding the confidentiality and personal boundaries of the participants, while simultaneously enhancing scientific knowledge.

4. Results

The findings of the thematic analysis yielded two primary themes that delineate the potentialities of IoT in education, as perceived by experts. The selection of these topics was predicated upon the following factors:

4.1. Hardware and software enablers for IoT in education

The Hardware and software enablers for IoT in education rely on fundamental components such as network availability, communication infrastructure, interactive devices, e-learning tools, integration of developing technologies, data analytics, sensors, and systems management. The information will be given in a comprehensive manner as outlined below:

4.1.1. Network and communications

The outcome of the thematic analysis identified the key material-based and software-based enablers of IoT in education by examining the content of experts' tweets. Having both wired and wireless communication networks available in all workspaces within the educational institution is essential for connecting IoT devices and users. It also allows for the utilization of behavior monitoring applications and ensures the smooth operation of the network. In order to enhance the educational environment, it is necessary to continually improve the network by monitoring and optimizing the devices and users. This is particularly important since one of the participants shared a tweet that included an infographic relevant to this topic:

> "The smart Internet of Things school […] complete coverage with high performance Wi-Fi […] network application analytics to monitor devices and network behavior" (B1i).

The outcome of the thematic analysis of the tweets from IoT specialists also highlighted the significance of granting network access to users and devices of various kinds, whether connected through local communication networks or the public Internet.

This connectivity plays a crucial role in enhancing the overall value of these devices by seamlessly integrating artificial intelligence. One of the participants' tweets included an infographic within this particular framework:

> "The Internet of Things From connecting devices to human value device connection: IoT devices, IoT connectivity, Embedded intelligence […] 03) communication: Focus on access networks, cloud, edge data transport "(A1i).

Other tweets emphasized the significance of using the high speeds offered by 5G technology to link IoT devices in a manner that is consistent with the network topology and facilitates communication across targets. Additionally, it facilitates the augmentation of the quantity of devices interconnected inside the network, thus resulting in an expansion and variety of solutions. IoT offers several benefits to end users and has a significant influence on the educational process environment. One of the participants sent a tweet with an infographic that illustrates these aspects:

> "The interconnection of computing devices embedded in everyday objects via Internet, enables them to communicate with each other […] 5G brings new aspects to the connectivity table: greater speed and volumes, lower latency, and the ability to connect a lot more devices at once" (A2i).

4.1.2. Sensors and system management

The outcome of thematic analysis yielded the key material-based and software-based enablers of the IoT in education by examining the content of experts' tweets. It has shown that sensors are crucial components of IoT since they serve as the primary data generators inside the network's tiered structure, enabling the implementation of IoT solutions in educational settings. One of the participants sent a tweet that included an infographic. The infographic displayed the following information, which is relevant to the current context:

> "Sensors generate data that is sent downstream to subsequent layers of the architecture enabling "things" in IOT" (A2i).

The outcome of thematic analysis revealed that sensors are crucial devices in the IoT and have various applications in the educational environment. These include controlling the opening and closing of doors, monitoring movement within the institution, and performing tasks to enhance the quality of the educational environment. For example, sensors can monitor air quality, regulate air conditioning temperature, and detect gases, smoke, and chemical elements. These sensors can be utilized in classroom laboratories or fire protection systems in educational institutions. The sensors included within the gadgets may also be used to monitor the overall well-being of learners. The participants' tweets included an infographic that highlighted the significant applications of sensors in wearable devices for monitoring physical and health performance:

> "Top sensor types in IoT: Accelerometer sensor, proximity sensor, IR sensor, gas sensor, temperature sensor, chemical sensor, smoke sensor, motion detector sensor" (B6i).

Within the same context of discussing the many applications of sensors, a tweet from one of the participants included an infographic that stated:

> "The smart Internet of Things school […] Wi-Fi sensors and locks, Entrance and exits, Classroom doors […] wearables for athletics and attendance tracking […]

> Internet of Things based HVAC […] monitor and display of air quality throughout school […] sensors on trash receptacles" (B1i).

Additional tweets suggested the potential use of sensors, including face recognition and motion sensors, to verify the presence of students and enhance the security systems of educational institutions. Sensors are used in systems to monitor and analyze the behavior and emotions of learners, displaying various manifestations of their happiness or sadness. Alternatively, in the context of fear or frustration, this provides data that is directly correlated with the degree to which the educational process needs improvement or the specific emotions that need to be encouraged or discouraged in learners. The learner's conduct in reading, writing, listening to the lesson, engaging in learning activities, responding, and raising their hand to participate may be used to examine their interaction and academic behavior. One participant in a tweet on a video stated that it is beneficial for the instructor to evaluate their teaching approach and educational resources:

> "This school in #China scans students every 30 seconds with #FacialRecognition technology" (B2v).

The tweet included a video that had both background music and live footage of the face recognition technology being used in an educational setting. The video also included a brief explanation in written English.

> "Facial recognition technology system, Learn about students' behavior in the classroom. Analysis of facial expressions of happiness, sadness, fear, disappointment, anger, surprise. The class behavior management system is called smart. Analysis of learner behavior reading, writing, raising the hand, listening. Attendance monitoring system: A system for storing local databases for facial recognition" (B2v).

Or with the objective of ensuring the safe and punctual arrival of students at school, through the systems and sensors of students' transportation vehicles and traffic management. One of the participants sent a tweet that included an infographic pertaining to this matter:

> "The smart Internet of Things school […] sensors struck busses and verify student passengers […] sensors in parking IOT and driveways" (B1i).

4.1.3. Data as a fundamental cornerstone

IoT facilitates the use of data, while data in turn facilitates the utilization of IoT. Data is seen as the cornerstone of digital transformation. A tweet from one of the participants included an infographic that encompasses these concepts.

> "Data is at the heart of the latest IT transformational wave […] Internet of Things: the interconnection of computing devices embedded in everyday objects via Internet, enables them to communicate with each other; sensors generate data that is sent downstream two subsequent layers of the architecture enabling things in IoT" (A2i).

As the rising volume of data increases with the development of artificial intelligence processes and applications, it is crucial to effectively manage and structure data. This involves establishing a systematic approach to storing data in databases, whether in the cloud or on local servers, and creating backup copies. Data collection should encompass diverse sources such as individuals, sensors, and IoT devices. The

tweet featured individuals depicted on an infographic that highlighted the potential benefits of utilizing data analysis and artificial intelligence in education. These benefits include generating knowledge through data analysis, using statistical data to assess learning, evaluating students, understanding student trends and needs, tailoring personalized learning experiences based on this data, and making informed decisions:

> "The Internet of Things From connecting devices to human value 02) Data sensing: Capture data, sensors, and tags storage. […] 04) Data analytics: Big data analytics, AI, and cognitive analysis at the edge. […] 05) Data value: analysis to action, APIs and processes, actionable intelligence" (A1i).

Similarly, the video accompanying one of the tweets included a written textual explanation inside the movie that emphasized the significance of the data in instructors' evaluation of their instructional approaches based on this data:

> "Helping the teacher to review his teaching style through statistical data" (B2v).

4.1.4. Tools of online learning

The outcome of thematic analysis yielded insights into the key material-based and software-based enablers of the IoT in education, as seen from the examination of experts' tweets. These insights have shown that educational institutions gain advantages from utilizing e-learning tools, and these advantages are further enhanced when integrated with IoT solutions. By incorporating various types of IoT devices, the quality of e-learning can be significantly improved, offering learners numerous opportunities for customization based on their individual experiences, behavior, interests, and cultural references. Additionally, these tools enable the storage of files and educational programs tailored to each learner's needs. In addition, IoT devices enhance the educational environment and facilitate continuous learning by utilizing smart and mobile devices. These devices offer learners support both within educational institutions and outside of regular working hours, with minimal human intervention required. Moreover, if the student is located in a different geographical region due to various circumstances, courses may be transmitted by webcams, recorded broadcasts, and practical experiments can be conducted by integrating IoT devices with learning and content management systems. The use of IoT technology may also serve to facilitate collaborative learning. IoT devices may also serve as valuable tools to assist those with impairments in their learning process. Participants in this setting include special needs pupils or students who speak languages other than English. One of the participants shared a tweet that featured an infographic:

> "The smart Internet of Things school […] personalized learning with adaptive E textbooks […] digital classroom whiteboards and display […] video recorders for lecture capture […] international collaboration and social exchange […] online testing […] student devices and ethics books (notebooks, tablet, smartphones […] file and program storage, or cloud based: (demographics, behavior, interests), (LMS, CMS, SIS), Educational programs and applications, Video files: lectures and recorded lab experiments" (B1i).

Within the same context, a tweet from one of the participants included an infographic that stated:

> "How IOT and AI is changing the education system for the better […] customized courses and materials, helping teachers to fill gaps in education, create a digital

content, helping teachers in grading and save their time, universal access for all students, support outside the classroom" (B6i).

4.1.5. Interactive devices

IoT devices enhance the educational process by creating a smart digital environment that encourages learners to interact. This is achieved using interactive educational devices and tools, such as smart boards, which can support multiple users and tasks and make the learning process more engaging and attractive. One participant mentioned in a tweet on a video that:

"If my teacher used #tech in the classroom, I would have never skipped school. 😂This teacher uses an interactive board to teach in #China. #AI #IoT #ArtificialIntelligence #InternetofThings #VR #AR #VirtualReality #AugmentedReality #MR" (A4v).

"The video attached to the tweet showed a teacher explaining on an interactive whiteboard while students interacted in what appeared to be Chinese." The instructor was drawing a cubic object on the smart board, coloring it, and rotating it in 3D dimensions using touching only. The board then demolished the cube in response to a command by a touching procedure, into two-dimensional squares with their colors, with a pop-up of a surprised student's voice, "Wow"" (A4v).

There are also a plethora of additional devices and innovations that can inspire inventive applications of some of the most recent technologies in use today. By utilizing mobile devices and other IoT devices to recognize text in textbooks and facilitate interaction through them, access rich media content, facilitate classroom activities, interpret data through wearable devices, interaction can be utilized in the classroom. One of the participants noted in a video-related tweet:

"A must have #Tech for any college student. #Innovation #Students #education #AR #VR #XR #edtech #IoT" (B4v).

"The video affixed to the tweet showcased an individual using an optical text reader pen device to navigate through lines in a book. The text is wirelessly transmitted from the pen to the laptop" (B4v).

Augmented and virtual reality technologies may enhance engagement in the classroom. Within this particular scenario, a tweet from one of the participants included an infographic that consisted of:

"The smart Internet of Things school […] augmented and virtual reality […] The infographic shows a picture of children immersed in the classroom and using virtual reality glasses with laptops" (B1i).

4.1.6. Integrating emerging technologies

The results of the thematic analysis of the key enablers of the IoT, encompassing both material-based and software-based aspects in the field of education, through the analysis of expert tweets, have unveiled that cutting-edge technologies are rapidly converging to a higher degree in the near future. This convergence is expected to give rise to novel technologies that will integrate multiple emerging technologies. As exemplified by one participant's tweet featuring an infographic, this integration is poised to bring about significant advancements:

"Emerging technologies and trends. #EmergingTech #AI #Metaverse #IoT #SmartCities […] The infographic shows a chart of the emerging technologies

> radar in 2022 and the number of years it will take for emerging technologies to intersect such as: edge AI, digital twin, advanced virtual assistants, hyperscale edge computing, IO T platform, multimodal UI, smart spaces, collaborative ecosystem product development, 6G, graph technologies, homomorphic encryption, digital ethics, synthetic data, generative AI, ART cloud, AI generated composite applications, self-supervised learning" (A5i).

Currently, certain technologies can be utilized to enhance the enablers of IoT in education. The goal is to create a smart environment in educational institutions. However, it is crucial that these technological systems are compatible and do not conflict with each other. This can be achieved through platforms that enable the management of IoT and its devices. One of the technologies that overlaps significantly with IoT is artificial intelligence. Its capabilities can be enhanced in IoT through leveraging programming and machine learning techniques, as well as analyzing big data, which is another emerging technology, due to the crucial role of data in IoT being an essential component of IoT, and by ensuring that this data is stored appropriately in the cloud. The following was the content of one participant's tweet:

> "The Internet of Things explained simply—get data about the real world from Internet-connected sensors; use that data to make decisions automatically via AI, machine learning, or algorithms; execute those decisions using humans or machines to cause real world changes; repeat #IoT" (B7t).

One of the attendees tweeted an infographic that included the following information in the same context on the significance that incorporating new technology plays:

> "Data is at the heart of the latest IT transformational wave, here are the 5 major technologies shaping you interconnected data-driven reality […] Internet of Things, 5G, blockchain & distributed Ledger, cloud, artificial intelligence" (A2i).

Robots equipped with sensors and integrated into IoT have the potential to be utilized not only in service-oriented roles within educational institutions, but also in educational settings. For example, an educational robot has the capability to support learners in various classroom activities and academic subjects. Additionally, a service robot can fulfill tasks related to maintaining the cleanliness and aesthetic appeal of school premises and classrooms. These tasks may include printing on surfaces and walls, as well as organizing exhibitions and events within the educational institutions. One of the participants' tweets included an infographic that, in the present context, featured the following information:

> "The smart Internet of Things school […] robotics for STEM and remote presence […] robot cleaning" (B1i).

Within the same contextual framework, a participant's tweet featured a video accompanied by a comment, highlighting the potential advantages of incorporating robots into IoT solutions.

> "#robot painter #AI #DigitalTransformation #3Dprinting #IOT #automation #robotic" (B5v).
>
> "The tweet included a video showcasing a robot capable of creating an artistic painting on a wall. Once the robot completes the painting process, the artwork materializes as a three-dimensional wall painting" (B5v).

The integration of 3D printing technology with IoT has positioned it as a prominent emerging technology. Consequently, it becomes vital to harness its potential and establish a dedicated platform within educational institutions to foster creativity and innovation. In addition, various technologies, including augmented, virtual, and mixed reality, can be effectively employed within educational institutions to create an engaging and intelligent learning environment. One of the participants' tweets included an infographic that, in the present context, stated the following:

> "The smart Internet of Things school […] makerspace with 3D printers and laser trimmers […] augmented and virtual reality" (B1i).

Within the same framework, the potential of incorporating augmented and virtual reality technology into IoT solutions was discussed. One of the attendees sent a tweet that included a video along with a remark:

> "Cool #AR powered glasses 👍 #AI #VR #MR #DigitalTransformation #IOT #3Danimation" (B5v).
>
> "The video in the tweet featured a user wearing augmented reality glasses that were the same size as regular glasses. The glasses had transparent lenses that allowed the user to see objects in the room. However, when the glasses were turned on, the lenses displayed a set of icons that resembled a laptop's desktop. A realistic-looking keyboard displays below as you adjust the glasses' viewing angle" (B5v).

4.2. Individual enablers of the IoT in education

The individual enablers of the IoT are rooted in fundamental components that encompass various aspects. These components include strategic planning, fostering the growth of a forward-thinking generation, facilitating training and professional development, ensuring sustainability, and safeguarding the security of the educational ecosystem. The following section will provide a comprehensive presentation of the topic at hand.

4.2.1. Planning

The findings of the thematic analysis on the key individual enablers of IoT in education, based on the examination of experts' tweets, revealed that planning is the primary factor in implementing IoT projects in education. This is because planning is closely associated with a set of factors that will determine the success of the experiment. These factors involve thorough examination of data throughout all stages of the project, both prior to and during its execution. This is because this data facilitates decision-making, enables analysis of institutional requirements, and supports the modification of essential processes for the successful execution of the IoT project, in alignment with the established plan. Effective planning also serves to persuade stakeholders of the inherent benefits that IoT will provide inside the educational institution. This also contributes to the promotion of the trend in acquiring the required governmental authorizations for implementing IoT in education, as well as enhancing institutions' capacity to financially sustain IoT with the aid of government funding. To effectively plan for IoT, it is crucial to draw upon the expertise of developed nations in artificial intelligence and IoT. Setting ambitious goals for success is essential, as the

prosperity of nations relies heavily on education. One participant aptly pointed out in their tweet about a video:

> "#China is leveraging #Education to win the #AI race >>> >>> #Automation #MachineLearning #DeepLearning #BigData #IoT #Robotics #HealthTech #EdTech" (B2v).
>
> "The video linked to the tweet showcases a sequence of scenes depicting individuals who seem to be developers engaged in the process of creating a range of cutting-edge technologies, followed by students using these technologies. The video further had accompanying music and written explanations for each sequence. Furthermore, it was said that artificial intelligence is projected to contribute a staggering four trillion dollars to the world economy by the end of 2022. However, China now lags behind America with just half the number of businesses operating in this field and aims to bridge this gap by establishing itself as a prominent educational superpower. The Chinese saying "If your plan is for one year, cultivate rice; if your plan is for 100 years, educate children" was also referenced. Moreover, it has been observed that with the substitution of low-skilled employment by robots, the significance of conventional education diminishes. China, on the other hand, has set a goal to take the lead in the artificial intelligence competition by 2030, and it is now making progress towards achieving this objective" (B2v)".

4.2.2. Preparing a pioneering future generation

The ambitious aspirations of nations have a crucial role in determining the success of their overall experiments and, specifically, their technological undertakings. Our evaluation of experts' tweets reveals that emphasizing the teaching of artificial intelligence and utilizing its capabilities in training and implementing courses directly contributes to preparing a future generation that is innovative in the fields of artificial intelligence and IoT. This has been recognized as a significant potentiality that contributes to the future adoption of IoT in education, as stated by one of the participants in his tweet about a video:

> "#China is leveraging #Education to win the #AI race >>>
> >>> #Automation #MachineLearning #DeepLearning #BigData #IoT #Robotics #HealthTech #EdTech" (B2v).
>
> "The video included in the tweet displays a series of scenes portraying individuals who seem to be software engineers engaged in the advancement of various cutting-edge technologies. Subsequently, it depicts pupils using these technologies. The video is accompanied by a musical soundtrack and contains written explanations for each scene. The proposal supports the inclusion of artificial intelligence education in schools to foster the development of future technology leaders who possess the ability to think critically and thrive in the competition for AI dominance. In 2017, China possessed over 50% of the global AI projects, but currently, it only had 5% of the skilled AI professionals. They now have 40 high schools around the country that offer AI classes, each with its own dedicated AI textbooks. Additionally, they are also developing a version of these textbooks specifically designed for middle school students. A novel

university course is designed with the objective of cultivating 5000 proficient technology specialists" (B2v).

4.2.3. Training and professional development

One crucial aspect to consider in order to fully utilize the immense potential of IoT in education is the training of workers, employees, and professionals. This training should focus on the installation and implementation of IoT devices in educational institutions, as well as fostering a culture of change and embracing the potential of digital transformation. Emphasizing the importance of nurturing skills and cultivating a professional mindset in the fields of IoT and artificial intelligence, which play a significant role in advancing the educational sector. This was highlighted in a tweet by one of the participants, who shared an infographic illustrating this concept:

> "A variety of factors influence at-scale IOT adoption and impact. […] Value achieved: Value or ROI provided by IOT solutions and systems meets or exceeds exceptions […] Perceived value proposition: belief by the end user that the value provided by the IOT is worth […] Installation: ease of installing IT solutions for the end user […] Public policy: influence of public policy (e.g., government regulation, incentives, ETC) […] Change management: organizations ability to align on and make required procedural, organizational, or cultural change […] Talent: access by the end user to the talent(technical, ETC) required to implement, scale, and operate IOT solutions" (A3i).

4.2.4. Ensuring the security and sustainability of the educational setting

To ensure the continued effectiveness of IoT in education, it is crucial to maintain optimal operational performance. This can be achieved by securing sustainable energy sources to power IoT solutions and tools. By doing so, we can preserve the environment while enhancing the overall quality of the project in general and those benefiting from the educational institution in particular. Ensuring the security and safety of all users in the educational institution is crucial. This may be achieved by implementing cybersecurity systems that mitigate security risks. These systems should include security apps and tools that are powered by sustainable energy sources. One of the participants sent a tweet that included an infographic. The infographic displayed the following information in relation to the topic at hand:

> "A variety of factors influence at-scale IOT adoption and impact. […] Power performance: power availability and power consumption of IOT systems […] Tech performance: required technology is available for IoT solutions and apple to consistently perform at the level required […] Interoperability: interoperability of IT systems with other IOT, IT systems or platforms […] Privacy and confidentiality: safeguarding of confidential IOT data […] Cybersecurity: prevention or intrusion of IOT system unauthorized actors" (A3i).

5. Discussion

The present study findings have been derived from the identification of two primary dimensions of IoT enablers in education, as seen by experts. The subsequent discussion will be centered around these two dimensions as outlined below:

5.1. Material-based and software-based enablers of IoT in education

This discussion will focus on the material-based and software-based enablers of the IoT in education, specifically network availability and communications, interactive devices, e-learning tools, integration of emerging technologies, data as a fundamental component, and sensors and systems management. The information will be given in a comprehensive manner as outlined below:

5.1.1. Network and communication availability

A survey of experts' tweets on the material-based and software-based enablers of the IoT in education revealed that the presence of wired and wireless communication networks is a crucial material enabler of IoT in education. This is because the communication network plays a crucial role in connecting IoT solutions and facilitating data transfer. It is one of the key physical components that directly contributes to enhancing the quality of IoT solutions in education. This aligns with the findings of the research conducted by Gul et al. (2017), which suggests that the integration of IoT in education necessitates the presence of fast wireless networks to support the transmission of high-quality audio and video content for instructional purposes. Furthermore, it aligns with the research conducted by Ramlowat and Pattanayak (2019) and Wollschlaeger et al. (2017), which examined the structure of IoT. These studies emphasize the significance of the network layer as a crucial element in developing educational solutions within the IoT framework.

5.1.2. Sensors and systems management

An analysis of expert tweets on the material-based and software-based enablers of the IoT in education found that sensors and systems management play a crucial role in providing solutions for the IoT in education. The versatility of smart systems enables the improvement of the educational environment by efficiently processing various forms of data. This, in turn, allows for innovative methods of controlling, securing, and enhancing the educational setting (Essa et al., 2023). The study conducted by Mershad and Wakim (2018) introduces additional insights on the potential utilization of IoT sensors in educational laboratories for monitoring scientific experiments. It also aligns with the present study's findings on the feasibility of controlling these sensors through educational electronic systems.

5.1.3. Data as a fundamental cornerstone

The analysis of experts' tweets about the material-based and software-based enablers of the IoT in education revealed that data is a crucial element for maximizing the advantages of IoT solutions in education. The digitalization of educational institutions depends on data, and all IoT solutions must be managed in a methodical and secure way when it involves storing, processing, and analyzing data. This approach highlights the importance of data and enhances its relevance in the context of artificial intelligence and big data analysis. Collecting, analyzing, storing, and organizing data is crucial for the advancement of educational institutions (Chweya et al., 2020; Hwang and Chen, 2017). Data plays a crucial part in understanding students' learning requirements and tailoring a customized learning experience for each student based on the information offered by this data. Additionally, it may be used in assessment procedures for both students and instructors to enhance the educational

process by incorporating IoT devices into contemporary learning approaches like gamification, instructional games, and others. This aligns with the research conducted by Islam et al. (2022) and Lv et al. (2022).

5.1.4. E-learning tools

The analysis of expert tweets on the material-based and software-based enablers of the IoT in education revealed that integrating IoT tools with e-learning tools can enhance the quality and capabilities of e-learning. This integration allows for a more flexible learning process that is not limited by time or place. This is achieved by using portable and mobile devices and linking them to IoT network inside the educational institution (Kadhim et al., 2023). Furthermore, IoT solutions contribute to diminishing dependence on human involvement in e-learning (Zeeshan et al., 2022). IoT solutions in e-learning may provide support to those with disabilities and non-native speakers of different languages (Chen, 2023; Islam et al., 2022; Van Murugiah et al., 2021).

5.1.5. Interactive devices

Undoubtedly, IoT devices have the potential to enhance interactivity in the classroom and educational processes. For instance, smart boards with advanced features enable multiple users to perform various tasks, while mobile devices can be connected through intelligent applications to take advantage of their diverse services (Alhasan et al., 2023; Mershad and Wakim, 2018). Similarly, the findings indicated that interactivity can be incorporated in novel ways by utilizing augmented reality on mobile devices and virtual reality on wearable devices. This aligns with previous research that has demonstrated the potential for integrating educational devices and IoT (Bucea-Manea-Ţoniş et al., 2022; Jo and Kim, 2019; Mozumder et al., 2023). Likewise, the findings also suggested the potential for incorporating interactivity into textbooks and utilizing IoT devices to transfer texts to learners' devices. This can be achieved by scanning the QR code to access educational activities and interactive textbook content, as well as connecting them to other interactive IoT solutions both inside and outside the classroom (Tan et al., 2018). The findings have also indicated the potential of leveraging IoT devices to enhance interactivity. These devices are diverse and offer various opportunities for interactive education, as aligned with previous research in this field (Jo and Kim, 2019; Metcalf et al., 2016; Van Murugiah et al., 2021). Therefore, it becomes necessary to develop training programmes through new technologies to equip stakeholders with the skills to use interactive devices in the context of the Internet of Things (IoT) (Al-Hafdi and Alhalafawy, 2024; Alnimran and alhalafawy, 2024; Alsayed et al., 2024; Alshammary and Alhalafawy, 2023; Alzahrani and Alhalafawy, 2023; Najmi et al., 2023; Saleem et al., 2024; Zaki et al., 2024).

5.1.6. Integrating emerging technologies

An analysis of expert tweets on the material-based and software-based enablers of the IoT in education revealed that IoT technology can be integrated with a range of other emerging technologies. It is anticipated that in the coming years, these technologies will converge to create a unified technological system. Currently, there is an opportunity to gain advantages by combining certain technologies with IoT, also known as SMACT (Hwang and Chen, 2017). The potential of IoT in education may be augmented via the use of artificial intelligence, programming, and machine learning

(Bucea-Manea-Ţoniş et al., 2022). The value of IoT solutions is further enhanced by the use of big data analysis (Chweya et al., 2020). Utilizing cloud computing technologies in the context of IoT is a significant opportunity (Mijailović et al., 2021). The findings also suggest that robotics and 3D printing, alongside other contemporary technologies, play a role in enhancing IoT solutions in education. These technologies are regarded as supplementary resources and software enablers for IoT in the educational context (Charlton and Avramides, 2016; Chweya et al., 2020; Curralo et al., 2022; Gul et al., 2017; Mijailović et al., 2021).

5.2. Individual enablers of IOT in education

This discussion will focus on the outcomes pertaining to the material-based and software-based enablers of the IoT in education. These outcomes encompass various aspects such as strategic planning, fostering the growth of a forward-thinking future generation, providing training and professional development opportunities, ensuring sustainability, and upholding the security of the educational environment. The information will be given in a comprehensive manner as outlined below:

5.2.1. Planning

The analysis of experts' tweets regarding the enablers of IoT in education revealed that successful IoT projects in this field require careful planning. This is because the development of IoT systems is more intricate compared to traditional software systems, as highlighted by Giray et al. (2017) and Tavana et al. (2020) Data analysis plays a crucial role in decision-making, assessing requirements, and adjusting processes throughout the implementation phases of IoT projects, as aligning with project goals. It serves as a key enabler for the integration of IoT education. This concept aligns with research conducted by Luque-Vega et al. (2020) that focuses on the design of IoT initiatives. However, the study specifically targets smart cities, which may include educational institutions as a subset. In addition, the research on planning has also shown that it assists in persuading executives and stakeholders to embrace IoT initiatives in education, hence securing government support and facilitating the advancement of such projects (Hsu and Yeh, 2017). In order to develop educational projects in IoT and create smart learning environments, which aid in the advancement of nations and peoples, it is also essential to draw on the experiences of developed nations and set highly valuable goals (Chen et al., 2014; Dai et al., 2021).

5.2.2. Preparing for a pioneering future generation

The analysis of experts' tweets on the individual enablers of IoT in education revealed the importance of ongoing investment in cultivating future human intellect. This investment aims to foster advancements in industries related to IoT, artificial intelligence, and programming, while tailoring them to the specific needs of societies at large and educational institutions in particular. This aligns with the research conducted by Chen et al. (2014), Wollschlaeger et al. (2017), and Zheng et al. (2016). Their studies focused on the growth of the communications industry and IoT networks during the Fourth Industrial Revolution. They emphasized the importance of preparing a forward-thinking future generation that can keep up with this progress, particularly in education as a cornerstone for societal advancement.

5.2.3. Professional training and development

The analysis of expert tweets on individual enablers of IoT in education has shown that it is essential for workers and employees in educational institutions to receive training when utilizing IoT solutions. Additionally, investing in their professional development and cultivating a mindset that embraces the transformation into smart educational environments is highly significant. Training a team of workers to install, maintain, and develop tools and devices for IoT and artificial intelligence is beneficial for their professional growth. This aligns with a study conducted by Shuzhen (2019) and Zheng et al. (2016). It is detrimental to build programs to train educational staff in the use of the IoT, in which case it is important to rely on digital environments and technologies that motivate trainees and enhance their adaptation to the content of the training programs (Al-Hafdi and Alhalafawy, 2024; Alnimran and alhalafawy, 2024; Alsayed et al., 2024; Alshammary and Alhalafawy, 2023; Alzahrani and Alhalafawy, 2023; Najmi et al., 2023; Saleem et al., 2024; Zaki et al., 2024).

5.2.4. Sustainability and ensuring security in the educational environment

The findings demonstrated that a key advantage of the enablers of IoT in education is its ability to consistently maintain the high standard of operational performance for IoT solutions throughout their entire existence. One of the contributing components to achieving sustainability is the use of sustainable energy sources to power IoT solutions. Ensuring the security and safety of the smart educational environment is crucial. This can be achieved by utilizing smart cyber systems to mitigate threats in educational institutions, as supported by various studies (Bedi et al., 2018; Bucea-Manea-Ţoniş et al., 2022; Martínez et al., 2021).

6. Limitation

Upon compiling a list of expert Twitter users on platform X, consisting of 12 participants, it became challenging to apply the standard of academic specialization to participants in computer science, information technology, and computer engineering-related fields. Some of these experts come from non-technical backgrounds, and their academic specializations have not been identified. However, they have significant influence on the IoT field and are considered authorities, sometimes being recruited as speakers at conferences or consultants in technological institutions. To verify the suitability of each expert on the list, the resume of each expert was reviewed by searching for their profiles on LinkedIn to confirm their expertise, academic background, and practical contributions in the fields of IoT and artificial intelligence. Additionally, an in-depth search was conducted within each participant's platform X account, not only limited to IoT, as it did not lead to the desired results based on search variables related to education. This necessitated using advanced search techniques, altering search terms associated with study variables, and experimenting with different terms each time to access the best tweets related to the potential of IoT in education from each participant's account. The research team attempted to reach the original tweet as much as possible in case there were instances of reused tweets with similar wording and content, striving to use the original tweets whenever feasible. Many tweets with good content were excluded due to containing links outside platform X. The primary focus of the research was to analyze tweets as textual content, but due to

the researcher's recognition of the importance of the media attached to the tweets, such as infographics and rich videos, the content of these was also transcribed.

7. Conclusion

The importance of the current research lies in demonstrating how to begin using IoT technology in education, as well as in helping to identify the key possibilities of IoT in education. The significance of the current research also lies in focusing on the analysis of experts' tweets in the field of IoT and artificial intelligence. These experts' tweet in the areas of IoT and AI are important to the audience interested in technology. Their tweets are used to develop a future vision for smart learning environments. The current study's most important findings regarding the material-based and software-based enablers of the IoT in education include network and communication availability, interactive devices, e-learning tools, integration of emerging technologies, data as a fundamental cornerstone, sensors, and system management. The key human capabilities for IoT in education are in planning, preparing future generations, professional training and development, sustainability, and maintaining the security of the educational environment. The results of the current study can serve as a cornerstone for prioritizing the deployment of IoT within educational environments, as the paper provides comprehensive evidence of the material and human factors that can be leveraged to enhance education using IoT. Future directions that can be pursued through the current research include the possibility of studying each potential aspect of IoT in education as an independent study, where a model can be presented based on linking IoT solutions to improve higher education environments or in public schools. Furthermore, the role of sensor data and IoT devices in assessing learning outcomes can also be studied. The application of IoT solutions to educational environments for students with special needs can also be the subject of research. Moreover, scientific investigations and educational laboratories may be utilized to conduct research on IoT solutions. Additionally, it is possible to generate proposed concepts that optimize the integration of IoT with emergent technologies in order to improve the educational process. In addition, research can be conducted on the impact of IoT on the professional development of faculty and staff, as well as on the training of instructors and students. The research team additionally recognizes the significance of reorganizing classrooms and the learning environment to accommodate IoT and for cultivating personnel capable of keeping up with this advancement in the field of education.

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