Perspectives on the Internet of Everything

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Abstract. In today's connected world, smartphones, watches, thermostats, and LEDs are a common feature of newly constructed buildings owned by not only technology enthusiasts but a majority of people. While the Internet of Things focuses on the connection of gadgets, the Internet of Everything (IoE) as a more holistic technology builds upon the idea of connecting devices, people, processes, data, and virtually everything via the internet. This paper provides an overview of the historical developments surrounding this evolving technology. Accordingly, the internet becomes a starting point and illustrates the steps towards a connected world. The ARPANET, mobile or connected devices, and the Internet of Things have fostered the consecutive stage – the IoE. It also outlines the current state of the art concerning its meaning, its effect on business models and research, and viewpoints toward future visions for education and other fields. The IoE is characteristic of the ambivalence of enormously high expectations and unresolved considerations that require intensive research and careful development in years to come.

Keywords: Internet of Everything · IoE · Things-people-data-processes · Historical overview · Future perspectives · People-to-machines

1 Introduction

A brief shopping tour for smart home devices quickly illustrates the breadth of the currently available technologies and applications. The world faces a transformation in homes from heating, light, power, and home security control to weather or indoor climate sensors and household robots. In addition, it has never been easier to manage one's household and even chores via the internet or a mobile device. The idea to connect single-purpose physical devices to the internet and each other aims at the intersection of gathering data and utilizing them.

The Internet of Everything (IoE) as a recently emerging concept goes even beyond this understanding, as it connects not only devices but people, processes,

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data, and things in an intelligent manner [17,37]. In this context, almost everything is online and connected via the internet, while data transfers (almost) occur in real-time. Moreover, due to content-based communication, artificial intelligence (AI), and machine learning, every interaction helps IoE devices become "smarter".

Therefore, the IoE has a greater scope and a broad range of possible future application scenarios, such as entertainment devices, distributed smart hardware, smart transportation systems or cities [35], and many more that cannot even list at this time point. The concept of IoE includes the Internet of Things (IoT) technology. It overlaps with ubiquitous computing, pervasive computing, industry 4.0, cognitive systems, the internet, communication protocols, cyber-physical systems, embedded systems, web 2.0, big data, and other related subject areas in computing.

This paper aims to provide a brief overview of the historical developments leading to the emergence of the IoE concept. This development comprises the emergence of the internet in the late 1960s, connected devices, the transition from fixed to mobile devices, and the Internet of Things. Furthermore, this work provides an overview of the IoE technology regarding its meaning, its effect on business models, and recent research on the IoE. It also outlines the importance of competency in IoE education and a vision of the IoE in the future.

2 Past Developments

The internet has been a persistent companion during the last decades for most people, even though its accessibility, appearance, and applications are constantly evolving. This section introduces some historical developments leading to the Internet of Everything that begins with the development of the technical

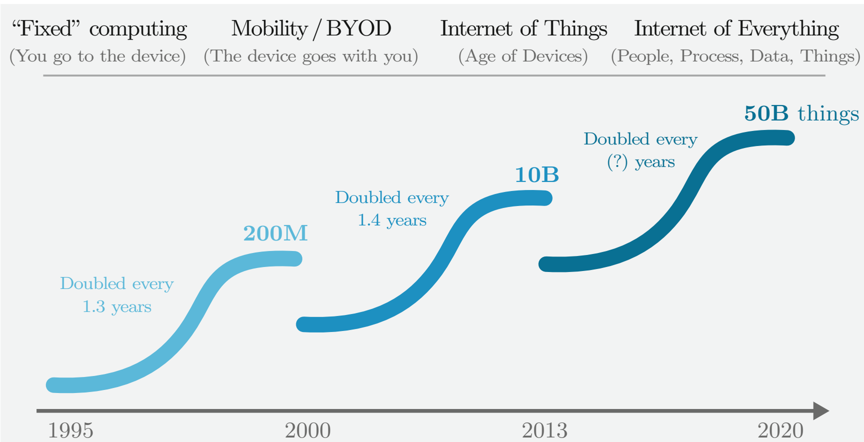

Fig. 1. Internet growth towards the IoE is occurring in waves [17].

foundation of the internet: The Advanced Research Projects Agency Network (ARPANET). The first connected devices, as well as the broad availability of mobile devices and WiFi, constitute further critical developmental stages culminating in the IoT as a precursor of the IoE (see Fig. 1) [17].

2.1 The Early Onset of Connected Devices

The internet has evolved through several stages since the late 1960s. These include academia (ARPANET), the informational stage (brochure ware), the transactional stage (e-commerce), and the social stage (web 2.0) [17]. Especially the ARPANET as a project on behalf of the U.S. Air Force constitutes a crucial starting point. It started in 1968 with a small group of researchers led by the Massachusetts Institute of Technology. It was the first network with distributed control. In 1977, the protocols TCP, and IP were first tested on ARPANET [18].

In the context of IoT and IoE, the connection of devices is of specific interest. For example, a Coke vending machine at Carnegie Mellon University was the first connected device. Students operated it, among them, David Nichols, a graduate student of computer science [1,25]. Due to the high demand for soda and the long travel ways on campus, he wanted to track the machine's contents remotely. So he worked together with Ivor Durham and John Zsarnay and established a connection to the ARPANET in 1982. Anyone connected to the university's Ethernet could find out if soda cans were available and which ones were cold enough. At the time, Kazar used to joke about toasters being connected to the Internet [51].

In 1990, John Romkey did connect a toaster to the internet by using a TCP/IP protocol, which unleashed creativity among scientists. Web cameras started monitoring coffee machines in computer labs [25], and in 1997 the idea of an internet-connected refrigerator emerged. LG Electronics introduced the cooling device with a LAN port for IP connectivity in 2000. It allowed users online shopping and video calls [1,25].

2.2 Mobile Devices and Expansion

With the emergence of mobile devices and wireless technology in the 2000s s and 2010s, connected devices started to upscale. In 2008, several big companies formed the Internet Protocol for Smart Objects Alliance and began to invest in respective research. Moreover, WiFi has become accessible to a significant number of people. The same is true for smart mobile devices [1]. Furthermore, in January 2010, Apple launched the first generation of the iPad [2].

Media coverage of connected devices and general interest increased at about the same time. The first international IoT conference occurred in Switzerland in 2008 and focused on Radio Frequency Identification (RFID) wireless communications over short distances and sensor networks. In the 2010s, the network layer protocol IPv6 emerged, and interconnected devices, such as thermostats, smart glasses, and light-emitting diodes (LEDs), were brought to the marketplace [25].

2.3 The Internet of Things

The label "Internet of Things" (IoT) was coined by Kevin Ashton in 1999 while working for Procter & Gamble. He used the term in the context of RFID-enabled device connectivity in the supply chain. The expression was supposed to attract the audience's attention [6,48]. In 2011, the IoT was added to the Gartner Hype Cycle for emerging technologies as "on the Rise" [19]. By now, the IoT refers to Internet-connected devices that can sense and share data, which is known as machine-to-machine (M2M) communication. Today, Internet Protocol (IP) forms a basis for IoT. The dictionary defines IoT as follows.

- "the networking capability that allows information to be sent to and received from objects and devices (such as fixtures and kitchen appliances) using the internet" [29]
- "objects with computing devices in them that are able to connect to each other and exchange data using the internet: Cloud applications will be used by billions of devices of all kinds, all connected to the internet of things. The internet of things might, for example, involve smart bins that can signal when they need to be emptied" [11]

The rapid evolution of the IoT has paved the way for further technological advances in numerous industries and markets, such as smart homes, transportation, cities, and healthcare. It connects things utilizing sensors, actuators, and network connectivity which allows them to collect and exchange data via the internet [43].

3 The Next Stage: IoE

The term "Internet of Everything", or IoE, was first used by CISCO's Dave Evans in 2012 [17] to describe a holistic concept of relevant and valuable connections between (1) people, (2) data, (3) processes, and (4) things. These "four pillars" are a novum compared to the IoT described by Weissberger [54], as IoT focuses mainly on the connections between things. However, it is still a relatively young term that is not widely known yet. Therefore, the IoE can also be perceived as the next stage of the IoT [15,48].

3.1 The Meaning of IoE

As depicted in Fig. 2, the IoE connects spaces such as people's homes with business and mobile settings. Connections to the internet include people-to-people (P2P), machine-to-machine (M2M), and people-to-machine (P2M) systems, while all of them comprise people, data, processes, and things. Thus, the IoE expands the communication channels beyond M2M communication in the IoT. According to Evans, the network effects create IoE's value and the opportunity for the internet's exponential growth and power. Eventually, individuals, businesses, and countries will be affected by the IoE as the gathered raw data

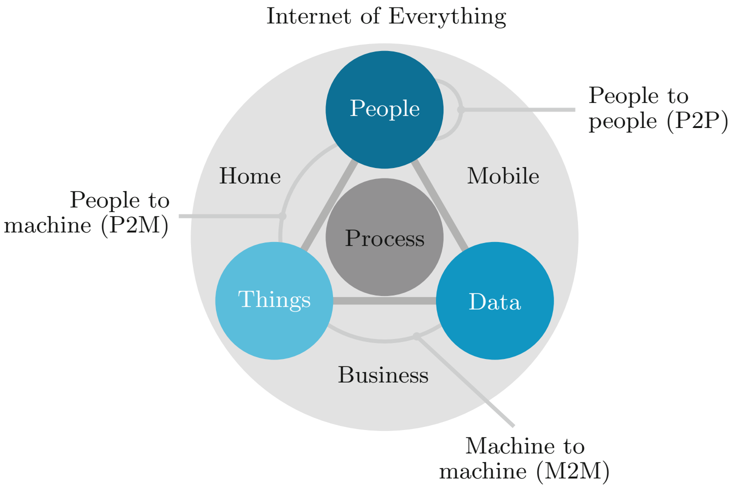

Fig. 2. The components of the Internet of Everything (IoE) [17].

becomes information. This activity is supposed to lead to learning processes, smarter decisions, and more effective control of the environment [17]. A CISCO study conducted in 2013 predicted a 14.4 trillion US$ value for net profit worldwide for the following decade [10]. It comprises the following key areas: asset utilization, employee productivity, supply chain and logistics, customer experience as well as innovation (including reducing time to market). In other words, the prediction is that IoE is a newly emerging and overly attractive market for businesses.

Nonetheless, CISCO's Chief Futurist describes the IoE as a technology that can benefit humanity, e.g., by making public communications more accessible via smart screens incorporating various modes of communication in real-time and offering WiFi to nearby devices. Conquering climate change utilizing sensors is one of the perspectives given in Evans' point of view for tomorrow. However, cooperation between government, organizations, businesses, and citizens is vital for overcoming the challenges of world hunger, water crises, and beyond [17]. Likewise, Mitchell et al. [35] suggest public policy goals, such as the monitoring of highways, education, and healthcare. Predicted barriers comprise technical challenges concerning network protocols (IPv6), power storage and energy capacities [17].

In 2015, Miraz et al. [31] note that the financial sector has already moved to mobile trading platforms by using smartphones and apps that IoE supports. Moreover, the expansion of cloud computing facilitates the connection of things, people, data, and processes in, for instance, shopping applications or mobile learning [24,32]. They assume that smart connections will determine the future. Due to the increasing urbanization by the 2050s, IoE will become a critical part of cities' infrastructures, and daily life [31]. Today, one can consider smart devices a constant companion in our everyday lives, even though we may not be fully aware of them. The transformation may have started subtle and unnoticeable. As the Internet of Things evolved during the last decade [38], we have become used to Alexa, smart TVs, doorbells, and other day-to-day objects. The explosion of available communication and interaction technologies leads to IoE being a broader perspective. According to Langley et al. [26], IoE expands IoT as it adds "links to data, people and (business) processes". Moreover, IoE comprises the Internet of People, the Internet of Nano Things, and the Industrial Internet.

Thus, it is possible to define the Internet of Everything as a distributed network of connections between people, smart things, processes, and data, whereas these components interact and exchange real-time data.

3.2 The Impact of IoE on Business Models

The Internet of Everything is certainly a door-opener for new applications connecting people and smart things as part of the increasing importance of digital technologies for value creation [9,21,23,28]. As IoE promises to change how we live, work, and interact, a significant number of industries and businesses require some remodeling to adapt and benefit from new opportunities related to smart things [50]. If smart things complement people's abilities, they can work on what they can do best and strive [27].

Langley et al. [26] review networked business models, service ecosystems, and how they organize their businesses. The resulting aspects concern the requirements for business transformation processes towards more value using IoE. For businesses, it is essential to consider the interoperability between systems and other industry partners, legacy processes and transactions, contracts, liability issues, security, data privacy, and the loss of control, to name a few [26]. In fact, the micro-, meso-, and macro-level of a service ecosystem are affected by a transformation towards IoE [39,41]. Another consequence is that current business models in individual industries may be fragmented and restructured due to overlapping systems and industries [40,52,55].

Fredette et al. [20] have outlined the perils and promises of hyper-connectivity as in IoE. Besides the suggested effects on social and professional organizations, neo-urbanization, (mobile) government (services), education, sustainability, and healthcare focus on businesses and the workforce. Furthermore, according to the Alcatel-Lucent report [20] as part of the World Economic Forum, the evolving IoE is going to affect the efficiency of supply chains positively. Supply and demand can be monitored and managed by employing sensors and machine-to-machine-to-human communications. The same is true for tracking inventories and the shipping of products. As a result, there is a significant reduction in human intervention, reducing costs and increasing profits.

Another aspect relates to the digitalization of human interaction within online social networks. For example, marketing and customer care need to take place on a new level (24/7) and via various online platforms and channels. In addition, expectations toward 99.9999 % of available services and systems and more are increasing. Therefore, platforms cannot fail in a hyper-connected business world. Similarly, workforces must face a significant shift towards mobile technologies and workplace settings. With increased broadband speeds, mobile devices, Web 2.0 tools, and applications, it has never been easier to work independently of a work location while collaborating with team members and customers. Also, the millennial generation is already using an interconnected environment, and they will embrace it as part of their work, which fosters the IoE transformation even further [20].

The IoE certainly has the potential to help transform today's business models and processes and to cause new cross-industry sectors and value chains in a globalized world. Depending on how smart things eventually become, networked business models will evolve. For example, Langley et al. [26] proposed a taxonomy of smart things based on their capabilities and their connectivity.

4 Recent Research on the IoE

Implementing the IoE comes with several challenges that, among others, affect the connection of billions of devices in terms of a smart network so that data can be gathered, analyzed, and shared, even distributed through users and devices. According to Shojafar and Sookhak [49], fog computing and cloud computing can provide the "network-plus-computing support by allowing the on-the-fly instantiation of software clones (e.g., virtual surrogates) of the physical sensing things onto resource-equipped nearby clouds (e.g., cloudlets) placed at the edge of the wireless access network" [49, p. 213]. Thus, dynamic local clouds might pose a solution with shorter service execution time and a greener computation and communication. At the same time, scalability and reliability can increase due to the highly dynamic environment, and fog computing can help decrease data traffic to the cloud.

Nevertheless, novel techniques and new approaches for modeling are required for its (network-aware) application in the context of IoE, as many devices have to become interconnected. Moreover, proper security and privacy-preserving mechanisms are necessary for its realization to avoid attacks and other security threats. The following studies illustrate the state-of-the-art challenges that are subject to research in the context of IoT and IoE models and architectures:

- Al-Janabi [3] describes a newly designed model which reduces both time and effort for students attending a lecture by using intelligent data analysis (IDA) and students' IoT devices.
- Mohsin et al. [36] focus on mutual authentication of IoT devices. They propose a comprehensive survey of current RFID systems with mutual authentification protocols with their strengths and weaknesses.
- Shamshirband and Soleimani [47] address the demand for efficient searching algorithms in peer-to-peer networks where there is no control over the object locations. They show the learning automata adaptive probabilistic search algorithm's superiority concerning its success rate with significantly reducing messages.

- Mishra and Jain [33] suggest ontologies as a semantic model for IoT-based devices and their representation of knowledge. The paper evaluates ontologies through several different metrics and presents pitfalls.

Similarly, the following research affects IoE performance issues.

- Mishra et al. [34] address security issues for IoT networks and data transfer, such as authentification, encryption, and cyber-attacks. The paper reviews various swarm-based anomaly detection methods and evaluates them.
- Jafari et al. [22] propose and validate a method for optimized energy consumption in wireless sensor networks by using a density-based clustering algorithm. The new approach derives from the OPTICS density-based clustering environment and excels at performance compared to similar algorithms.
- Venkatesvara et al. [53] introduce a hybrid texture features extraction method that is applied to the data transfer between edge/vehicular devices to estimate a video's motion. As a result, it is possible to reduce the storage capacities required for real-time video processing.
- Okafor et al. [42] investigate the Smart Hierarchical Network in the context of IoT, as it is considered a reliable Fog dynamic design structure based on a Software Defined Artificial Neural Network. The results encourage high scalability for networks with massive computational/traffic workload requirements.

Further research related to IoE concerns the investigation of connectivity linking sensors and control systems required to connect smart things and users. Technological developments will help the IoE to strive, especially concerning artificial intelligence [45], neural networks, big data [16], semantic interoperability and data management, localization and tracking capabilities, embedded security and privacy-preserving mechanisms [30], distributed technologies such as blockchain [5], interconnectivity [7], and so much more [12].

5 An Author Vision for IoE Education

The emergence of the Internet of Everything leads to a computing education question: Should there be a curriculum surrounding IoE? We have already seen that the concept of IoT started in the 1980s, but curricula and related degree programs began around the mid-2000s, with baccalaureate degrees awarded in the 2010s, specifically in China. Hence, it has taken about twenty years (a generation) for IoT to become a computing discipline. The authors see a similar emergence developing with IoE. Namely, the concept began in the late 1990s, so we expect an IoE discipline to emerge later in the 2020s.

5.1 The Meaning of Competency

If an IoE education discipline did emerge, what might it be? We can speculate many possibilities, from ubiquitous computing to other generalized forms. It should be clear that if indeed an IoE computing education discipline became a reality, it would have to reflect the needs of its stakeholders – mainly the computing industry. The IoE curriculum should focus on competency in this situation, as promoted in the CC2020 report [13]. The CC2020 competency definition evolved from many models and definitions. Specifically, the IT2017 report [46] and the CC2020 report [13] have promoted that knowledge, skills, and dispositions (behaviors) form a cluster described as

$$\text{Competency} = \text{Knowledge} + \text{Skills} + \text{Dispositions}$$

taken in context to accomplish a task. Figure 3 is an illustration of this concept, as shown in the CC2020 report.

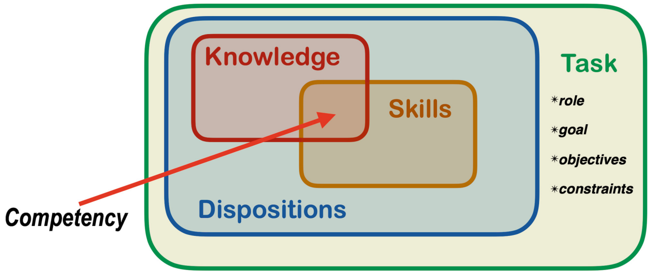

Fig. 3. Illustration of Competency [13].

We can think of *Knowledge* as the "know-what" dimension, an essential core concept for competency. The *Skills* element expresses the "know-how" dimension of competency, while the *Dispositions* frame the "know-why" dimension, suggesting a requisite characteristic in performing a task. Current teachers of computing programs at universities are experts in conveying knowledge to students. Some are also good at teaching computing skills. However, it remains questionable whether computing instructors can teach a disposition if it is some innate part of a person's character [14]. Perhaps dispositions are only an inherent outcome desired by employers. Irrespective of its current state, dispositions become a dimension of competency [44,56], the link between education and the practical world.

5.2 IoE Education

For an Internet of Everything curriculum to be successful, it must focus upon competency-based learning so that the curriculum links with the needs of its stakeholders, namely industry practitioners, educational authorities (e.g., ministries, governing bodies), computing educators, and students. Specifically, computing educators should understand how their current curriculum and a prospective IoE curriculum connect with the stakeholders. Likewise, the stakeholders should have their obligations to explore the potentially rich IoE curriculum and assist in shaping its structure so that IoE competent graduates can find a home in the workplace or delve further into advanced studies. Industry can foster active "partnerships" through meaningful internships and advisory board participation.

The Internet of Everything offers a unique opportunity to create a vibrant curriculum to address the computing curriculum-industry skills gap. The nascent nature of IoE allows it to be flexible in its curriculum development, unaffected by previous norms and faculty biases. The situation presents new horizons covering anticipated needs through a stakeholder partnership with global benefits through competency-based learning. Stakeholders should encourage computing programs to consider IoE education and establish a wholesome environment in this new learning area. IoE stakeholders must become inventive in contributing to this new horizon where competencies are central to learning. Using competency in IoE education should be a cornerstone of this new endeavor.

6 Other Visions for IoE

This section outlines several perspectives on the future of the IoE. Even though the field still requires much research, the majority of visions for a future with IoE are bright [8,10,17,35]. We start with CISCO's business-driven perspective on new markets and value. Then, Sandra Khvoynitskaya's reflection on security concerns and factors driving the IoE development and Tom Moran's extensive vision of the IoE offer other perspectives.

6.1 Market Perspective

In the business context, the CISCO white papers of 2013 and 2014 are straightforward [8,10,17,35]. They promise newly emerging market and business models for IoE. Above all, they imply huge monetary benefits for investing in transformational processes. In 2013, Bradley et al. [10] assumed a 14 trillion US$ value in the IoE, as costs can decrease while revenues are increasing. This situation is due to increased productivity of employees, a more efficient supply chain and logistics, more customers, and a high degree of innovation, causing a reduced time to market.

In 2014, Barbier et al. [8] claimed a 19 trillion US$ total value opportunity in the private sector for the following decade while expecting 50 billion connected devices in 2020. At the same time, they promote the more "efficient" exploitation of fossil fuels, oil and gas reserves through the IoE [8]. This condition seems particularly important as the world population is on the increase, more likely to live in big cities and therefore causing a lot of pressure on the energy market. So, Evans' early claims concerning humanity's benefits and counteracting climate change with the help of IoE must be questioned [17]. The same is true for the propositions by Mitchell et al. [35] regarding the improved livability in cities as a result of the IoE technology. Connected utilities and smartly monitored transportation systems certainly offer both value and opportunity for the global population [8]. The source of energy, however, is a critical aspect.

In 2020, the IoE market's value worldwide was estimated at 928.11 billion US$ [4]. Unfortunately, verifying these numbers is impossible within the scope of this paper. Nonetheless, recent predictions reveal that the IoE market expects to reach 4,205.5 billion US$ by 2030 at an annual growth rate of 16.5 % from 2021 to 2030 [4]. These trends in the IoE market are due to increasing urbanization, IoE software, and the internet's ubiquity, especially in North America.

6.2 Khvoynitskaya's Perspective

Sandra Khvoynitskaya presents another perspective as she discusses the expected merge of the IoE with other technologies, such as virtual and augmented reality, big data, AI, cloud computing, blockchain, and others [25]. Furthermore, the link to AI and machine learning strengthens in this context, as devices expect to become smarter and more autonomous by learning from users' patterns. This assumption reflects IoE's holistic nature and connections to several other subject areas. Furthermore, Khvoynitskaya assumes that the IoE will become more industry-specific, and new cross-industry technologies will develop (e.g., smart agriculture, smart retail, the Internet of Medical Things, etc.).

Khvoynitskaya outlines several security concerns she perceives as blind spots in the future. These comprise integration difficulties, unclear return on investment, lack of expertise to implement technology, interoperability concerns, data portability and ownership, vendor sustainability, transition risks, legal and compliance barriers, and network and vendor lock-in concerns. Nonetheless, the IoE development should strive due to falling costs for sensors, data gathering, and storage due to cloud solutions, expansion of internet connectivity, as well as an increasing number of mobile devices and computational resources [25].

6.3 Moran's Perspective

In a 2021 Tedx Talk, Tom Moran [37] presents a significant number of opportunities and developments for humans by using the IoE, thereby reflecting Dave Evans's early expectations [17]. The real power of the IoE is what Moran refers to as the "hive mind", the AI analyzing and "learning" from the gathered data. He considers the IoE the next evolutionary step, where even walls, pipes, and radiators become smart by utilizing nanotechnology. Moran includes people in this vision, as they may use smart wearables (e.g., contact lenses or augmented reality glasses) to interact with the AI or connect it to minds by some interface. Eventually, homes may become smart, alert people before a pipe breaks, or even call a plumber without inhabitants knowing or being home, or having to utter questions and needs [37]. The idea of the "big mother" taking care of our medical, mental and social activities and demands accompanies a vision of zero-emission homes, smart streets, neighborhoods, smart cities, and mega cities. According to Moran, scaling up IoE can lead to new growth and a new type of self-sustained civilization able to control emissions, electricity, farming, waste, water, traffic, and more. In other words: an intelligent world with complete control over humanity and nature. The smart solar system could be next [37].

If we continue Moran's purely capitalist narrative of infinite growth, the question arises whether the system would eventually end itself. Would humanity still strive for growth beyond the frontiers of space if everybody is taken care of by IoE? Will nature even survive the exploitation required for constructing the IoE? Will we survive in a world that will soon be hotter than ever by 2100? What happens to governments, lawmakers, and religious leaders? Will they accept the loss of power to the hive brain?

7 Conclusion

This paper addressed several perspectives on the Internet of Everything through historical pathways that led to one or more visions of its future. The IoE is a superset of IoT, which is a machine-to-machine phenomenon. However, IoE is much more than that. In addition to machine-to-machine experiences, IoE addresses the people-to-machine and the people-to-people incidents involving data and processes in an internet environment. IoE visions support this concept. The future of IoE education should encompass competency-based learning, which was the foundation of the CC2020 project and its report. The dispositions and skills dimensions of competency form the "people" part of IoE education. A competency-based framework of IoE education would ensure its success.

A realistic vision for the Internet of Everything should increase the understanding of a world that can strive for increased innovation in the future. Moreover, IoE can provide the groundwork for solving complex computing issues. One of the main questions is whether people desire to become transparent users by sharing all data and giving up control. Are we ready to do that? If so, who will push for further innovations? How will IoE reshape today's society?

The implications of IoE certainly go well beyond current computing and computing education. Therefore, IoE will soon require intensive consideration and research from all disciplines. Whether IoE becomes "the next big thing" is hard to guess. Its future is in your hands.

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