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Review

Education 4.0 in Developing Economies: A Systematic Literature Review of Implementation Barriers and Future Research Agenda

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Abstract: Education 4.0 (EDUC4) was driven by the onset of the Fourth Industrial Revolution (4IR) to meet labor market requirements resulting from learning that is customized, flexible, accessible, and skills-based. As the concept of EDUC4 develops popularity in the education and innovation research domains, various challenges about its implementation have emerged, especially in developing economies. Thus, there is a need to investigate the existing barriers to EDUC4 implementation. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, a systematic literature review of journal articles in the Scopus database was conducted. Of the 299 journal articles generated from the initial search on Scopus, 30 met the inclusion criteria and were included in the review. The content analysis yielded 12 barriers which include cybersecurity threat, costly, skills gap of human capital, apprehensive stakeholders, lack of training resources, lack of collaboration, knowledge gap for the customization of curriculum design, insufficient available technologies, health issues, time constraint for material preparation, complexity of learning platforms, and insufficient foundation of basic education. They were then associated with seven themes for better operationalization in Higher Education Institutions (HEIs): (1) human resources, (2) infrastructure, (3) financial, (4) linkages, (5) educational management, (6) learners, and (7) health and environment. Finally, a theoretical predictive model was constructed to present the causal relationships in modeling the problems associated with implementing EDUC4. The insights generated from this work offer both theoretical and practical perspectives for stakeholders of HEIs in the implementation of EDUC4 in developing economies.

Keywords: Education 4.0; higher education institutions; PRISMA; systematic literature review; barriers; developing economies

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1. Introduction

Education 4.0 (EDUC4) is a pedagogical approach that aligns with the fourth industrial revolution (4IR). It answers to the demands of the 4IR, in which the convergence of science and technology is utilized in augmenting manual processes for improved effectiveness and efficiency. EDUC4 recently captured the attention of policymakers, driven by the onset of 4IR. According to Fisk [1], a new vision of learning encourages learners to learn the skills and information they need and find the resources necessary to learn them. Learning is based

on understanding where and how to comprehend, and performance is tracked through data-driven customization. For example, Dunwill [2] reported that technology innovations continually change the teaching method and the learning environment. The learning process in EDUC4 may require the use of virtual learning environments (VLEs) to combine natural and virtual materials [3], a smart blended learning process with adaptive Internet of Things (IoT) using wearables and intelligent sensors [4], and artificial intelligence (AI) for system automation [5]. In the context of EDUC4, curriculum design, especially in higher education institutions (HEIs), reflects technology-based environments [6]. As EDUC4 intends to enhance higher education, every stage of its implementation is crucial and may not be straightforward. For instance, education leaders may overlook the possible causal relationship of challenges (or barriers) surrounding such implementation. A system view of EDUC4 implementation is, thus, warranted to address this problem. To this end, this work systematically identifies and examines the barriers to EDUC4 implementation.

Several frameworks have recently surfaced, describing how EDUC4 can be applied. For instance, Thailand's higher education commission implements the third framework of its 15-year long-range plans, which focuses on improving its people's quality—the so-called "Thai people 4.0" blueprint [7]. Also, Malaysia redesigned its learning and teaching curriculum to meet the unknown demands of the 4IR. With this, the Ministry of Higher Education [8] launched the book "Framing Malaysia Higher Education 4.0: Future-Proof Talents" to develop and enhance individual potential and fulfill the nation's aspirations. Similarly, Singapore launched the Smart Nation initiative, which drives the pervasive adoption of digital and smart technologies [9]. These practices form some benchmarks for developing countries to follow, such as the Philippines. Economists have highlighted that anytime new technologies are brought into an economy, there is a considerable lag period for the technology to be fully adapted to a level where they generate demonstrable productivity impacts [10,11]. The difficulties arise from the fact that technology development necessitates sufficient and appropriate educational change.

As the concept of EDUC4 gains traction in the domains of education and innovation research, several challenges about its implementation have become noticeable. For instance, managing educational systems in EDUC4 requires a manifold of digital skills for using intelligent agents, mobile technologies, cloud computing, among others [12,13]. While these skills are commonly taught in technology-intensive degree programs (e.g., engineering, computer science, information technology, among others), they are not as common in education programs that focus more on pedagogies. From this observation, it can be interpreted that university training of educators is causal to the lack of education professionals with digital skills to facilitate the implementation of EDUC4. Thus, higher education is necessary for improving the skills of the workforce that could effectively meet the implementation requirements of EDUC4 [14].

Creativity is an essential human characteristic necessary in EDUC4 [7]. Puncreobutr [12] emphasized ten powerful EDUC4 teaching tools: visual learning, evolved currencies, personalization, gamification, social media, game-based learning, connectedness, project-based learning, and digital and physical merge. The instrumentation of these tools requires teachers to become dynamic and more adaptive, unlike the conventional rigid approach to pedagogy. Empirical works in the education domain largely support the utility of these tools in learning (e.g., [15–17]). Despite the presence of these tools, education continues to be primarily considered through traditional lenses [18], which is apparent in the largely adopted formalist approaches of syntactical and formal knowledge [19]. However, the growth of new knowledge and its increasing availability via digital media suggest that educators need to become more flexible and creative in their instruction to be at par with industrial innovation. Infrastructure requirements (e.g., internet connectivity, digital communication suites, data centers and networks, digital hardware, among others) are essential to achieve this goal. Unfortunately, they are among the most difficult challenges HEIs need to address, especially in developing economies. Infrastructure to support information and communication technologies (ICTs) is one of the core components

of EDUC4 [20], while financial resources are the drivers of educational reform [21]. The limited resources that characterize developing countries warrant the adoption of alternative infrastructures for implementing EDUC4. A systematic investigation of these barriers would benefit the implementation of EDUC4 in financially desperate regions.

Apart from the pedagogical-, human capital-, and infrastructure-related barriers highlighted in previous discussions, the fundamental challenge to EDUC4 implementation is mainly institutional. Hershock et al. [22] reported that institutional change among HEIs lags against the growth of technological innovations. Among the cited causes of the slow response of HEIs to technological change is the asymmetry in the strategies of institutions to implement EDUC4 and the capacity of learners to respond to or comply with its requirements. Thorell et al. [23] pointed out the need to align EDUC4 implementation strategies to the needs and capacities of learners. For instance, strategies implemented by HEIs may require learners to have computers, but, in developing countries, such a strategy may not be effective due to the limited capacity of most families to acquire one. HEIs may instead provide within-campus access to computers and local area networks (LANs), but this entails costs shared among learners through miscellaneous school fees—making EDUC4 inequitable to learners coming from financially desperate households. Government institutions are also concerned by these challenges, especially with the rising importance of the roles of digital devices in education. Investigating the role of government institutions in addressing these problems is a relatively unexplored topic in the EDUC4 literature. Such intervention is vital, especially in developing countries.

A major challenge in digital education lies with how policymakers can more effectively assess and scaffold the development of EDUC4 [24]. It is apparent from previous discussions that there is a need to develop public-private collaborations, promote change mindsets, and provide the vital skill sets for teachers and learners to implement EDUC4. Addressing these concerns is critical to producing resilient and productive professionals in this technology-driven environment [8]. Indrajit et al. [25] stressed that it is paramount for governments and top management of universities in developing economies to initiate proactive measures that address the financial impediments surrounding the implementation of EDUC4. Partnerships with the public sector and ventures with other industries might be essential to achieving this goal. However, the current literature provides limited information on the effectiveness of these courses of actions.

The gaps in knowledge that are present in this domain may be summarized in three folds. First, limited efforts have been made to exhaustively identify EDUC4 implementation barriers in HEIs, particularly in developing economies. Second, little attention is provided in creating pathways to operationalize the barriers which would be adaptive for HEIs. Lastly, an attempt at developing a theoretical model that explains the relationships of EDUC4 implementation barriers for developing countries is not yet explored in the current literature. In bridging these gaps, this work employs a systematic literature review of barriers to EDUC4 implementation in the context of developing economies. It proposes a theoretical model of causal relationships among barriers for future empirical research agenda. This paper is organized as follows: Section 2 details the methodology of the systematic literature review of extracting barriers of EDUC4 implementation. Some descriptive results are shown in Section 3. Section 4 discusses the identified barriers within certain themes. Section 5 presents the future research agenda following a theoretical model that explains the problems associated with the implementation of EDUC4. It ends with the conclusion and discussion of future works in Section 6.

2. Methodology

This section describes how the final list of EDUC4 implementation barriers is established through a systematic literature review via the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [26]. The PRISMA offers a standard methodology using a rigorous set of guidelines in performing systematic literature reviews. The procedure begins by selecting a search database, implementing a search

through keywords, collecting reference articles, performing content analysis by identifying barriers, and evaluating the relevance and redundancy of the initial list of barriers. Finally, descriptive statistics are used to present the review's findings.

2.1. Selection of Databases

To extract a wide array of peer-reviewed articles from leading sources, the Scopus database was accessed. Only the relevant journal articles were extracted from the database to ensure extensive coverage of publications significant in identifying the possible barriers of implementing EDUC4.

2.2. Collection of Articles

EDUC4 is a relatively new topic and has not been comprehensively explored in the literature. The prominence of 4IR has widely influenced its emergence. Figure 1 reports the process of generating the final list of barriers through the PRISMA statement. The search query conducted in the Scopus database using the keyword "Education 4.0" yielded 5219 document results. Then, a filter applied to this query was based on the year of publication (i.e., 2015–2022), document type (i.e., article), subject areas (i.e., Engineering, Social Sciences, Computer Science, and Business, Management, and Accounting), language (i.e., English), source type (i.e., journal), and exact keywords (i.e., Education, Engineering Education, Education 4.0). A total of 299 articles were generated from the application of these filters. They were then evaluated based on the relevance of the barriers in implementing EDUC4. Journal articles that are not discussing EDUC4, the barriers to implementing EDUC4, and the implementation of EDUC4 in HEI settings were discarded. With these, 30 journal articles were identified to be adequate and appropriate for this study. Content analyses of these articles were performed to extract the relevant barriers. Appendix A shows the list of 30 journal articles with their corresponding year of publication, author(s), journal name, and title.

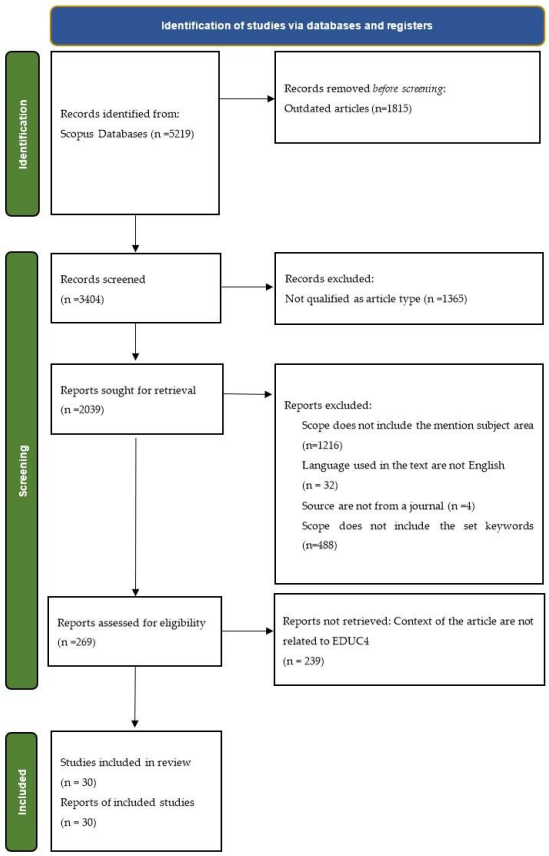

Figure 1. Reporting items for the systematic review (adapted from the PRISMA 2020 statement).

3. Results

3.1. Year-Wise Publication

The notion of EDUC4 has gained prominence since 2015, following the popularity of 4IR studies. As a result of the PRISMA statement, Figure 2 shows that interests in implementing EDUC4 have emerged for the past six years.

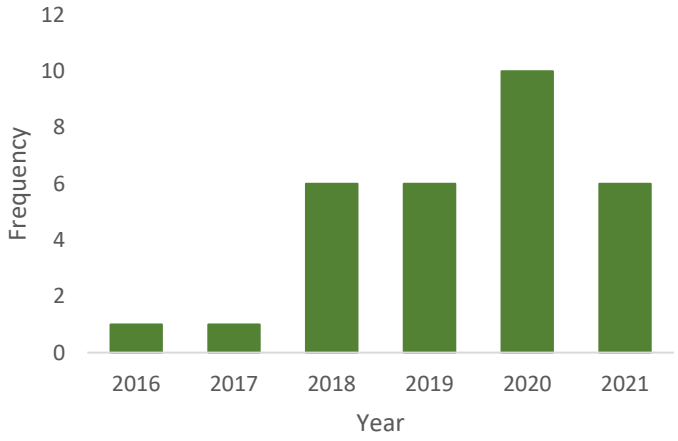

Figure 2. Number of publications per year.

3.2. Contributions by Publishers

A significant number of the available sources (15 out of 30) came from Elsevier, MDPI, Emerald, and Taylor & Francis (see Figure 3). Apparently, discussions of possible barriers to EDUC4 implementation are tackled across journals from different publishers. These insights imply that EDUC4 has been an emerging topic of scholars across related domains.

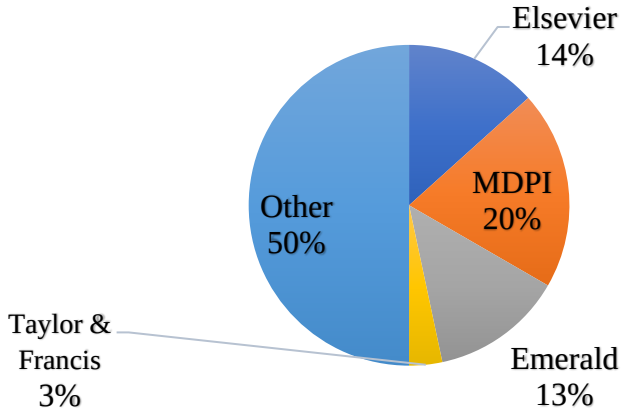

Figure 3. Number of publications from various publishers.

3.3. Contributions from Journals

Table 1 shows the journals along with the number of papers that were extracted for this study. It can be observed that the barriers to EDUC4 implementation are covered in various journals with a focus ranging from social sciences to applied technology. Results suggest that EDUC4 has been considered in different domains, as evidenced by the distribution of papers in various journals.

Table 1. Number of papers in each publishing journal.

Name of Journal	Publisher	No. of Papers Extracted
Social Sciences	MDPI	1
International Journal of Innovation, Creativity and Change	International Journal of Innovation, Creativity and Change	3
Computers and Electrical Engineering	Elsevier	1
Eurasian Journal of Educational Research	Eurasian Journal of Educational Research	1
Inteligencia Artificial	IBERAMIA Sociedad Iberoamericana de Inteligencia Artificial	1
Future Internet	MDPI	1
Journal of Applied Research in Higher Education	Emerald	1
Informatics	MDPI	1
Higher Education Pedagogies	Taylor & Francis	1
International Journal of Engineering Research and Technology	International Research Publication House	1
International Journal of Advanced Trends in Computer Science and Engineering	International Journal of Advanced Trends in Computer Science and Engineering	1
Computers, Materials and Continua	Tech Science Press	1
Rapid Prototyping Journal	Emerald	1
On the Horizon	Emerald	1
Education for Chemical Engineers	Elsevier	1
Education Sciences	MDPI	1
Sustainability	MDPI	2
Open Engineering	De Gruyter Open Ltd.	1
International Journal of Scientific & Technology Research	Other	1
Journal of Surgical Education	Elsevier	1
Cakrawala Pendidikan	Universitas Negeri Yogyakarta	1
Computer Applications in Engineering Education	Wiley Periodicals	1
Universal Journal of Educational Research	Horizon Research Publishing	1
Revue Roumaine des Sciences Techniques Serie Electrotechnique et Energetique	Romanian Academy	1
International Journal of Advanced Computer Science and Applications	Science and Information Organization	1
Asian Education and Development Studies	Emerald	1
Procedia Manufacturing	Elsevier	1

3.4. Contributions by Country

Based on the results shown in Figure 4, countries with leading research on the barriers of EDUC4 implementation are primarily from developing countries. In particular, authors from Malaysia have the highest percentage of publications (i.e., 26.67%). It was then followed by Mexico and Romania (i.e., 10.00%) and Vietnam (i.e., 6.67%). The remaining 13 countries, mostly developing economies (i.e., India, China, UK, South Africa, Russia, Netherlands, Spain, Finland, Michigan, Turkey, Philippines, Thailand, Czech Republic, and Indonesia), have 3.33% publications.

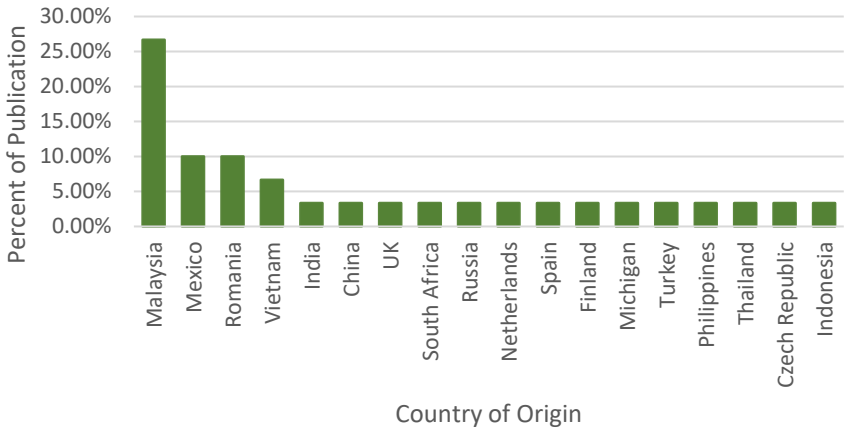

Figure 4. Number of publications according to the country of origin.

3.5. Content Analysis

A comprehensive evaluation of the 30 journal articles was conducted to extract the barriers. The initial list of barriers was then evaluated to remove redundancy or merge the barriers with similar concepts. As a result, 12 barriers were identified, as presented in Table 2. In addition, a brief description from the relevant articles is supplied to each barrier.

Table 2. List of Barriers in Implementing EDUC4.

Code	Barriers	Brief Description	References
B1	Cybersecurity threat	The threat of information leakage, security attacks, and misusage of technology.	Hariharasudan and Kot [27]; Mogoş et al. [28]; Bonfield et al. [29]
B2	Costly	Implementation of EDUC4 is associated with higher costs (e.g., acquisition of equipment, maintenance).	Hariharasudan and Kot [27]; Halim et al. [30]; Jamaludin et al. [6]; Liljaniemi and Paavilainen, [31]; Bonfield et al. [29]; Boca [32]
B3	Skills gap of human capital	Insufficient knowledge and experience of the human capital in using digital technology for education, including the lack of specific skills (i.e., critical thinking, emotional intelligence).	Suhaimi et al. [33]; Halim et al. [30]; Chen et al. [34]; Lea, [35]; Liljaniemi and Paavilainen [31]; Alabi, [36]; Alakrash and Razak [37]; Boca [32]; Kumar et al. [38]; Asfar et al. [39]
B4	Apprehensive stakeholders	Apprehension of some stakeholders (i.e., learners, educators, administrators) to EDUC4.	Mogoş et al. [28]; Popkova and Zmiyak, [40]; Sarsar et al. [41]; Jamaludin et al. [6]
B5	Lack of training resources	The lack of training resources (i.e., facility, materials) for the professional development of educators.	Anito and Morales, [42]; Lea, [35]; Ishak and Mansor, [43]; Jamaludin et al. [6]; Boca, [32]
B6	Lack of collaboration	Lack of collaboration with other sectors (i.e., community, government, other HEIs, industry) is essential in successfully implementing EDUC4.	Turcu and Turcu, [44]; Vu, [45];
B7	Knowledge gap for the customization of curriculum design	Current lack of knowledge to create a customized curriculum design to enhance learners' skills (i.e., creativity, critical thinking) and promote skills-based training.	Buasuwan, [7]; González and Calderón, [46]; Turcu and Turcu, [44]; Mogoş et al. [28]; Vu, [45]; Anito and Morales, [42]; Halim et al. [30]; Abdul Bujang et al. [47]; Lea [35]; Marie and Kaur, [48]; Miranda et al. [20]; Ramírez-Montoya et al. [49];
B8	Insufficient available technologies	Due to the rapid advancement of technology, developing countries cannot catch up with those developed ones. Some technologies might be available in some countries but not in others.	Halim et al. [30]; Jamaludin et al. [6]; Ishak and Mansor [43]; Alakrash and Razak [37]; Miranda et al. [20]; Zamora-Antuñano, [50];
B9	Health issues	Prolonged exposure to the technology may cause health issues in the physical and mental well-being of the learners and educators.	Suhaimi et al. [33]; Alakrash and Razak, [37];
B10	Time constraints for material preparation	Preparing and teaching in a virtual learning platform requires more time than the traditional one.	Ambani et al. [51]; Boca, [32]
B11	Complexity of learning platforms	The challenge that the users (i.e., learners and educators) face on utilizing the virtual learning platform.	Mogos et al. [28]; Abdul Bujang et al. [47]; Azman et al. [52]; Jamaludin et al. [6];
B12	Insufficient foundation of basic education	Quality primary education of learners is essential in the implementation of EDUC4 in HEIs.	Hariharasudan and Kot, [27]; Bonfield et al. [29]; Alakrash and Razak, [37];

4. Thematic Analysis of EDUC4 Implementation Barriers

From the identified 12 barriers of EDUC4 implementation, we extracted various themes that may be relevant in decision- and policy-making at the HEI level. Table 3 shows a mapping of the barriers to specific themes, where a ✓ mark indicates such a mapping. It is crucial to note that a particular barrier (e.g., skills gap of the human capital) may be associated with different decision-making areas in an HEI organization. On this note, responding to such a barrier requires collective action from various role-players of the HEI. Thus, it would be more efficient to identify areas (i.e., themes) that are well-defined in an organization and then formulate corresponding response mechanisms. On the other hand, identifying those themes along with the barriers associated with those themes would facilitate economies of scale and economies of scope. This happens as a specific response strategy on a theme may target more than one barrier within the same theme; hence, desired targets are achieved more efficiently.

Table 3. Barriers relation to identified categories.

Barriers	Brief Description	Themes						
		Human Resources	Infrastructure	Financial	Linkages	Educational Management	Learners	Health and Environment
Cybersecurity threat	The threat of information leakage, security attacks, and misusage of technology.	✓	✓			✓	✓	
Costly	Implementation of EDUC4 is associated with higher costs (e.g., acquisition of equipment, maintenance).		✓	✓		✓		
Skills gap of the human capital	Insufficient knowledge and experience of the human capital in using digital technology for education, including the lack of specific skills (i.e., critical thinking, emotional intelligence).	✓	✓	✓	✓	✓		
Apprehensive stakeholders	Apprehension of some stakeholders (i.e., learners, educators, administrators) to EDUC4.	✓			✓	✓	✓	
Lack of training resources	The lack of training resources (i.e., facility, materials) for the professional development of educators.	✓	✓	✓	✓	✓		
Lack of collaboration	Lack of collaboration with other sectors (i.e., community, government, other HEIs, industry) is essential in successfully implementing EDUC4.		✓		✓	✓		
Knowledge gap for the customization of curriculum design	Current lack of knowledge to create a customized curriculum design to enhance learners' skills (i.e., creativity, critical thinking) and promote skills-based training.	✓	✓			✓	✓	
Insufficient available technologies	Due to the rapid advancement of technology, developing countries cannot catch up with those developed ones. Some technologies might be available in some countries but not in others.	✓	✓	✓	✓			
Health issues	Prolonged exposure to the technology may cause health issues in the physical and mental well-being of the learners and educators.	✓	✓			✓		✓
Time constraint for material preparation	Preparing and teaching in a virtual learning platform requires more time than the traditional one.	✓				✓		✓
Complexity of learning platforms	The challenge that the users (i.e., learners and educators) face on utilizing the virtual learning platform.	✓	✓			✓	✓	
Insufficient foundation in basic education	Quality primary education of learners is essential in the implementation of EDUC4 in HEIs.					✓	✓	

In generating these themes, we evaluate the framework proposed by Miranda et al. [20] and appropriately customize such a framework to capture the broader scope of an HEI organization when EDUC4 is implemented. Miranda et al. [20] suggest four core components of EDUC4: competencies, learning methods, ICTs, and infrastructure. We extend these components into a more overarching scope within the decision-making borders of an HEI. A brainstorming session among HEI administrators was conducted to identify these components or themes cautiously. After a careful discussion and deliberation, while keeping the core components of Miranda et al. [20] into consideration, seven themes were generated: human resources, infrastructure, financial, linkages, educational management, learners, and health and environment. In addition, another brainstorming session associates each barrier with the themes. The association of barriers to themes signifies their inclusion within the scope of the themes. This mechanism allows response efforts of the HEI on a theme to address multiple barriers. In the following discussions, we (1) discuss each theme in the context of the associated barriers, (2) examine how these barriers play in developing economies.

4.1. Human Resources

Human resources refer to the professionals (e.g., educators, managers, technicians) that accomplish the processes required to implement EDUC4 in HEIs. The human capital theory posits that the productivity of human beings is determined by their level of education and skills training [53]. In the context of EDUC4, it is desirable to have human resources skilled at digital technologies [34,35]. Lack of human resources with these skills **(B3)** is one of the most common barriers to EDUC4 implementation [31,36].

This barrier is prevalent in developing economies due to insufficient infrastructures and other resources that facilitate the training of professionals **(B5)** on digital technologies essential to the implementation of EDUC4 [20,37,50]. It is more relevant in developing countries having relatively lower computer literacy [54]. On the other hand, the limited experience of educators on EDUC4 would limit them to design a curriculum **(B7)** customized to fit the sophisticated EDUC4 system [20,49].

Cybersecurity threats **(B1)** also arise from the lack of technology-competent professionals in the education sector. Cybersecurity relies heavily on competent "techno-savvy" individuals [27–29] for keeping online "pirates" at bay. Lower computer literacy **(B3)** entails less competent human resources for jobs related to cybersecurity. These threats may brand EDUC4 less reliable and reduce stakeholders' confidence towards it **(B4)** [6]. The lack of technology-competent professionals and insufficient infrastructures **(B8)** for operating EDUC4 technologies also has a negative impact on the perception of stakeholders towards the effectiveness of EDUC4 **(B4)** [6,28,40,41]. This apprehension towards technology-driven change can derail efforts to increase intention to adopt EDUC4.

This apprehension of stakeholders is enforced by ignorance about EDUC4 and the latent fear for change, especially with potential health implications **(B9)** [33,37]. For instance, prolonged exposure to digital devices has been associated with health problems such as eye strains, insomnia, stress, and anxiety disorders [55]. Furthermore, the lack of experience in using digital devices could reduce the utility of digital technology in automating otherwise manual processes involved in instruction. For instance, novice users might take more time or incur more mistakes when preparing class discussions using digital technologies than the traditional method [32,47,52]. This issue is also attributed to the complexity of learning platforms required in EDUC4.

The implications of EDUC4 implementation barriers on human resources can be summarized into two main themes: technical and behavioral. Technical implications are directly related to the skills, reliability, productivity, and physical well-being of human resources in an education system. On the other hand, behavioral implications are related to the trust or confidence, satisfaction, and emotional well-being of educators in an education system. Determining these themes is essential in measuring the effects of interventions for addressing EDUC4 implementation barriers in the future. For instance, interventions

targeted at minimizing technical implications may be assessed by direct measurements, e.g., pen-and-paper assessments for skills evaluation. On the other hand, those targeted at reducing behavioral implications may be evaluated through indirect methods, e.g., qualitative surveys.

4.2. Infrastructure

Infrastructure refers to a combined set of hardware, software, networks, facilities, among others (including information technology-related equipment and facilities), necessary to implement EDUC4. The unavailability of technology has been an identified barrier to EDUC4 implementation in developing economies. Malaysia's Ministry of Education recognized the need for reforms in response to EDUC4, including adjusting to new learning environments and using new technologies [56]. As Malaysia tries to turn itself into a developed economy, such shifts have caused challenges to educational institutions [57]. Limited and inefficient educational resources **(B5)**, outmoded teaching approaches **(B7)**, poor infrastructure **(B8)**, and a lack of close links between educational institutions **(B6)** are among the obstacles [58]. These barriers are more prominent in developing countries due to the lack of facilities and other resources **(B8)** that enable the implementation of EDUC4. EDUC4 requires adjusting traditional curricula to fit the IoT platforms. These platforms require critical thinking, problem-solving, communication, teamwork, and inventive thinking skills. Critical thinking and problem-solving skills, in particular, entail the ability to comprehend an issue and search for relevant information so that many points of view can be considered. Due to the nature of EDUC4 that is technology-driven, it demands innovative and creative thinking. A lack of digital proficiency among some educators **(B3)** would be a significant barrier with the new technology brought by remote learning. This may be overcome by conducting training programs and workshops for educators [37]. These barriers were made evident during the onset of COVID-19.

COVID-19 caused an unprecedented crisis across the board. In the education sector, a large part of the measures that countries have adopted in the face of the situation has been related to the suspension of face-to-face classes at all levels, which has given rise to three main fields of action: the deployment of distance learning modalities through the use of a variety of formats and platforms (with or without the use of technology), the support and mobilization of educational staff and communities, and attention to the health and integral well-being for both teachers and learners [59,60]. To cope with the abrupt switch to distance learning, both learners and educators used online teaching software and social media platforms with limited engagement [37]. They used Zoom, Google Classroom, Telegram, Free Conference, and WhatsApp extensively for more accessible communication with learners during the pandemic. Problems commonly faced in remote learning due to the insufficient availability of technology (no webcam) or unstable Internet connections, not only to Malaysia but also to other developing economies. The pandemic has brought with it not only the risk of infection but also health issues from long-term exposure to the new technology utilized in distance learning. These problems may be relevant in the long-term implementation of EDUC4.

Nevertheless, adopting technology to improve learning in EDUC4 has many advantages but entails some drawbacks that impede implementation. With such large amounts of data and sophisticated educational systems **(B11)** [28], data privacy issues **(B1)** become a significant challenge. Moreover, despite the positive impact of EDUC4 in facing disruptive changes and global trends, specific considerations must be critically examined. Successful implementation of EDUC4 requires a considerable investment from the government to aid in infrastructure development. For instance, the Massive Open Online Courses learning concept is only workable if the Internet coverage is inclusive and meets the quality standards [30], which may not be observed in developing economies.

4.3. Financial

The teaching and learning process has evolved as a result of the rapid advancement of technology. The transition of HEIs from their previously well-adapted nature of education to EDUC4 is a much-needed reform that will equip learners with skills that conform to future labor market requirements [27]. In this advancement, according to Lee (2020), technology is gradually replacing human capital **(B3)** in nearly all tasks, including transportation, manufacturing, health, and security. A lack of consumer technology **(B8)** and expertise, managerial support, and economic advantages from digital initiatives are identified as impediments in adopting such transition among the human resource [23].

To adapt to current societal settings, initiatives and programs must match educational institutions' demands and requirements [20]. Some HEIs have already been setting the basis for a new approach to higher education [29] and examining how the sector may adapt to employment requirements by investing in innovative technology (e.g., sensors, cyber-physical systems, IoT, modified adaptive resonance theory neural networks, automation of machines) [27]. As part of EDUC4 implementation, investments in digital technologies have unknown economic advantages and significant financial investment needs.

4.4. Linkages

Cross-sector linkages and partnerships of HEIs are in high demand and a crucial factor in a successful EDUC4 implementation. Cross-sector linkages are based on a whole institution approach, which considers that universities operate within complex environments. All parts of this environment need to be considered when implementing sustainability strategies and innovation (e.g., EDUC4) [61]. Hence, a great variety of actors need to be involved in realizing them. The challenges of linkages and collaboration strategies between HIEs and the emerging global and local skill providers make educational reform more complex among developing economies [6]. The lack of collaboration **(B6)** between HEIs and external sectors, especially the industrial sector, leads to the inability of the curricular offerings to provide learners with a good set of skills necessary to address the gap of the human capital, a prevalent barrier of implementing EDUC4. Thus, it is essential for HEIs to reach out for collaboration and linkages with external sectors since such linkages are a gateway for HEIs to develop essential modern training procedures necessary for the implementation of EDUC4 [35].

The benefits gained from the linkage of HEIs with industries, public institutions, and professional and local communities include the promotion of ICT usage in creating learning networks and sharing knowledge and support necessary for interdisciplinary learning and research. It implies that the availability of technology necessary for the implementation of EDUC4 and the training materials often rely on the strength of these linkages [7]. Thus, the lack of institutional and external support would lead to the availability of technologies and training resources becoming insufficient. On the other hand, the apprehension of stakeholders **(B4)** in the implementation of EDUC4 is considered one of the factors that weaken the linkage between stakeholders and hinder realizing innovation initiatives [28]. EDUC4 requires high implementation cost **(B2)** [27]. HEIs, especially public HEIs, usually rely on external sectors for financial funding to support significant investments [30]. Thus, having apprehensive internal and external stakeholders would hinder the implementation of EDUC4.

4.5. Educational Management

Educational management processes involve the arrangement and deployment of systems that ensure the implementation of policies, strategies, and innovation initiatives throughout a set of integrated practices to achieve educational goals [62]. Almost all the barriers in EDUC4 implementation are associated with educational management. The most compelling one is the customization of the curriculum design **(B7).** An essential component of EDUC4 is designing an enhanced curriculum that caters to learners' technical and soft skill competencies necessary to address labor market needs. For instance, the

demand for a human resource with knowledge and skills in machine automation requires HEIs to rethink educational aims and redraft contemporary curricular designs, such as setting machine automation as a significant subject in simulation and control systems in engineering education [31]. Thus, for educational management, the challenge lies in developing an effective and efficient curriculum design that caters to the demands of globalization, focusing on developing a set of necessary skills to address such needs.

One of the elements of EDUC4 is virtual engagement between learners and educators **(B11)**. Advances in technology significantly support distance education which gives rise to virtual classrooms. The effectiveness of this type of virtual setting lies in the available infrastructure and its efficiency [47]. Virtual platforms can be complex and challenging to navigate, which leads to a slow learning and instruction pace. It is also important to note that virtual learning implies prolonged screen time **(B9)**, which can be detrimental to the well-being (i.e., mental and physical) of educators and learners [33]. Moreover, the considerable amount of data caused by the complex design of the learning platforms poses a threat to data privacy [28] **(B1)**. Another challenge brought by virtual classrooms is the time constraint for material preparation **(B10)**. For educators, preparing the necessary virtual environment and materials for successfully conducting effective instruction requires more time and effort compared to the traditional way of instruction [32].

Another barrier associated with educational management is the skills gap of the human capital **(B3)** in providing quality instruction. This is due to the insufficient knowledge and experience of the teachers in using new technologies and the inability to execute required pedagogies for a new curriculum designed to cater to EDUC4 requirements [30]. This barrier is associated with the lack of training resources **(B5)** for professional development, which could be a case of insufficient institutional support in educational management. Aside from that, skills- and knowledge-gap and differences in learners' learning pace (B12) are highly associated with the teachers' guidance and curriculum design [33]. Moreover, since implementing EDUC4 is a costly initiative **(B2)** which is heavily dependent on institutional support (i.e., funding) and monitoring to be successfully employed, the lack of this support subsequently leads to unsuccessful transition of education systems to EDUC4 [63], particularly relevant in developing economies. This consequence is brought by having apprehensive stakeholders **(B4)**. Without the support of these stakeholders and the lack of collaboration with external and internal stakeholders **(B6)**, initiatives in the EDUC4 implementation would be hindered. Hence, institutional support in HEIs is essential in carrying out innovation strategies to accomplish educational goals.

4.6. Learners

A shift of pedagogy brought by the adoption of EDUC4 has driven teaching practices to focus on catering to the individual needs of learners. In particular, the efforts of HEIs for EDUC4 must ensure the development and enhancement of learners' technical and methodological skills. Thus, it is evident that the implementation of EDUC4 brings forth challenges that directly confront the learners who must adapt to this change. Moreover, the capacity of the learners to adapt to EDUC4 has a significant impact on the success of implementation. It is noticeable in developing economies that learners' competency is highly challenged. In fact, the study conducted by Hinostroza [64] showed that the learners' more advanced ICT skills are significantly dependent on their economic, social, and cultural capital. Thus, a need to consider the learners' capacity to implement EDUC4 in developing economies is necessary.

EDUC4 encourages educational institutions to focus on a skills-based teaching approach rather than the traditional instructional method. Furthermore, the curricula in EDUC4 need to cater to the individual needs of the learners and allow them to acquire skills and knowledge **(B7)** that are unique to human beings to compete in the machine-dominated era [42]. This poses a challenge since this particular process has not been widely executed, and the resources to be regarded as references are limited. To address this challenge, Mogoş et al. [28] emphasized the relevance of the learners in the development

of their curriculum, wherein their input on the content and flexibility of their courses are regarded as critical. Moreover, the curriculum design needs to consider the learners' skills and knowledge gap and the difference in learning pace **(B12)** [33]. This particular gap is identified by Bonfield et al. [29] as a challenge posed by emerging technologies. The skills gap is highly notable in developing economies, where most people have no access to new technologies [64]. Thus, there is a limited familiarity with the usage of those technologies.

Contemporary learners are digital natives who prefer e-learning platforms [47] and online assessment [32]. However, the use of smart products in the classroom, which obtains data that may disclose classified information unknown to users, including the school, poses a considerable dilemma on cyber security **(B1)**. Furthermore, Mogos et al. [28] highlighted the learners' excessive usage of data due to the complexity of the educational system that poses a threat to data privacy since learning confined in a classroom has shifted to learning through different platforms. Software, mobile applications, digital libraries, coursework-specific technologies, and the likes are essential means, and educators combine these platforms for best results. Multiple system interconnections may also discourage learners **(B4)** whose basic education background was in a conventional way of learning. Furthermore, learners still have a skeptical attitude towards the usage of ICT tools for learning purposes. However, Sarsar et al. [41] emphasized that this skepticism can be reduced if ICT tools should be integrated into the designed curriculum.

4.7. Health and Environment

Mentorship of state-of-the-art educators, digitally inclined learners, and technology-based learning environments are necessary for EDUC4. Smart classrooms are enhanced by augmented reality, and those virtual classrooms are emerging in today's learning [65]. However, the dominance of this type of learning engagement requires a significant amount of time spent interacting virtually rather than socially. In EDUC4, learners spend more time in digital resources than reading books and interacting with educators online rather than face-to-face [7]. Cyber collaboration among learners and the HEI community is increasingly popular in an EDUC4 environment. Such a type of more virtual engagement has made both teachers and learners digitally connected but socially disengaged. Lawrence et al. [66] highlighted that technology-driven learning makes learners disconnected from the real world.

As EDUC4 is taking advantage of technology, learners' screen time is significantly increasing. Prolonged screen time negatively affects health, including mental health [33,37,67] **(B9)**. Social contact is crucial to keeping one's mental health sound, which has become a limitation with the implementation of EDUC4. Potential tradeoffs in digital tools include loneliness paradox and Zoom fatigues [68]. This barrier is relevant both in developed and developing economies. In the Philippines (i.e., as a developing economy), where Internet speeds are significantly slower than those in the developed world, teachers and learners are more exposed to digital screens, which may have adverse health impacts. The exact number of tasks would require higher screen time at slower Internet speeds than those working with faster speeds. In addition, with the presence of virtual classrooms, educators would require a significant amount of time in teaching material preparation [51], [32] **(B10)**, in contrast to the traditional classroom setup. Most of the time spent preparing for teaching materials is consumed in front of screens, which may have detrimental health effects. Thus, health and environmental issues become an essential point of discussion in the implementation of EDUC4.

5. Future Research Agenda

As demonstrated in the previous section, the implementation of EDUC4, particularly in developing economies, is faced with an array of barriers linked to potential problems in HEIs. Furthermore, the identified implementation themes which encompass a defined set of barriers must be treated in a network of causal relationships. Identifying these causal relationships is crucial in modeling the problems associated with the implementation of EDUC4. This section proposes a set of future research agendas by offering a theoretical pre-

dictive model which describes the EDUC4 implementation problems of HEIs, particularly in developing economies.

5.1. Educational Management

The curriculum design for EDUC4 must sufficiently cater to the learners' technical skills and, at the same time, consider teacher competency. Moreover, curriculum design can also address labor market demands set by various industries [31]. Thus, the need for participation from the various stakeholders (i.e., human resources, learners) and proper training to address the skills gap of the educators is an essential component to consider in EDUC4 implementation. On the other hand, the complexity of virtual learning platforms can lead to data security [28] and misinformation threat, which reflects the poor design of technological infrastructure and can also directly affect implementation problems of EDUC4. Furthermore, the implementation of EDUC4 is a costly initiative for HEIs [63], especially in developing economies.

Consequently, the need to collaborate with the sectors for external funding has a critical role in the implementation process. In particular, university administrators must carefully study their respective institutions' fiscal management, acquisition of funds, and educational infrastructure [69] to secure external financial support. Furthermore, the HEI organization must also address the apprehension of significant stakeholders to adopt innovative changes by EDUC4 to cushion immediate problems caused by the implementation. These aspects primarily need institutional support to accomplish the educational goals of EDUC4. Thus, the following hypotheses are stated:

Hypothesis 1 (H1). *EM impacts linkages.*

Hypothesis 2 (H2). *EM impacts financial aspects.*

Hypothesis 3 (H3). *EM impacts human resources.*

Hypothesis 4 (H4). *EM impacts infrastructure.*

Hypothesis 5 (H5). *EM impacts learners.*

Hypothesis 6 (H6). *EM impacts implementation problems of Education 4.0.*

5.2. Linkages

Linkages from international organizations and industries can help institutions stretch limited resources and improve their curricula. The barriers associated with this theme include the insufficient knowledge and experience of the human capital in conducting quality instruction and the learners' lack of skill competencies to cater to labor market needs. These barriers are linked to the lack of training resources, apprehensive stakeholders, and the lack of partnerships and collaboration strategies between HEIs and industries, public organizations, and professional and local communities [6], which are more pronounced in developing economies.

Cross-sector linkages of HEIs are crucial in augmenting their financial capabilities to support initiatives associated with the implementation of EDUC4 [70]. Note that in developing economies, HEIs rely heavily on external funding to carry out educational goals. Thus, the presence of barriers associated with linkages undermines the financial capabilities of HEIs, such that the lack of collaboration means reduced external funding, which is essential in progressing innovative initiatives. As discussed in the previous section, one benefit of linkages is the provision of available technologies by the external sectors to HEIs [7]. The lack of collaboration among stakeholders would lead to the unavailability of technologies and infrastructure that are essential in carrying out EDUC4 implementation. In a broad sense, linkages indirectly affect human resources and learners since they can

develop exchange faculty programs and faculty emersion, on-the-job training, and learner project-based funding. Hence, the following hypotheses are proposed.

Hypothesis 7 (H7). *Linkages impact financial aspects.*

Hypothesis 8 (H8). *Linkages impact infrastructure.*

5.3. Financial

The viability of implementing EDUC4 is primarily tied to financial constraints. In developing economies, these constraints are worsened by a manifold of political and socio-economic challenges. The constructs that impact the financial construct are educational management (H2) and linkages (H7). Politics in developing economies are usually characterized by patronage more so than effectiveness and efficiency. The roots of this problem are typically cultural and are often extended to institutions, e.g., educational institutions. Incompetent management of educational institutions may compromise the safeguarding of funds essential to EDUC4 implementation. Mismanagement or even malversation of funds causes educational institutions to settle for substandard infrastructures. It also deprives human resources of funds for needed equipment, skills development, and adequate employee compensation. A way to address this problem is through linkages for which financial support can be sought. Nevertheless, the impact of the financial construct on infrastructure and human resources is apparent, although the complexity between these relationships makes the impact unclear. The following hypotheses are developed from these arguments:

Hypothesis 9 (H9). *Financial impact infrastructure.*

Hypothesis 10 (H10). *Financial impact human resources.*

5.4. Human Resources

For the most part, the construct of the human resources is the recipient of the impacts coming from other constructs such as educational management, financial, and health, and environment. These relationships can be rationalized in three ways. First, the effectiveness of human resources in educational systems is inherently dependent on leadership. Second, the availability of financial resources restricts the productivity of human resources. Lastly, the inherent physical and mental health limitations, and motivational needs of human resources, along with their work environment's role in supplementing these needs, determine their degree of participation in the implementation of EDUC4.

The vision of educational leaders (or managers) is vital in directing human resources into implementing EDUC4. In developing economies where EDUC4 is a relatively foreign concept, efficient and effective leadership is critical to encourage the workforce to accept technology-driven change. It is essential to recognize the needs and limitations of human resources in instituting EDUC4 transition policies to minimize backlash. In this respect, providing sufficient funds for human resources to participate in EDUC4 implementation effectively is essential in boosting morale and reducing apprehension to change. Similarly, developing a work environment that is safe, sensitive, and motivating while providing excitement, challenge, and engagement to employees is vital in reducing fear and apprehension towards new technologies, their associated responsibilities, and the necessary skills required to work with them. From these arguments, it can be easily deduced that addressing these barriers impacts EDUC4 implementation problems. However, the extent and polarity of such impact and its net result are not readily apparent and may be non-standard, especially in culturally diverse settings. Thus, investigating this impact is an interesting topic in its own right. Hence, the hypothesis:

Hypothesis 11 (H11). *Human resources impacts EDUC4 implementation problems.*

5.5. Infrastructure

Infrastructure, defined as a collection of information technology-related equipment and facilities required for the operation of EDUC4, impacts several other themes. Hariharasudan [27], for example, claims that sufficient knowledge or digital learning of industrial operations prior to employment or during work might positively encourage learners. In addition, digital learning can help learners build self-motivation and professionalism, which will help them increase their learning quality [71]. However, various studies have pointed out the implications of prolonged screen time on learners' general health, particularly mental health, due to the predominance of more virtual setup in EDUC4 [37,67]. On the other hand, Venkatesh [72] argued that infrastructure significantly impacts other themes. It produces robust tools and platforms that seek to improve the teaching-learning process in various ways.

Hypothesis 12 (H12). *Infrastructure affects the learners.*

Hypothesis 13 (H13). *Infrastructure affects health and the environment.*

Hypothesis 14 (H14). *Infrastructure affects the implementation problems in Education 4.0.*

5.6. Learners

Chen et al. [34] revealed that learners' experiences in EDUC4 are unbounded with time and more personalized. Consequently, learners play a significant role in the formulation of the individualized curriculum for EDUC4 [28], wherein failure to execute such an approach directly implicates the implementation problems of EDUC4. Since the development of curriculum for EDUC4 depends on the individual learner's competencies, the learners' existing skills and knowledge gap have a direct causal relation to EDUC4 implementation [33]. Moreover, in developing economies, learners' skills gap due to the inaccessibility of available emergent technologies is prevalent [64]. Meanwhile, the inefficient design of the complex virtual learning platforms used by the learners implies data security threat and apprehension of learners towards the adoption of the innovation brought by EDUC4. Thus, if these aspects are not attained or training is not attuned to achieving these learning goals, the implementation is more likely to become problematic. Hence, the succeeding hypothesis is formulated:

Hypothesis 15 (H15). *Learners affect the implementation problems of EDUC4.*

5.7. Health and Environment

Due to the prevalence of more virtual environments in EDUC4, various works have pointed out the effects of prolonged screen time on learners' overall health, including mental health (see [33,37,67]). In a particular case, AI-assisted higher education is now engaged with health data from wearables. For instance, in an online fitness course, wearable enhanced learning synthesizes data for health (i.e., heart rate, steps) and environment (i.e., weather, temperature) [73]. Aside from learners, teachers are also at the other end of adverse health impacts brought by the extended use of virtual environments [32,51]. Thus, Ciolacu and Svasta [4] cautioned that the education system must consider investing in human resources' fitness, including mental wellness while increasing the likelihood of staying competitive. Collectively, these health issues may impact the pathways of the implementation of EDUC4. While this evidence may be relevant, such relationships are limited under an EDUC4 environment. Thus, the following hypotheses are formulated:

Hypothesis 16 (H16). *Health and environment impact human resources.*

Hypothesis 17 (H17). *Health and environment impact the learners.*

Hypothesis 18 (H18). *Health and environment impact the implementation problems in EDUC4.*

5.8. Implementation Problems in EDUC4

The term "implementation problems in EDUC4" is operationally contextualized from Kearns and Sabherwal's [74] behavioral items. The construct refers to the underlying reasons for project difficulties, including crises distracting attention from implementation, unclear delineation of responsibilities and authorities, vague statement of overall goals, performance requiring more time than planned, and a lack of clear communications among participants. The construct is customized to fit the projects, problems arising from, leadership, and the stakeholders of the implementation of EDUC4.

The proposed theoretical predictive model associated with the problems HEIs faced with the implementation of EDUC4 is shown in the path model of Figure 5. Note that Figure 5 only shows the causal relationships among themes and not the prioritization of the themes in overcoming the barriers.

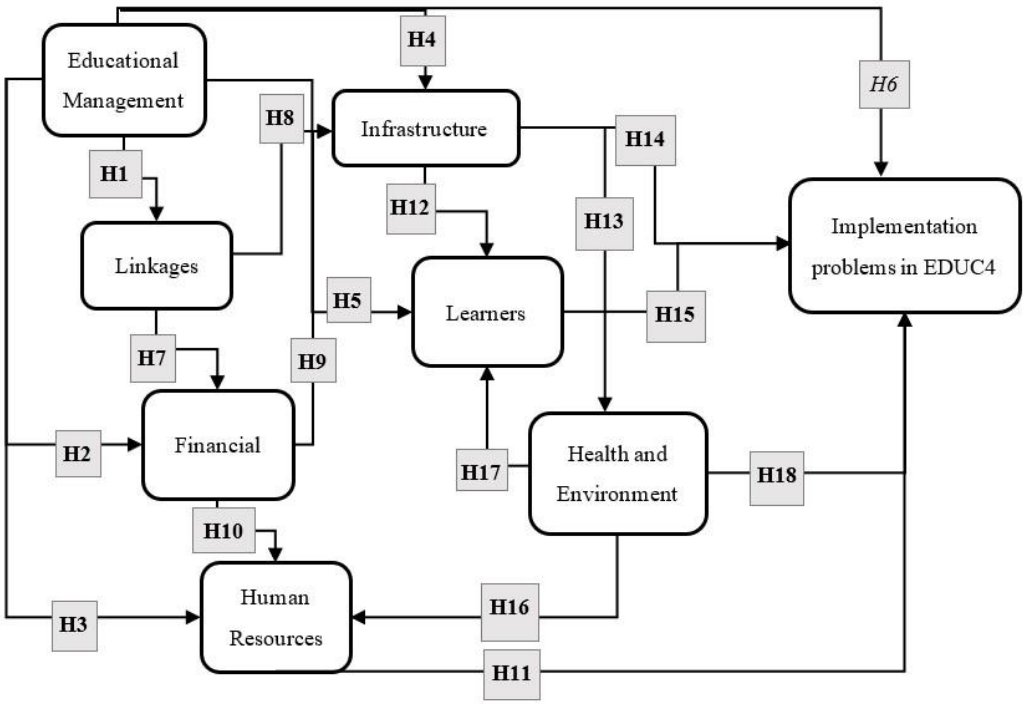

Figure 5. Proposed path model on the implementation of EDUC4.

6. Conclusions and Future Works

Following a systematic literature review, this work obtained 30 published journal articles that highlight EDUC4 implementation. Content analyses of these articles revealed 12 barriers in implementing EDUC4. Moreover, seven themes were obtained from the thematic analysis. The association of the 12 barriers with the seven themes was also discussed. The thematic analysis mapped which aspects of each theme are affected by the barriers. These aspects highlight the specific points of association between the themes and the barriers, which is essential in expounding the utility of addressing the identified barriers in the context of their associated themes. Furthermore, by treating each theme as constructs that impact EDUC4 implementation, this study also elucidated the causal relationships between the constructs. A path model is developed from this analysis and various hypotheses that can be tested to advance research on EDUC4 implementation.

In summary, the findings of this study are two folds. First, it was found that the barriers to EDUC4 implementation are associated with the following themes: educational management, linkages, financial, human resources, infrastructure, learners, and health and environment. Second, based on evidence obtained from previous studies, barriers

to EDUC4 implementation may be viewed as a complex causal network, which suggests a systems perspective for addressing the EDUC4 implementation problem, unlike the traditional linear and static lens for which most studies on EDUC4 are viewed. The unconventional findings of this study provide new insights for the design of interventions to address EDUC4 barriers in developing economies. Developing countries are mired with a manifold of social, economic, and environmental challenges that act as obstacles to EDUC4 implementation. The barriers determined in this study capture these challenges. Furthermore, the analysis performed in this work on these barriers and the findings obtained from the analysis is a step forward in revolutionizing higher education in developing economies with EDUC4.

It is important to note that the results of this study are limited to the keywords in the search process of the systematic review. In line with this, the results may be verified in future works by considering other search keywords related to EDUC4 implementation. On a similar note, the scope of the search may be expanded by considering a longer timeline. Furthermore, some restricting criteria employed in the systematic literature review may be discarded in future works to increase the evaluation coverage in terms of the number of relevant articles. Also, it may be a worthwhile undertaking for future works to verify the path model proposed here using empirical data and statistical techniques. It is also important to note that the proposed path model is a general framework encompassing the entire EDUC4 implementation problem. However, focusing on a specific construct and building a surrogate model on that construct may be meaningful future research to elucidate construct-specific ideas to address the EDUC4 implementation problem in developing economies. Finally, identifying priority themes relevant to developing economies is an interesting future agenda.

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Appendix A

Table A1. The final list of journal articles from the Scopus database.

Year	Author	Journal Name	Title	Reference
2018	Hariharasudan, A., Kot, S.	Education Sciences	A scoping review on Digital English and Education 4.0 for Industry 4.0	[27]
2020	Lea, Q.T.	Sustainability	Orientation for an education 4.0: A new vision for future education in Vietnam	[35]
2021	Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J.-M., Ramírez-Montoya, M.-S., Navarro-Tuch, S.A., Bustamante-Bello, M.-R., Rosas-Fernández, J.-B., Molina, A.	Open Engineering	The core components of education 4.0 in higher education: Three case studies in engineering education	[20]

Table A1. *Cont.*

Year	Author	Journal Name	Title	Reference
2020	Ishak, R., Mansor, M.	International Journal of Scientific & Technology research	The relationship between knowledge management and organizational learning with academic staff readiness for education 4.0	[43]
2020	Chen, Z., Zhang, J., Jiang, X., Hu, Z., Han, X., Xu, M., Savitha, V., Vivekananda, G.N.	Journal of Surgical Education	Education 4.0 using artificial intelligence for student's performance analysis	[34]
2021	Ramírez-Montoya, M.S., Loaiza-Aguirre, M.I., Zúñiga-Ojeda, A., Portuguez-Castro, M.	Sustainability	Characterization of the teaching profile within the framework of education 4.0	[49]
2020	Jamaludin, R., McKAY, E., Ledger, S.	Cakrawala Pendidikan	Are we ready for Education 4.0 within ASEAN higher education institutions? Thriving for knowledge, industry and humanity in a dynamic higher education ecosystem?	[6]
2020	Abdul Bujang, S.D., Selamat, A., Krejcar, O., Maresova, P., Nguyen, N.T.	Computer Applications in Engineering Education	Digital learning demand for future education 4.0-case studies at Malaysia education institutions	[47]
2020	Bonfield, C.A., Salter, M., Longmuir, A., Benson, M., Adachi, C.	International Journal of Innovation, Creativity and Change	Transformation or evolution?: Education 4.0, teaching and learning in the digital age	[29]
2018	Vu, T.L.A.	Universal Journal of Educational Research	Building CDIO approach training programmes against challenges of industrial revolution 4.0 for engineering and technology development	[45]
2019	Suhaimi, S., Rosli, A.N., Ariffin, A.H., Muniandy, T., Wahab, M.H.A.	Revue Roumaine des Sciences Techniques Serie Electrotechnique et Energetique	Education 4.0: The impact of computer architecture and organization course on students' computer anxiety and computer self-efficacy	[33]
2021	Alakrash, H.M., Razak, N.A.	International Journal of Advanced Computer Science and Applications	Education and the fourth industrial revolution: Lessons from COVID-19	[37]
2020	Alabi, M.O., de Beer, D.J., Wichers, H., Kloppers, C.P.	Asian Education and Development Studies	Framework for effective additive manufacturing education: a case study of South African universities	[36]
2019	Popkova, E.G., Zmiyak, K.V.	Procedia Manufacturing	Priorities of training of digital personnel for industry 4.0: social competencies vs. technical competencies	[40]
2021	Kumar, V.V., Carberry, D., Beenfeldt, C., Andersson, M.P., Mansouri, S.S., Gallucci, F.	Education Sciences	Virtual reality in chemical and biochemical engineering education and training	Kumar et al. [38]
2018	González, I., Calderón, A.J.	Sustainability	Development of final projects in engineering degrees around an Industry 4.0-oriented flexible manufacturing system: preliminary outcomes and some initial considerations	[46]
2021	Boca, G.D.	Open Engineering	Factors influencing students' behavior and attitude towards online education during COVID-19	[32]
2020	Liljaniemi, A., Paavilainen, H.	International Journal of Scientific & Technology Research	Using digital twin technology in engineering education—course concept to explore benefits and barriers	[31]
2020	Marie, A.S., Kaur, P.	Journal of Surgical Education	Digitizing the teaching process to best meet the needs of Generation Z a study in understanding the importance of digitizing education to match Gen Z needs	[48]
2016	Ambani, S.N., Lypson, M.L., Englesbe, M.J., Santen, S., Kasten, S., Mullan, P., Lee, C.T.	Sustainability	The Surgery Fellow's Education Workshop: a pilot study to determine the feasibility of training senior learners to teach in the operating room	[51]

Table A1. *Cont.*

Year	Author	Journal Name	Title	Reference
2021	Zamora-Antuñano, M.A., Rodríguez-Reséndiz, J., Segura, L.R., Cruz Pérez, M.Á., Altamirano Corro, J.A., Paredes-Garcia, W.J., Rodríguez-Reséndiz, H.	Cakrawala Pendidikan	Analysis of emergency remote education in COVID-19 crisis focused on the perception of the teachers	[50]
2020	Azman, M.N.A., Kamis, A., Kob, C.G.C., Abdullah, A.S., Jerusalem, M.A., Komariah, K., Budiastuti, E.	Computer Applications in Engineering Education	How good is MYGURU The lecturer's perceived usefulness and attitude	[52]
2019	Sarsar, F., Kale, Ö.A., Andiç-Çakir, Ö., Gueorguiev, T., Evstatiev, B., Georgieva, T., Kadirova, S., Mihailov, N., Różewski, P., Kieruzel, M., Lipczyski, T., Prys, M., van Leeuwen, M.	International Journal of Innovation, Creativity and Change	Multicultural investigation of the students' acceptance of using digital learning materials in laboratory classes	[41]
2019	Halim, M.F., Shokheh, M., Harun, M.H., Ebrahimi, M., Yusoff, K., Romadi	Universal Journal of Educational Research	The insight of the industrial revolution 4.0 in the higher education system	[30]
2019	Anito, J.C., Morales, M.P.E.	Revue Roumaine des Sciences Techniques Serie Electrotechnique et Energetique	The pedagogical model of Philippine steam education: Drawing implications for the reengineering of Philippine steam learning ecosystem	[42]
2018	Mogos, R.-I., Bodea, C.-N., Dascalu, M.-I., Safonkina, O., Lazarou, E., Trifan, E.-L., Nemoianu, I.V.	International Journal of Advanced Computer Science and Applications	Technology enhanced learning for Industry 4.0 engineering education	[28]
2018	Turcu, C.O., Turcu, C.E.	Asian Education and Development Studies	Industrial internet of things as a challenge for higher education	[44]
2018	Buasuwan, P.	Procedia Manufacturing	Rethinking Thai higher education for Thailand 4.0	[7]
2017	Benešová, A., Tupa, J.	Education Sciences	Requirements for education and qualification of people in Industry 4.0	[13]
2019	Asfar, A.M.I.T., Asfar, A.M.I.A., Asfar, A.H., Sirwanti, Rianti, M., Kurnia, A.	International Journal of Innovation, Creativity and Change	The elaboration study as an innovative learning model in an effort to improve the understanding of mathematics	[39]

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