Education 4.0 unravelled: deciphering critical success factors for successful implementation

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Abstract
Purpose – Education 4.0 (E 4.0) represents a new paradigm in the field of education, which emphasizes a student-centric approach that allows learners to access education anytime, anywhere, tailored to their individual needs through modern-day technologies. The purpose of the study was to unearth the critical success factors (CSFs) essential for the successful implementation of E 4.0.

Design/methodology/approach – The CSFs were unearthed using a literature review and further the interrelationships were analysed using multi-criteria decision making (MCDM) approach.

Findings – The study unearthed 15 CSFs for the successful implementation of E 4.0. The most important factor for the successful implementation of E 4.0 was personalized learning which was found to be the casual factor. The other causal CSFs were clear vision and leadership for E 4.0, stakeholder involvement, data analytics in teaching and learning, inter-disciplinary learning and blended learning environments. The effect factors were digital citizenship-based education, teacher training and development for E 4.0, supportive environment, curriculum redesign for E 4.0, open educational resources, digital technologies, formative assessments, infrastructure for E 4.0 and sustainability in education.

Research limitations/implications – This is the first study which unearthed the CSFs and found the interrelationships among them, thus contributing to the theory of technology organization environment.

Originality/value – This study represented a pioneering effort in understanding the CSFs underpinning the successful adoption of E 4.0, paving the way for a more personalized, tech-savvy and effective education system.

Keywords Education 4.0, Critical success factors, Personalised learning, Digital technologies, DEMATEL

Paper type Research paper

1. Introduction
Industry 4.0 (I 4.0) technologies have impacted all areas in human endeavours (Maware and Parsley, 2023). Education is one of the areas which is transformed by the I 4.0 technologies. Education has always undergone technology-oriented transformation over the period of time (Dao et al., 2023; Jain and Jain, 2022). Education 1.0 (E 1.0) represents a basic model where in teacher-centred approach was given due importance. Here the educators are seen as authorities and serve as the primary knowledge providers within the classroom (Dao et al., 2023). Education 2.0 was moving beyond the traditional teacher-centred approach of E1.0. It came with a concept of increased communication and collaboration between teachers and students. The main emphasis of the model was increased interaction, collaboration and use of basic technologies with a greater focus on student engagement and participation. In this model the emphasis was on knowledge provider centric design. Technologies such as computers, printers and calculators were used. The main educational philosophies were mainly constructivist and andragogical. The teachers’ role changed from sage to source of
Education 3.0 brought a paradigmatic shift towards student centerism. A marked difference compared to other two era was a shift towards a student-centred model, where students not only receive knowledge but called for active engagement as connectors, creators and constructivists. The role of educators shifted into coordinators or advisors, fostering a more interactive and participatory learning environment. Technologies such as online tools, e.g. pspice for electronic circuit optimization, multi-media and virtual laboratories were used (Dao et al., 2023).

Education 4.0 (E 4.0) is a result of the technology revolution in I4.0 which has brought a revolution to conventional educational systems. E 4.0 is defined by Miranda et al. (2021a, b) as “E 4.0 is the current period in which Higher Education institutions apply new learning methods, innovative didactic and management tools, and smart and sustainable infrastructure mainly complemented by new and emerging ICTs to improve knowledge generation and information transfer processes. Combining these resources during teaching-learning processes will support the training and development of desirable critical competencies in today’s students”. The four components of E 4.0 are (1) Competencies. It consists of training and development of desirable critical competencies in today’s students using technology (2) Learning Methods. This emphasis the use of technology to facilitate incorporation of new learning methods (3) Information and Communication Technologies (ICTs). Use of current and emerging ICTs in all activities of education and (4) Infrastructure. The use of innovative facilities, services and systems to improve learning processes (Miranda et al., 2021a, b). The knowledge generation in E 4.0 uses an approach that combines peeragogy, heutagogy and cybergogy (Miranda et al., 2021a, b). There is a strong emphasis on fostering self-directed learning which is based on constructivist and humanist principles. A marked distinction here is that the student is at the centre of the learning and teaching process. A student is encouraged to take ownership of their learning journey. Besides, students actively engage in self-reflection and metacognition. This help in gaining a deeper understanding of their own learning processes. E 4.0 has restored the concept of peeragogy, by promoting collaborative learning. Peeragogy encompasses a range of teaching techniques that facilitate learning among peers further encouraging to work together, exchange knowledge and collectively advance their understanding of a subject or skill (Corneli et al., 2016).

The technology revolution has given rise to the concept of cybergogy by using a set of learning strategies facilitated by information and communication technologies (ICTs) (Asad and Malik, 2023). It further helps in learning experiences that transcend the constraints of time and space. It also helps in leveraging the capabilities of digital tools and online platforms to provide flexible and accessible learning opportunities to meet the diverse and inclusive needs of students. The key drivers of E 4.0 have been (1) COVID-19-induced remote learning, (2) an increase in the gap between the competencies of graduates and the competencies and skillsets required for jobs, (3) increased societal awareness towards solving social problems through creativity and innovativeness, (4) the necessity for educators to handle volatility, uncertainty, complexity and ambiguity (VUCA) due to pandemics, (5) escalating climate change, (6) social unrest and geopolitical tensions, (7) the increasing role of students in the teaching-learning process, (8) changing methodologies used to deliver knowledge and (9) the increasing role of stakeholders such as researchers in education, employers, professional organizations, regulators (Ministries of Education), other than students, teachers and school administration in the teaching-learning process (Ciolacu et al., 2018; Gowripeddi et al., 2021; Salmon, 2019; Wang et al., 2023). The VUCA environment has to be managed by educators in order to achieve the mission of education in society. E 4.0 emphasizes a collaborative approach to teaching and learning, using technology and innovation to improve educational outcomes (Miranda et al., 2021a, b). This shift is not only a response to the demands of the modern workforce but also recognition of the need for students to develop critical thinking, problem-solving and adaptability skills to thrive in a VUCA world (Ciolacu et al., 2023).
success of E 4.0 is based on the pivotal role played by teachers, as they need to possess a wide variety of competencies from technological skills to modern-day pedagogical skills and cross-disciplinary learning (Mourtzis et al., 2022; Saragih et al., 2020). E 4.0 serves as a precursor to E 5.0 (E5.0), providing the necessary groundwork, principles and practices that continue to be relevant and valuable in shaping the future of education (Oliver, 2014). While E 5.0 introduces new dimensions and priorities, it does not invalidate the contributions and lessons learnt from the E 4.0 era (Nikum, 2022). Instead, it builds upon them to create a more comprehensive and inclusive educational framework for the future. In a VUCA world, knowledge is dynamic and constantly evolving (Waller et al., 2019). Hence teachers must be able to guide students in critically evaluating information, distinguishing between reliable and unreliable sources, and adapting to new knowledge as it emerges (Ramírez-Montoya et al., 2021). Thus, educators are challenged not only to redefine the process of learning but also to reconsider the knowledge imparted, ensuring it equips children for meaningful contributions to future economies and societies. The urgency is underscored by concerning statistics: nearly three-quarters of young people in 92 countries are off-track to acquire essential employment skills, according to United Nations International Children’s Emergency Fund (UNICEF) and the Education Commission. UNESCO warns that the world is falling short of meeting its education commitments by 2030 (World Economic Forum, 2023). Responding to this imperative, the E 4.0 Alliance aims to spotlight public-private collaborations reshaping learning.

Termed E 4.0 Lighthouses, these examples serve as inspirations for educators, parents, policymakers and employers seeking transformative practices to enhance education quality. These are from countries both developed and developing countries (World Economic Forum, 2023). E 4.0 is relatively new concept and there is a scant literature on how to implement it (Advani, 2023; Miranda et al., 2021a, b; Moraes et al., 2023). Previous studies has concentrated on understanding, exploring and describing E 4.0 (Dao et al., 2023; Fr et al., 2021; Kin et al., 2020; Miranda et al., 2021a, b; Saragih et al., 2020). However, none of them elucidated how to implement E 4.0 in terms of what are its critical success factors (CSFs). CSFs are those key elements or factors that, when given special attention and effectively managed, significantly contribute to the successful implementation of an initiative, project or endeavour (Antony et al., 2023; Chaurey et al., 2023; Merhi, 2023). These factors are considered critical because they have a substantial impact on achieving the desired outcomes and objectives. Thus, it is pertinent to understand from E 4.0 implementation perspective (1) What are the CSFs for successful implementation of E 4.0 (2). How these factors interrelated with each other. The next section is devoted to background of the study, followed by methodology, findings, discussion and conclusion and implications.

2. Literature review
E 4.0 designs education as a lifelong process wherein the student can use digital technologies in education to learn at anywhere, any time and most importantly as per needs of the student (Miranda et al., 2021a, b). It reimagines education as inclusive lifelong personalized experience, which is centred on skill building around the learner, with teacher’s role revolving around as mentors and facilitators (Advani, 2023). Thus, E 4.0 has a complex intertwining of human and technical elements in order to create a unique personalized learning experience for the students. In a white paper by the world economic forum, the eight critical characteristics of E 4.0 are (1) Global Citizenship Skills (2) Innovation and Creativity Skills (3) Technology Skills (4) Interpersonal Skills (5) Personalized and Self-Paced Learning (6) Accessible and Inclusive Learning (7) Problem-Based and Collaborative Learning and (8) Lifelong and Student-Driven Learning (World Economic Forum, 2019). In the United Nations’ sustainable development 2030 agenda is quality education is one of the main goals. Sustainable development centres around social well-being, with education playing a pivotal role.
advent of information communication technology (ICT) has become a driving force behind educational reforms, facilitating the dissemination of shared knowledge. This is evident in the integration of technology-assisted learning tools, such as mobile devices, smartboards, simulations, massive open online course (MOOC), laptops, tablets, dynamic visualizations and virtual laboratories, has significantly transformed educational practices (Haleem et al., 2022). The Internet of Things (IoT) has proven to be a cost-effective method for educating young minds and a robust mechanism for providing a world-class learning experience for all (Dreimane and Upenieks, 2020; Keengwe and Bhargava, 2014). Educational technology companies continually strive to create innovative solutions to expand access to education, particularly for those who lack adequate educational facilities (Haleem et al., 2022). Social media has evolved into a valuable learning tool, with many teachers and students incorporating it as an essential element of the overall e-learning experience. Social media platforms serve as critical venues for exchanging information on crucial topics and fostering networking opportunities, potentially leading to new opportunities (Greenhow and Lewin, 2019). E 4.0 is in the early stages of implementation, and hence there is no standard framework for implementation (Miranda et al., 2021a, b; Moraes et al., 2023). In the absence of the standard framework, it is pertinent to understand what are the factors that are vital for the successful implementation. CSFs are those factors which if present the initiative would be successful (Antony et al., 2023; Freund, 1988; Laureani and Antony, 2012). Thus, from the previous literature the CSFs are elucidated in Table 1.

The factors along with description is given in Table 1 and the main purpose of this study is to understand how these factors are related to each other and is there any cause effect relationship among them. Since these factors are technical and non-technical in nature, we use technology-organization-environment (TOE) framework (Tornatzky et al., 1990) to understand the impact of E 4.0 on educational organizations and their environments. It comprises three main components: technology, organization and environment. TOE is one of the widely used framework in education (Alshaikh et al., 2021; Ergado et al., 2021). TOE framework is further chosen because it focusses on organizational level factors instead of individual ones. In the context of E 4.0, the TOE framework can be applied to understand how the integration of technology (T) affects the organization’s variables (O) and how the external environment (E) influences the adoption and implementation of technology in education.

3. Research methodology
This study used a quantitative research methodology, as the CSFs of E 4.0 were derived from the existing literature and it has to ranked and interrelationship found out among them. To find the CSFs of E 4.0 a systematic literature review (SLR) was conducted. The SLR consisted of six phases, starting with planning the review. In this phase, the study’s objectives were aligned with the formulation of the review (Tranfield et al., 2003). This is followed by formulating the literature search method. The keywords such as E 4.0, CSFs, implementation, I 4.0 and education etc. were employed to identify articles relevant to the present study. Various databases of bibliographic citations including Web of Science, IEEE Xplore, Scopus, Science Direct and Google Scholar were utilized. Out of the articles pertaining to the search words only the ones that are published till June 2023 were included in the study. The selected articles underwent a rigorous quality check to ensure that they met the inclusion criteria. An elimination is conducted for the articles published in predatory journals based on the Cabells list (Cabells, 2018; Das and Chatterjee, 2018). After the first screening, a total of 226 articles were considered for review. Further processing included the removal of duplicate articles. Each contributing author independently reviewed the remaining articles for their relevance and to ensure consensus (Bettany-Saltikov, 2016). This further screening resulted in 28 highly relevant articles that are included in the thematic analysis. This helped in finding the 15 CSFs.
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<th>Critical success factor</th>
<th>Descriptions</th>
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<tr>
<td>1</td>
<td>C1</td>
<td>Clear Vision and Leadership for E 4.0</td>
<td>Strong leadership with a well-defined vision for the transformation of education. It emphasizes the importance of having a well-defined vision that guides the educational transformation and strong leadership that can navigate the institution through the challenges and opportunities presented by E 4.0</td>
<td>Fr et al. (2021, p. 0), Jedaman et al. (2019), Kin et al. (2020)</td>
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<td>2</td>
<td>C2</td>
<td>Teacher Training and Development for E 4.0</td>
<td>Continuous professional development programs to equip educators with digital skills and innovative teaching methodologies of E4.0. It underscores the significance of continuous professional development programs designed to equip educators with the essential digital skills and innovative teaching methodologies required for the successful implementation of E 4.0</td>
<td>Alda et al. (2020), Miranda et al. (2021a, b), Teo et al. (2021)</td>
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<tr>
<td>3</td>
<td>C3</td>
<td>Infrastructure for E 4.0</td>
<td>Reliable and accessible digital infrastructure, including high-speed Internet, devices, power supply etc for students and educators. It emphasizes the foundational elements required to create an environment conducive to digital learning. A reliable and accessible digital infrastructure ensures that students and educators can effectively leverage the benefits of E 4.0, enabling a seamless integration of technology into the teaching and learning processes</td>
<td>González-Pérez and Ramírez-Montoya (2022), Miranda et al. (2021a, b), Pambayun et al. (2020)</td>
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<td>4</td>
<td>C4</td>
<td>Curriculum Redesign for E 4.0</td>
<td>Integration of technology, relevant digital content into the curriculum to enhance learning outcomes. When executed cohesively, this redesign enhances the overall learning experience, aligns with educational goals, and prepares students for success in a digitally driven world</td>
<td>Dao et al. (2023), Ellahi et al. (2019), Jeganathan et al. (2018), Miranda et al. (2021a, b)</td>
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<td>5</td>
<td>C5</td>
<td>Personalized Learning</td>
<td>Development of adaptive learning pathways that cater to individual student needs and learning styles using digital technology. It involves the intentional customization of educational experiences using adaptive learning pathways and digital technology. This approach recognizes the diversity of learners, promotes student empowerment, and creates a dynamic and tailored learning environment that prepares students for success</td>
<td>Mansor et al. (2020), Mourtzis et al. (2022, 2022), Peng et al. (2019), Spector (2014)</td>
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<tr>
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<td>6</td>
<td>C6</td>
<td>Blended Learning Environments</td>
<td>Creation of flexible, blended learning environments that combine online and in-person instruction. Blended learning environments aim to create a dynamic and adaptive educational experience by combining online and in-person instruction. This approach capitalizes on the strengths of both modalities, fostering flexibility, personalization, and enhanced engagement for students in a technology-integrated educational landscape</td>
<td>Raman and Rathakrishnan (2019, 2019), Saragih et al. (2020)</td>
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<td>7</td>
<td>C7</td>
<td>Data analytics in teaching and learning</td>
<td>Effective use of data analytics in teaching and learning, e.g. monitor student progress and personalize instruction. The effective use of data analytics in teaching and learning involves harnessing data to monitor student progress, personalize instruction and make informed decisions that enhance the overall educational experience. By leveraging data-driven insights, educators can create a more responsive and adaptive learning environment tailored to the unique needs of each student</td>
<td>Ashaari et al. (2021), Ciocaru et al. (2017), Qureshi et al. (2021)</td>
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<td>8</td>
<td>C8</td>
<td>Open Educational Resources</td>
<td>Access to a wealth of high-quality, open-source educational materials. It is freely accessible and openly licenced educational materials that can be used, shared and modified by educators and learners. The availability of high-quality, open-source educational materials through OER promotes accessibility, affordability, collaboration and continuous improvement in education. This open approach to learning resources contributes to the democratization of education and empowers educators and learners to actively participate in shaping their educational experiences</td>
<td>Akturk et al. (2022), Ismagilov et al. (2022), Miranda et al. (2021a, b)</td>
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<td>9</td>
<td>C9</td>
<td>Stakeholder involvement</td>
<td>Involvement of stakeholders such as parents, communities and industry partners in supporting students’ learning journeys</td>
<td>Gonzales et al. (2022), Gupta et al. (2023), Jamahudin et al. (2020), Himmetoglu et al. (2020), Komalasari and Anggraini (2020), Widodo et al. (2021)</td>
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<td>10</td>
<td>C10</td>
<td>Digital citizenship-based education</td>
<td>Comprehensive programs to teach students responsible and ethical technological use. The goal is to equip individuals with the knowledge, skills and attitudes necessary to navigate the digital world safely, responsibly and ethically. It is done by instilling critical digital literacy skills, fostering a sense of responsibility and promoting ethical behaviour, these programs contribute to the development of informed and conscientious digital citizens</td>
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Table 1. (continued)
and is explicated in Table 1. To find the interrelationships among the factors we used decision-making trial and evaluation laboratory (DEMATEL) (Duval et al., 1974) method as it is the tool to construct a structural model and visualize the causal interplay among subsystems. This is a type of structural modelling method used to analyse the cause and effect relationships among different components of the system. It can be used to analyse the variables within the system and utilize the expert knowledge to understand how the variables

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<td>11</td>
<td>C11</td>
<td>Inter-disciplinary learning</td>
<td>Encouragement of inter-disciplinary and cross-disciplinary learning. Inter-disciplinary learning involves the integration and collaboration of knowledge and methods from multiple disciplines to address complex issues or solve real-world problems</td>
<td>Mahmud and Ridgman (2019), Vieira et al. (2022), Wermann et al. (2019)</td>
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<td>12</td>
<td>C12</td>
<td>Formative Assessments</td>
<td>Implementation of frequent, formative assessments to provide timely feedback for student improvement. Formative assessments are designed to monitor student learning and provide ongoing feedback to inform instructional decisions</td>
<td>Ciolacu et al. (2023), Kleppe and Bjelland (2022), Silva et al. (2022)</td>
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<tr>
<td>13</td>
<td>C13</td>
<td>Sustainability in education</td>
<td>Integration of social, economic, environmental and governance aspects to address global challenges. This holistic approach aims to cultivate a sense of responsibility and awareness among students, preparing them to contribute to a more sustainable and equitable future</td>
<td>Chaka (2022), Grybauskas et al. (2022), Lupi et al. (2022)</td>
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<tr>
<td>14</td>
<td>C14</td>
<td>Digital technologies</td>
<td>Utilization of digital technologies such virtual and augmented reality, block chain, artificial intelligence etc to enhance learning experiences. The integration of digital technologies in education opens up new possibilities for innovative and interactive learning experiences. These technologies contribute to personalized learning, engagement and the development of essential skills for the digital age. As education continues to evolve, leveraging these digital tools can create dynamic and adaptive learning environments that better prepare students for the challenges of the future</td>
<td>Haleem et al. (2022), Katyeudo and Souza (2022)</td>
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<td>15</td>
<td>C15</td>
<td>Supportive environment</td>
<td>Fostering an environment that encourages creativity, innovation, critical thinking and change management. By incorporating these strategies, organizations and educational institutions can establish a supportive environment that nurtures creativity, innovation, critical thinking and change management. This approach not only enhances individual and collective performance but also positions the community to thrive in rapidly evolving contexts</td>
<td>Chaka (2022), Miranda et al. (2021a, b), Ramirez-Montoya et al. (2022)</td>
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Source(s): Authors own work

Table 1.
interacts within the system. DEMATEL methodology helped in understanding the tacit knowledge, drawing upon expert experiences and instincts (Sharma et al., 2020). To use this method the complex system should be understood in terms of factors influencing the successful implementation of E 4.0. This was done through literature review. After that a measurement scale was developed to express the relationship and its strength between the factors. The scale used here was "0" to "4". 0 is “no influence”, “low influence”, “medium influence”, “high influence”, and 4 is “very high influence”. We selected 16 experts. The experts were senior professors who had considerable teaching, administrative and research experience. In addition, they also had knowledge and experience in E 4.0. The sample size of 16 was adequate for this study, as previous studies using DEMATEL was conducted with similar sample size for example 4 (Fu et al., 2012), 5 (Sivakumar et al., 2018), 8 (Lin, 2013), 10 (Kaur et al., 2018). DEMATEL method suggested by authors (Dalvi-Esfahani et al., 2019; Shieh et al., 2010; Sumrit and Anuntavoranich, 2013), it consisted of following steps.

Step 1: Expert opinion
We gathered 16 expert opinion on the CSF’s. In terms of terminology l experts E = {E1. E2. … . El} regarding the influence on factors F = {F1. F2. . . . Fn} on each other using above scale, we created a pair-wise comparison matrix. The kth expert gives ab individual direct influence matrix $Z_k = \begin{bmatrix} Z_{1j}^k & \cdots & Z_{ij}^k \\ \vdots & \ddots & \vdots \\ Z_{nj}^k & \cdots & Z_{nn}^k \end{bmatrix}_{n \times n}$. A zero value on the diagonal of the matrix. $Z_{ij}^k$ represents the opinion of expert $E_k$. Regarding how factor $F_i$ influences the factor $F_j$.

Step 2: Computation of Average matrix
Average matrix $Z = [Z_{ij}]_{n \times n}$ is constructed by including the opinion of all experts.
$Z = \frac{1}{l} \sum_{k=1}^{l} Z_{ij}^k$ for $1, 2, \ldots , n$. Thus $Z$ is the average matrix.

Step 3: Calculating normalized influence matrix $X = [X_{ij}]_{n \times n}$

$$X = Z \frac{S}{S}$$

$$S = \max \left( \max_{1 \leq i \leq n} \sum_{j=1}^{n} Z_{ij}, \max_{1 \leq j \leq n} \sum_{i=1}^{n} Z_{ij} \right)$$

Step 4: Total relationship matrix
The experts only estimated the direct influence of the factors. The total relationship matrix $T = [t_{ij}]_{n \times n}$ is obtained using the transition theory and summing up all direct and indirect effects.

$$T = X + X \cdot 2 + X \cdot 3 + \cdots + X \cdot h = X(I - X) - 1$$
when $h \to \infty$ and $I$ = identity matrix.

Step 5: Calculating the influence relationship map
The vectors R and C are achieved by summing up the rows and columns of total relation matrix $T$

$$R = [r_{i}]_{n \times 1} = \left( \sum_{j=1}^{n} t_{ij} \right)_{n \times 1}$$
In this context, “r_i” corresponds to the cumulative value of the sum of all elements within the ith row of matrix T. It encapsulates both the direct and indirect effects emanating from the factor Fi and extending to other elements or factors. Similarly, “c_j” signifies the total value of the sum of elements within the jth column of matrix T. It encompasses all the direct and indirect effects that the determinant Fj acquires from interactions with other determinants.

To visually depict the roles of factors within the system, a diagram is created using a horizontal axis labelled (R + C) and a vertical axis labelled (R – C). The degree of centrality or importance of factor i within the system is quantified as (ri + ci), where (ri – ci) indicates the net impact or significance of factor i on the overall system. These factors are categorized into two groups: “cause” factors (drivers) and “effect” factors (receivers). If the value of (ri – ci) is positive, factor Fi falls into the driver category, signifying its influence on other factors. Conversely, if the value of (ri – ci) is negative, factor Fi is categorized as a receiver, indicating that it is influenced by other factors.

To generate the informative relation map (IRM) diagram, which offers valuable insights for decision-making, a dataset is mapped onto the (R + C, R – C) axes. To streamline the analysis and exclude insignificant effects, decision-makers should set a predefined threshold value for influence levels. If the threshold value is too low, the resulting IRM diagram may become overly complex. Conversely, if the threshold value is too high, many predictors may remain independent and fail to reveal their relationships with other predictors. The predictors with influence levels surpassing the defined threshold value in the matrix T are selected to construct the IRM diagram. The detail research procedure is depicted in Figure 1. In the phase 1, we carried out a SLR and in phase 2 DEMATEL analysis was conducted to find the interrelationships between the factors.

4. Results

The CSFs which are expounded in the literature review are investigated through DEMATEL analysis. This analysis is used to rank and explore the interrelationships among the CSFs.

Source(s): Authors own work

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**Figure 1.** Research procedure
The average matrix was calculated by the procedure depicted in step 2 elucidated in the methodology section. Subsequently, the normalized matrix was calculated by using the procedure depicted in step 3 of the research methodology section. Table 2 shows the total relationships matrix, which was calculated following the method outlined in step 4 of the research methodology section. The total relationships matrix illustrates the interdependencies between the factors being analysed. Each cell in the matrix represents the strength and direction of the relationship between two factors. The total relationships matrix in DEMATEL analysis serves as a comprehensive representation of the relationships between factors within a system, enabling researchers to gain a deeper understanding of its structure and behaviour.

Table 3 was constructed using step 5 and it depicts the net cause and effect matrix. By examining this table, it can be understood how each factor is a cause or effect.

The study depicts that based on $c + r$ the most important CSFs is personalized learning (4.108) and the lowest in ranking is supportive environment (1.061). The factors are ranked in order of importance in Figure 2.

From Table 3 the CSFs can be divided into causes and effects. Causes based on $(C - R > 0)$ and effect $(C - R < 0)$. The figure depicts the causal relations between the criteria diagram. The prominence-causal diagram is constructed from Table 3 and is depicted in Figure 3. In DEMATEL analysis, understanding causal and effect factors is crucial for identifying the drivers and outcomes within a system. Factors located above the $Y$-axis with values greater than 0 are considered causal factors. These factors have a net positive influence on other factors within the system. In other words, they are the drivers or influencers that directly contribute to the performance or outcomes of the system. Factors located below the $Y$-axis with values less than 0 are effect factors. These factors are influenced by other factors within the system and represent outcomes or consequences of the system’s functioning. All the factors above the $y$ axis $(C-R) > 0$ is causal factors and below this line are effect factors. The strength of factor is dependent on $x$ axis, higher the value on $x$-axis, stronger the factor in the system. The casual factors are clear vision and leadership for E 4.0, stakeholder involvement, personalized learning, data analytics in teaching and learning, inter-disciplinary learning and blended learning environments and these are depicted in Table 4. Considering the large number of cause and effect factors we suggest that casual factors should be given top priority, where conditions do not permit the implementation of all the factors identified, without adversely affecting the outcomes.

The effect factors are teacher training and development for E 4.0, curriculum redesign for E 4.0, digital technologies, formative assessments, open educational resources, sustainability in education, infrastructure for E 4.0, digital citizenship-based education and supportive environment and it is depicted in Table 5.

Personalized learning stands out as the most impactful CSF. It serves as the causal factor, making it imperative that, during the implementation of E 4.0, responsiveness to student needs and the design of personalized learning experiences take precedence. To explore the significant relationships between these factors, we devised the inner dependency matrix. The inner dependency matrix highlights the significant relationships between different CSFs. The matrix is constructed using values that exceed a predefined threshold, indicating the significance of the relationships. Only relationships with values above the threshold are included in the matrix, emphasizing those connections that have a notable impact on the system. The construction of the inner dependency matrix involved omitting values below the specified threshold, denoted as the matrix T. In this study, the threshold value is determined as the average of the values within the $T$ matrix (Awasthi and Grzybowska, 2014; Kaur et al., 2018). In this case the threshold value is 0.092698044. The inner dependency matrix is given Table 6 is constructed with values greater than threshold depicting the significance of the relationship. This table helps us to understand how the CSFs are related to each other. To cite
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Source(s): Authors own work
an instance the personalized learning which is a casual factor impacts other factors such as teacher training and development for E 4.0, infrastructure for E 4.0, curriculum redesign for E 4.0, open educational resources, formative assessments, sustainability in education, digital technologies and supportive environment. The second most important CSFs is teacher training and development for E 4.0. This is the effect factor.
The inner dependency matrix further depicts that teacher training and development for E 4.0 is influenced by clear vision and leadership for E 4.0, personalized learning, blended learning environments, data analytics in teaching and learning, stakeholder involvement and interdisciplinary learning.

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**Source(s):** Authors own work

The inner dependency matrix further depicts that teacher training and development for E 4.0 is influenced by clear vision and leadership for E 4.0, personalized learning, blended learning environments, data analytics in teaching and learning, stakeholder involvement and interdisciplinary learning.

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**Source(s):** Authors own work

The inner dependency matrix further depicts that teacher training and development for E 4.0 is influenced by clear vision and leadership for E 4.0, personalized learning, blended learning environments, data analytics in teaching and learning, stakeholder involvement and interdisciplinary learning.

**Table 4.** Prominence of causal factors

**Table 5.** Prominence of effect factors
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Source(s): Authors own work
5. Discussion

This study first explores the 15 CSFs for implementing E 4.0. Subsequently, these factors were ranked and classified into cause-effect groups to understand the dynamics of implementation of E 4.0. The section will first discuss the causal factors and subsequently the effect factors. Casual factors are the variables that influence each other within a system of CSFs (Kaur et al., 2018). These could be variables affecting a particular outcome, and their relationships are explored to understand the dynamics of E 4.0 implementation. In terms of importance, the CSFs within the causal group are ranked as follows: personalized learning, blended learning environments, data analytics in teaching and learning, inter-disciplinary learning, stakeholder involvement and clear vision and leadership for E 4.0.

Personalised learning includes tailoring education as per the needs, preference and abilities of each student by making use of technology (Koul and Nayar, 2021), and hence it would be the most important factor for the successful implementation of E 4.0. Educators need to recognize that the integration of technology in education is not a novel concept (Ramírez-Montoya et al., 2022). However, the pivotal shift lies in personalizing education for students through technology, fostering inclusive learning. This personalized approach stands as a key factor crucial to the successful implementation of E 4.0 (Peng et al., 2019). Thus, the choice of digital technologies should revolve around promotion of personalized learning and educators should keep in mind two key questions (1) Which digital technologies will help in designing personalized learning? (2) How can we use the digital technologies in a phased manner to implement E 4.0.

The second important CSF in the causal group unearthed in this study is blended learning environment. This include creation of flexible, blended learning environments that combine online and in-person instruction using digital technologies (Raman and Rathakrishnan, 2019, 2019; Saragih et al., 2020). In principle thus blended learning environment helps in meeting the goals of E 4.0 by integrating technology, personalizing learning, enabling flexibility and emphasizing lifelong learning skills. Thus, it brings in dynamic and adaptable approach to education, which will help the students for success in a technology driven workplace. The two important questions educators should ask while implementing blending learning environment using E 4.0 is (1) How can we ensure equitable access to blended learning resources and technologies for all students? (2) What training and support structures are needed to empower teachers in effectively integrating blended learning environments into their teaching methods?

The third important CSF in casual group is use of data analytics in teaching and learning. It includes effective use of data analytics in teaching and learning. Data analytics is a foundational element of E 4.0, as it empowers educators, administrators and policymakers to make data-driven decisions in education sector, personalize learning experiences (Ashaari et al., 2021; Soncin and Cannistrà, 2022), and continuously improve educational practices and hence it essential tool for achieving successful implementation of E 4.0. Educators should ask two questions before using data analytics for E 4.0 (1) What specific educational goals are we addressing using data analytics (2) How student privacy and data security issues can be handled while using data analytics in E 4.0?

The fourth important CSF while implementing E 4.0 is inter-disciplinary learning. The volatile, uncertain, complex and ambiguous environment presents problems which require inter-disciplinary perspective (Mack et al., 2015). Therefore, inter-disciplinary learning is well-suited to the goals of E 4.0 as it promotes critical thinking, adaptability, real-world relevance and collaboration. Thus, for successful implementation of E 4.0 inter-disciplinary learning has to be promoted. Two questions educators should ask while implementing inter-disciplinary learning (1) How will we facilitate meaningful integration between disciplines to find a balance between depth and breadth of knowledge? (2) What are the resources and support needed to effectively implement inter-disciplinary learning?
The next CSF is stakeholder involvement in the students learning journey. This could be parents, communities, and industry partners. Involving parents, communities and industry partners in students’ learning journeys will help in creating a more holistic, relevant and adaptable educational experience that better prepares students for the complexities of the real world. Two pertinent questions educators should ask is (1) How can we effectively integrate stakeholder involvement in the student learning journey? (2) What mechanisms and structures are needed to facilitate meaningful stakeholder involvement and ensure that their contributions align with the goals of E 4.0?

The last CSF in the cause group is clear vision and leadership for E 4.0. A clear vision and strong leadership provide the necessary guidance, motivation and resilience to navigate the complex changes and opportunities that come with transforming education while implementing E 4.0 (Fr et al., 2021; Jedaman et al., 2019; Kin et al., 2020). Two questions educators should ask is (1) What do we want to achieve with the implementation of E4.0, and how will these align with our institution’s mission and vision? (2) How will we prepare and support our teachers and staff to effectively adapt to the changes associated with E 4.0, including technology integration and new teaching methods?

The effect factors are teacher training and development for E 4.0, curriculum redesign for E 4.0, digital technologies, formative assessments, open educational resources, sustainability in education, infrastructure for E 4.0, digital citizenship-based education and supportive environment. Teacher training and development are paramount, ensuring educators are equipped with the necessary skills to effectively utilize digital tools and pedagogies (Himmetoglu et al., 2020). Curriculum redesign for E 4.0 is essential, aligning educational content with the demands of a digital era (Mahmud and Ridgman, 2019). Digital technologies, including hardware and software, provide the foundation for E 4.0 implementation, facilitating interactive and immersive learning experience (Ismagilov et al., 2022). Formative assessments allow for ongoing evaluation and adaptation, ensuring that learning remains dynamic and responsive (Chaka, 2022). Open educational resources democratize access to quality educational materials, fostering inclusivity and equity (Koul and Nayar, 2021). Sustainability in education emphasizes the long-term viability of E 4.0 initiatives, considering environmental, economic and social impacts (Lupi et al., 2022). Infrastructure for E 4.0, including robust internet connectivity and digital devices, is fundamental to enable seamless integration. Digital citizenship-based education promotes responsible and ethical use of technology, empowering students to navigate the digital landscape safely and responsibly (Advani, 2023; Katyeudo and Souza, 2022). A supportive environment, encompassing administrative support, community engagement and stakeholder collaboration, is essential for sustained success in E 4.0 implementation (Himmetoglu et al., 2020). Together, these cause and effect factors form a comprehensive framework for the effective integration of technology in education, ensuring that learners are prepared for the challenges and opportunities of the digital age.

6. Implications for theory
This study identifies CSFs for E 4.0 implementation and its interrelationships; thus it contributes to the theory of Technology Organization Environment framework. In terms of technology factors Personalized Learning, Digital Technologies, Blended Learning Environments, Data Analytics in Teaching are Learning, Digital Citizenship-based Education could be categorized. In Organization level factors Teacher Training and Development for E 4.0, Curriculum Redesign for E 4.0, Inter-disciplinary Learning, Formative Assessments, Open Educational Resources, Stakeholder Involvement, Clear Vision and Leadership for E 4.0 and Supportive Environment are classified. In terms of environment Sustainability in Education and Infrastructure for E 4.0. The application of the TOE
framework to the identified CSFs for E 4.0 implementation can provide valuable insights into how these factors interact with each other and how they influence the organization’s structure, processes and external environment. Educational institutions are socio-technical in nature, as social (human) and technical systems interacts in goal directed manner to meet the objectives of education (Lee, 2018). To cite an instance the adoption of digital technologies (T) can lead to changes in teaching methods and curriculum design (O), which in turn can impact the educational organization’s structure and processes. The availability of funding for infrastructure (E) can influence the successful implementation of E 4.0 and the adoption of digital technologies (T). The involvement of stakeholders (O) such as parents, communities and industry partners can create a more supportive environment (O) for E 4.0 implementation. This study therefore extends the application of the TOE framework to the identified CSFs for E 4.0. It further suggests that for E 4.0 implementation educational institutions understand the complex interplay between technology, organization and environment and develop strategies to effectively integrate technology in education.

Educational institutions while implementing E 4.0 can use this study in 14 step methodology which was derived from the findings of the study.

Step 1: Establish a Leadership Team
Step 2: Define the Vision and Goals for E 4.0
Step 3: Conduct a Needs Assessment
Step 4: Develop a Strategic Plan
Step 5: Personalized Learning (this includes identifying digital technologies that support personalized learning, develop guidelines and standards, provide training and pilot personalized learning initiatives in select classrooms.

Step 6: Blended Learning Environments (Evaluate the availability of technology infrastructure, choose appropriate digital tools and platforms for blended learning, develop a phased implementation plan for blending online and in-person instruction, provide professional development for teachers on effective blended learning strategies.

Step 7: Data Analytics in Teaching & Learning (implement data collection systems and analytics tools, define clear goals for data analytics, such as improving student performance, ensure data privacy and security measures are in place, train educators on using data analytics to inform instruction)

Step 8: Inter-disciplinary Learning (Promote inter-disciplinary collaboration among teachers and departments, identify key inter-disciplinary learning opportunities within the curriculum, provide resources and professional development for educators on inter-disciplinary teaching methods, encourage the creation of inter-disciplinary projects and courses.)

Step 9: Stakeholder Involvement (develop strategies to involve parents, communities and industry partners, communicate the benefits of their involvement and the role they can play, establish channels for regular communication and feedback, encourage industry partnerships for real-world learning experiences.)

Step 10: Clear Vision and Leadership (Continually communicate and reinforce the E 4.0 vision, provide leadership training and support for administrators and educators, foster a culture of innovation, adaptability and continuous improvement, establish mechanisms for evaluating progress and making necessary adjustments.)
Step 11: Pilot Programs and Evaluate (Begin with small-scale pilot programs to test and refine your initiatives, collect data and feedback from educators, students and stakeholders, use this information to make data-driven adjustments to your implementation plan.)

Step 12: Scale and Sustain (Gradually expand successful programs and initiatives to reach the entire institution, continue to monitor progress and adapt as needed, ensure ongoing professional development and support for educators)

Step 13: Assess Impact (regularly assess the impact of E 4.0 on student outcomes and educational quality, make data-driven decisions to further refine and improve the implementation)

Step 14: Continuous Improvement (Embrace a culture of continuous improvement, adapting to evolving technologies and educational trends, stay informed about emerging technologies and best practices in education, encourage collaboration and knowledge sharing among educators and stakeholders.)

Some institutions are still stuck in the transition from Education 2.0 and 3.0 to E 4.0, due to various social economic, political, legal and technological factors. The top management of these institutions should understand should make a rationale choice on the importance of E 4.0 and how they can leverage technology, innovation and a learner-centric approach to transform the offering of the institutions. These can guide institutions through this transition by providing a strategic framework for key elements. Here’s how institutions can use CSFs to facilitate the shift to E 4.0.

The shift to E 4.0, heavily dependent on digital technology and emerging technologies, indeed poses potential challenges related to the digital divide, particularly for middle-income and developing economies. This divide is often exacerbated by limited access to reliable enabling technologies such as broadband Internet, which is a critical enabler for the effective implementation of E 4.0. The social implications of this disparity are significant and multifaceted as it can create educational inequality, employability divide, cultural relevance, social stratification, exclusion of rural areas, unequal access to information and dependency on external assistance (González-Perez and Ramírez-Montoya, 2022). To address these social implications, there is a need for a concerted effort from various stakeholders from global collaboration, localized technology development, encouraging the development of technology solutions that are sensitive to the social, economic and cultural contexts of specific regions can help in ensuring inclusivity, infrastructure Investment, policy frameworks and community engagement.

7. Conclusion, limitation and scope for future research

This study has significantly contributed to the literature on the successful implementation of E 4.0 by identifying and analysing 15 CSFs. Through the application of DEMATEL analysis, these factors have been systematically ranked, shedding light on their relative importance in the context of E 4.0. Furthermore, this research has delved into the intricate web of inter-relationships among these factors, classifying them into cause and effect categories, providing valuable insights into the dynamics of implementing E 4.0. However, it’s important to acknowledge the limitations of this study. Firstly, the scope of the study could benefit from a larger and more diverse pool of respondents for the DEMATEL analysis to enhance the generalizability of the findings. Secondly, future research endeavours could consider exploring potential variations in the CSFs based on categories such as the type of educational institution (public/private), the educational level (higher education, secondary, primary) and the nature of courses (arts, science, medicine, engineering, etc.). Furthermore, an intriguing avenue for future research lies in the practical implementation of E 4.0 using the CSFs.
identified in this study. Such empirical investigations would provide valuable insights into the applicability and effectiveness of these factors in real-world educational settings, offering actionable guidance for educators and administrators navigating the transformative landscape of E 4.0. Another area of research would be to develop input-process-output-outcomes model to implement E 4.0. This will help the educators to implement E 4.0. Another interesting area for future investigations could expand on personalized learning, focussing on customized teaching methods, content and pacing to accommodate the diverse needs, interests and situations of learners.

References


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