Article

Assessment in the Age of Education 4.0: Unveiling Primitive and Hidden Parameters for Evaluation

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Abstract: This study delves into the nuanced aspects that influence the quality of education within the Education 4.0 framework. Education 4.0 epitomizes a contemporary educational paradigm leveraging IoT devices, sensors, and actuators to facilitate real-time and continuous assessment, thereby enhancing student evaluation methodologies. Within this context, the study scrutinizes the pivotal role of infrastructure, learning environment, and faculty, acknowledged as fundamental determinants of educational excellence. Identifying five discrete yet crucial hidden parameters, awareness, accessibility, participation, satisfaction, and academic loafing, this paper meticulously examines their ramifications within the Education 4.0 landscape. Employing a comparative analysis encompassing pre- and post-implementation scenarios, the research assesses the transformative impact of Education 4.0 on the educational sector while dissecting the influence of these hidden parameters across these temporal contexts. The findings underscore the substantial enhancements introduced by Education 4.0, including the provision of real-time and continuous assessment mechanisms, heightened accessibility to educational resources, and amplified student engagement levels. Notably, the study advocates for bolstering stakeholders’ accountability as a strategic measure to mitigate academic loafing within an ambient educational milieu. In essence, this paper offers invaluable insights into the intricate interplay between hidden parameters and educational quality, elucidating the pivotal role of Education 4.0 in catalyzing advancements within the education industry.

Keywords: Education 4.0; IoT; hidden parameters; assessment

1. Introduction

In recent years, the emergence of Education 4.0 has redefined the educational landscape by integrating cutting-edge technologies such as IoT devices, sensors, and actuators. These innovations aim to enhance real-time and continuous assessment methodologies, thereby improving the overall quality of education. However, the transition to this new paradigm necessitates a deeper understanding of various underlying factors that may influence educational outcomes. This study revolves around the following research question:

“How do hidden parameters such as awareness, accessibility, participation, satisfaction, and academic loafing influence the quality of education within the Education 4.0 framework?”

This question guides our exploration of the pivotal role these hidden parameters play in the successful implementation of Education 4.0 and their impact on enhancing student evaluation methodologies. Infrastructure, learning environment, and faculty are the three basic criteria that national and international education evaluation agencies use to assess educational institutions [1–3]. These criteria are essential for ensuring that educational institutions can offer a setting that encourages learning and success for students. This
study tries to offer an expert and academic assessment of these parameters. The physical resources and facilities required for teaching and learning make up an educational institution’s infrastructure. These include educational spaces like classrooms, playgrounds, labs, libraries, auditoriums, and other structures. The quality of education can be significantly impacted by the infrastructure, which is a key component. An institution must have a sufficient number of classrooms and buildings with the tools it needs to deliver high-quality instruction. Additionally, providing students with adequate furniture and well-maintained infrastructure can help to create a comfortable and conducive learning environment [2,3]. Several factors, including the learning environment, play a role in the institution’s overall educational quality [4,5]. The learning environment’s essential elements include the course syllabus, the assessment and evaluation process, the examination system, teaching–learning activities, administrative tasks, and academic activities. Students can learn the skills and knowledge they need to thrive in their careers with the aid of a well-designed curriculum that is in line with industry standards [6,7]. Additionally, pinpointing areas where students need to improve can be aided by an efficient assessment and evaluation mechanism that measures student performance [8]. An educational institution’s faculty plays a key role in ensuring that it can deliver high-quality instruction. The faculty’s competence, intelligence, engagement, performance, experience, and research capabilities may have a big influence on the learning results of the students [9]. Students can be guaranteed to receive individualized attention and support with sufficient faculty resources and staffing. Additionally, professors with relevant industry experience can give students the skills and knowledge they need to succeed in the workplace. Faculty members' engagement and research skills might also influence the institution’s overall educational standard [10]. Figure 1 illustrates various direct/primitive parameters that contribute to quality assessment. This figure also illustrates that for the actual participation of stakeholders for quality assessment in the present education scenario, awareness and accessibility is also mandatory; without awareness and accessibility, participation is not possible. The educational revolution integrates the characteristics of Industry 4.0 for data acquisition, filtering, analysis, predictions, automation and many other operations, which is commonly known as Education 4.0.

**Main Features of Education 4.0**

Education 4.0 is a modern educational approach that aims to incorporate the technology breakthroughs of Industry 4.0 into the learning process. This innovative framework utilizes Internet of Things (IoT) devices, sensors, and actuators to establish a captivating and flexible learning environment. The main characteristics of Education 4.0 encompass:

- **Real-Time and Continuous Assessment:** Education 4.0 integrates Internet of Things (IoT) devices and sensors to enable the collection and assessment of data in real-time and continuously. This enables instructors to promptly assess student development and make informed judgments based on data to customize educational experiences according to individual requirements. Continuous evaluation improves the precision and effectiveness of educational interventions, fostering flexible and responsive learning environments [11].

- **Enhanced Accessibility:** The implementation of IoT technology in Education 4.0 enhances the availability of educational resources. Students have the ability to retrieve educational resources from any place and at any moment, thereby eliminating conventional obstacles to learning. This enhanced accessibility facilitates the connection between conventional and digital learning settings, hence ensuring equal learning opportunities for all students [11,12].

- **Personalized Learning Experiences:** Education 4.0 facilitates tailored learning experiences by incorporating new technology. The real-time data obtained from IoT devices enables the tailoring of curriculum and learning paths to cater to the distinct requirements of individual students. This customization boosts student involvement and optimizes learning results by specifically targeting individual strengths and limitations.
- Collaborative Learning Environments: Education 4.0 promotes collaborative learning by utilizing digital platforms that enable students and teachers to engage and cooperate with one other. These platforms facilitate diverse collaborative activities, such as group projects and peer assessments, fostering a more engaged and captivating learning experience [12].

- Smart Infrastructure: Smart infrastructure is a fundamental component of Education 4.0. IoT-enabled devices and smart systems are installed in educational institutions to enhance the physical learning environment. This encompasses intelligent classrooms, automated administrative procedures, and sophisticated resource management, all of which enhance efficiency and create a favorable learning environment [13].

- Faculty Development and Engagement: Education 4.0 highlights the significance of faculty proficiency and involvement. It facilitates continuous professional development for educators, providing them with the necessary skills and expertise to successfully incorporate technology into their teaching methods. In order to fully utilize the capabilities of Education 4.0 technologies, it is crucial to have faculty members that are actively involved and highly skilled [13].

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Figure 1. Direct/Primitive Parameters contributing for quality assessment.
The integration of Internet of Things (IoT) devices, sensors, and actuators for data acquisition within an ambient educational environment, coupled with real-time and continuous data assessment, constitutes a cornerstone of Education 4.0. These advanced technologies enable the seamless collection and analysis of vast amounts of data, providing valuable insights into various educational processes. By leveraging IoT and sensor networks, educational institutions can monitor and optimize the learning environment, track student progress, and tailor educational experiences to individual needs in real time. This continuous data assessment not only enhances the accuracy and efficiency of educational interventions but also supports dynamic and adaptive learning, making Education 4.0 a transformative approach to modern education [6, 8]. Apex body is responsible for the assessment and accreditation of an educational institution. The apex body uses a comprehensive assessment algorithm for assessing an institution; this assessment algorithm is connected with an application interface to make the assessment and accreditation process user-friendly for both stakeholders and the apex body. The stakeholders participated in the assessment and accreditation process through the application interface. All the stakeholders are subdivided into subgroups, i.e., the first sub-groups consist of unaware stakeholders, who do not know about the assessment and accreditation process; this sub-group did not participate in the assessment and accreditation process. The second major sub-group consists of aware stakeholders who are aware about the assessment and accreditation process; this sub-group is further divided in to three sub-groups, i.e., aware stakeholders who do not have access to the assessment and accreditation process, and the other sub-group consists of the aware stakeholders who have access to the assessment and accreditation process, but did not participate knowingly or unknowingly in the assessment and accreditation process. The last sub-group is of the aware stakeholders who have access to the assessment and accreditation process and actually participated in the assessment and accreditation process [11].

Although these parameters contribute a lot to quality education, some other parameters are also responsible for quality education. In many earlier studies on quality education, many hidden parameters were explored. As this study focuses on the Education 4.0 environment, the hidden parameters that are significant improved by the incorporation of IoT devices, sensors, and actuators for real-time assessment are considered for further evaluation. Education 4.0 is a completely new environment that only affects the outer space of educational infrastructure, without hindering the internal workings in the inner space. To investigate the hidden parameters that influence how well education is delivered in the Education 4.0 context, the purpose of this study is to determine if integrating IoT devices, sensors, and actuators for real-time evaluation will have an impact on educational quality [14]. The study attempts to offer an in-depth understanding of how technology might be used to enhance education in the Education 4.0 environment by analyzing these hidden factors. Figure 2 illustrates various indirect/hidden parameters that affect quality education under Education 4.0.

The four main findings of this study are presented in the following sections of this research paper, with each one being discussed in its own section. Section 2 digs deep into an investigation of the unspoken factors that influence educational quality in the context of Education 4.0. The effect of these criteria on the education sector and the study’s findings are discussed are then explored in Section 3. Section 4 presents this study’s conclusion and considers its potential future application.
To establish a welcoming and comfortable learning environment, it is crucial to maintain pre-Education 4.0 scenario, identifying fundamental and hidden parameters that influence educational quality [15]. The quality of education is, however, adversely impacted by a number of additional, less obvious issues as well. This study’s major objective is to identify the unobservable factors that are influenced by the Education 4.0 environment. The term “Education 4.0” refers to a cutting-edge setting where Internet of Things (IoT) gadgets, sensors, and actuators are used to enable real-time and continuous assessment, which affects many little-noticed elements for educational institutions. Infrastructure, learning environment, and teachers make up the three key elements that directly influence outstanding education. The equipment and environments required for teaching and learning make up the infrastructure of an educational institution [16].

The availability of a variety of facilities, such as classrooms, playgrounds, labs, libraries, auditoriums, and other necessary buildings, is crucial for facilitating high-quality instruction in educational institutions. These facilities are essential to making it possible for instruction to be effective. To establish a welcoming and comfortable learning environment, it is crucial to maintain infrastructure and furnish classrooms with the appropriate equipment, in addition to having an appropriate number of buildings and classrooms. The detailed flowchart of the investigation methodology is illustrated in Figure 3. This study initially investigates the pre-Education 4.0 scenario, identifying fundamental and hidden parameters that influence the quality of education. By examining these parameters, we aimed to understand the underlying factors that impacted educational outcomes before the implementation of Education 4.0. These identified parameters were then applied to the post-Education 4.0 scenario to assess their effects within the new educational paradigm. Through rigorous analysis, we explored the mathematical relationships among these parameters, leading to the development of a comprehensive mathematical model. This model incorporates the identified hidden parameters, offering a robust framework for understanding and enhancing educational quality in the post-Education 4.0 context.

Figure 2. Direct/primitive parameters for assessment.

2. Materials and Methods

High-quality education is a fundamental aspect of any civilization. In order to ensure the delivery of high-quality education, it is essential to consider a variety of variables that have an impact on the educational environment [15]. The quality of education is, however, adversely impacted by a number of additional, less obvious issues as well. This study’s major objective is to identify the unobservable factors that are influenced by the Education 4.0 environment. The term “Education 4.0” refers to a cutting-edge setting where Internet of Things (IoT) gadgets, sensors, and actuators are used to enable real-time and continuous assessment, which affects many little-noticed elements for educational institutions. Infrastructure, learning environment, and teachers make up the three key elements that directly influence outstanding education. The equipment and environments required for teaching and learning make up the infrastructure of an educational institution [16].

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The course syllabus, evaluation and assessment procedures, examination systems, teaching and learning procedures, administrative procedures, and academic procedures are important elements of the learning environment. Students can acquire the skills and knowledge essential to succeed in their particular professions by creating a professionally developed curriculum that complies with industry standards. Furthermore, a valid system of assessment and evaluation that monitors student performance can point out areas where students need to develop [17]. An institution’s faculty has a big impact on its capacity to deliver high-quality instruction. The competence, intelligence, engagement, performance, experience, and research talents of the faculty may have a considerable impact on the quality of training they provide. Making sure that students receive customized attention and support is doable with sufficient faculty resources and staffing. Students can benefit from the knowledge and skills that professors with relevant industry experience can offer them in order to be successful in their chosen profession. The faculty’s level of involvement and research skills may also have an effect on the institution’s overall academic standards. The quality of education is influenced by a number of unsaid elements in addition to the obvious ones. In prior studies on high-quality education, many of these hidden characteristics were examined. However, we will focus only on the unobserved factors that are influenced by the Education 4.0 environment in this study [18]. One way that Education 4.0 has improved the education sector is through real-time and continuous assessment, which has an effect on many unspoken elements for educational institutions.

It also examines the vital contributions of all campus stakeholders, including students, faculty members, and administrative staff, to the assessment and accreditation processes within the Education 4.0 framework. Each group’s role and impact on these processes are crucial for a comprehensive understanding of how Education 4.0 can be effectively implemented and sustained. Detailed descriptions of the characteristics and responsibilities of these stakeholders, as provided in the Introduction section, underscore their importance in fostering a collaborative and data-driven educational environment. By integrating the perspectives and efforts of these diverse groups, this research aims to enhance the
overall efficacy and robustness of assessment and accreditation under the Education 4.0 paradigm. This study considers the five hidden parameters for exploration, i.e., awareness, accessibility, participation, satisfaction, and academic loafing [2,19]. Awareness about the assessment and accreditation process is a crucial hidden parameter that affects the quality of education. In the Education 4.0 environment, real-time and continuous assessment enables students to become aware of their academic progress and areas of improvement. This helps them to take corrective measures and improve their learning outcomes. Another unobserved factor that influences the quality is the accessibility in terms of taking part in the assessment and accreditation process.

2.1. Hidden Parameters: Definition, Selection, and Measurement

2.1.1. Introduction to Hidden Parameters

Hidden parameters refer to subtle, often overlooked factors that significantly influence the quality of education. In the context of Education 4.0, which leverages IoT devices, sensors, and actuators to facilitate real-time and continuous assessment, understanding these hidden parameters is crucial for enhancing student evaluation methodologies. This study identifies and scrutinizes five key hidden parameters: awareness, accessibility, participation, satisfaction, and academic loafing.

2.1.2. Selection of Hidden Parameters

The five hidden parameters were chosen based on their critical impact on the educational process and their relevance within the Education 4.0 framework:

- **Awareness**: knowledge of the assessment and accreditation process.
- **Accessibility**: ability to access educational resources and participate in assessment activities.
- **Participation**: engagement in the assessment and accreditation processes.
- **Satisfaction**: stakeholder contentment with the assessment and accreditation process.
- **Academic Loa fing**: irregularities and lack of effort in academic activities.

These parameters were selected because they are pivotal to the successful implementation and functioning of Education 4.0, impacting the overall quality of education.

2.1.3. Measurement with Technology Devices

These hidden parameters are measured using a range of technological devices and methods that provide real-time and continuous data:

- **IoT Devices and Sensors**: used to track and monitor student activities and engagement levels.
  - Example: sensors can measure the time students spend on educational platforms, indicating their participation and engagement.
- **Learning Management Systems (LMSs)**: collect data on student access to resources, submission of assignments, and participation in online discussions.
  - Example: LMS logs can provide data on student accessibility to learning materials and their active participation in course activities.
- **Biometric Devices**: monitor physiological responses to gauge emotional engagement and satisfaction.
  - Example: wearable devices that track heart rate variability and skin conductance to infer levels of stress and engagement.
- **Feedback Systems**: surveys and feedback tools used to measure stakeholder satisfaction with the assessment and accreditation processes.
  - Example: online surveys can gather data on student and faculty satisfaction levels regarding the educational environment and processes.

2.1.4. Prior Research

Several studies have explored these hidden parameters in various educational contexts:
• Awareness and Participation: studies have shown that increased awareness of assessment processes leads to higher levels of participation and engagement among students [11–13].
• Accessibility: research indicates that better accessibility to educational resources enhances learning outcomes and reduces educational disparities [18,19].
• Satisfaction: student and faculty satisfaction has been linked to improved educational experiences and outcomes [14,15].
• Academic Loafing: this phenomenon has been studied extensively, with findings suggesting that accountability mechanisms can mitigate its effects [10].

2.1.5. Other Hidden Parameters in the Literature
In addition to the selected parameters, other hidden factors discussed in the literature include self-efficacy, metacognitive strategies and social presence. These additional parameters were not included in this study due to the focus on factors that can be directly influenced and measured through the integration of IoT and real-time assessment technologies within Education 4.0.

2.1.6. Rationale for Choosing These Parameters
The chosen hidden parameters were selected to provide a comprehensive understanding of the nuanced aspects influencing educational quality in the Education 4.0 environment.

The hidden parameters selected for this study—awareness, accessibility, participation, satisfaction, and academic loafing—were chosen based on their profound impact on educational quality, as evidenced by prior research and theoretical frameworks.

Awareness: Awareness of the assessment and accreditation processes is crucial as it directly affects students’ engagement and motivation. Studies by [20–22] have demonstrated that increased awareness leads to higher student participation and better academic performance.

Accessibility: Accessibility ensures that educational resources are available to all learners, thereby reducing disparities in educational outcomes. Research indicates that enhanced accessibility through digital platforms significantly improves learning effectiveness and equity [23,24].

Participation: Active participation in learning activities and assessment processes is linked to improved learning outcomes. According to [25–27], participation fosters a sense of belonging and enhances collaborative learning, which are essential components of Education 4.0 [26,27].

Satisfaction: Stakeholder satisfaction, including students, faculty, and administrative staff, is a key indicator of the success of educational interventions. Researchers found that satisfaction correlates with increased retention rates and positive educational experiences [28–31].

Academic Loafing: This parameter, often overlooked, refers to reduced effort in group settings, which can detrimentally affect learning quality. Studies such as [32,33] highlight the need for accountability mechanisms to mitigate academic loafing and promote active participation. These parameters were selected due to their substantial influence on the dynamics of Education 4.0, and their selection is supported by a wealth of literature [34–37] emphasizing their relevance in enhancing educational outcomes.

By focusing on awareness, accessibility, participation, satisfaction, and academic loafing, this study aims to address key areas that are critical for enhancing educational outcomes through technological interventions. These parameters are well-supported by prior research, ensuring that the findings of this study can contribute meaningfully to the existing body of knowledge and offer practical insights for the effective implementation of Education 4.0.

Students can access instructional resources at any time and from any location in the Education 4.0 environment through the use of IoT devices and sensors. By bridging
the traditional and digital learning gap, this expands students’ access to higher education. Moreover, the other hidden factor that influences how well education is delivered is participation in the assessment and accreditation processes. Real-time and continuous evaluation is a feature of the Education 4.0 environment that encourages student engagement. Their engagement and academic results are enhanced as a result of this. Further, stakeholders’ satisfaction with the assessment and accreditation process is one additional parameter that needs exploring under Education 4.0. Before the actual implementation of Education 4.0 at the institutional level, it is necessary to ensure satisfaction among stakeholders about Education 4.0. Similarly, the impact of academic loafing (irregularities in teaching–learning process, administration and other educational aspects) directly aligns with stakeholders’ accountability. In the context of Education 4.0, irregularity is defined as any deviation from the minimum required value of a specified parameter within a designated time period and the specific area of the educational environment. In the context of Education 4.0, accountability is defined as the ability of stakeholders to achieve the minimum required value of a specified parameter within a designated time period and specific area of the educational environment. In essence, if any stakeholder or group of stakeholders meets this minimum required value, their accountability is affirmed. Conversely, failure to meet the minimum required value constitutes an irregularity attributed to the stakeholder or group. Therefore, by improving accountability among stakeholders, academic loafing can be reduced in an ambient educational environment [2].

3. Results and Discussion

This section provides a comparative analysis of the characteristics of pre-Education 4.0 and post-Education 4.0, as detailed in Table 1, and examines the impact of these pre- and post-implementation scenarios of Education 4.0 on the education industry, summarized in Table 2. The pre-Education 4.0 scenario pertains to the state of the education industry before the adoption of Education 4.0, while the post-Education 4.0 scenario represents the actual education industry scenario under a simulation environment. This section also includes an examination of the impact of hidden parameters under these scenarios. The results of the pre-Education 4.0 scenario were obtained from prior research, which highlights the significance of awareness, participation, accessibility, and satisfaction with assessment and accreditation [2]. The subsequent section of this paper provides a detailed explanation of the justification for post-Education 4.0. The pre-Education 4.0 scenario, as observed in previous research, indicated a lack of clear understanding of the assessment process enforced by the governing, affiliating, examining, and accreditation bodies among stakeholders, primarily students and teachers [38]. Consequently, special programs were required to increase awareness among stakeholders, as they needed to participate in various surveys and provide feedback to these apex bodies for assessment purposes [25]. In the pre-Education 4.0 scenario, real-time assessment data are automatically collected by IoT devices, sensors, and actuators, eliminating the need for stakeholders to be aware of the assessment process [39]. Even if stakeholders are not aware of the assessment process, they still serve as a source of data for these devices and sensors [40]. Therefore, awareness does not play a significant role in the post-Education 4.0 scenario. The use of IoT devices ensures that data are collected regardless of stakeholders’ knowledge of the assessment process, making it a more efficient and streamlined approach to assessment. In the pre-Education 4.0 scenario, the participation of stakeholders in the assessment process was limited to those who were aware of it due to the direct correlation between awareness and participation. This resulted in low participation rates. However, in the post-Education 4.0 scenario, participation is no longer dependent on awareness but rather on the functioning of IoT devices in the institution. As long as the IoT devices are properly working, any stakeholder present in the institution during a specific time interval \(\Delta T\) will automatically participate in the real-time assessment. Table 2 outlines the anticipated changes in key educational parameters as influenced by the shift from traditional education methods (pre-Education 4.0) to modern, technology-enhanced approaches (post-Education 4.0).
Table 1. Characteristics of pre-Education 4.0 and post-Education 4.0 scenarios.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pre-Education 4.0</th>
<th>Post-Education 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching Approach</td>
<td>Traditional classroom-based learning with limited technology usage</td>
<td>Blended learning approach with a focus on technology integration</td>
</tr>
<tr>
<td>Learning Environment</td>
<td>Conventional classroom settings with limited access to digital tools</td>
<td>Interactive and adaptive learning environments with digital resources</td>
</tr>
<tr>
<td>Curriculum Design</td>
<td>Static and standardized curriculum delivery</td>
<td>Dynamic and personalized curriculum tailored to individual needs</td>
</tr>
<tr>
<td>Assessment Methods</td>
<td>Emphasis on exams and standardized tests</td>
<td>Diverse assessment methods including project-based assessments</td>
</tr>
<tr>
<td>Teacher’s Role</td>
<td>Mainly as knowledge providers and instructors</td>
<td>Facilitators of learning, mentors, and guides for student-centered learning</td>
</tr>
<tr>
<td>Student Engagement</td>
<td>Passive learning with limited interaction</td>
<td>Active participation, collaboration, and engagement through technology</td>
</tr>
<tr>
<td>Skills Development</td>
<td>Focus on traditional academic skills</td>
<td>Emphasis on critical thinking, problem-solving, digital literacy, and adaptability</td>
</tr>
<tr>
<td>Lifelong Learning</td>
<td>Limited emphasis on continuous learning beyond formal education</td>
<td>Encouragement of lifelong learning and upskilling for future readiness</td>
</tr>
</tbody>
</table>

Table 2. Impact on hidden parameters under pre- and post-Education 4.0 scenarios.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre-Education 4.0</th>
<th>Post-Education 4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness</td>
<td>Very Low</td>
<td>Very High</td>
</tr>
<tr>
<td>Participation</td>
<td>Very Low</td>
<td>Very High</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Very Poor</td>
<td>Very Good</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Low</td>
<td>May be improved</td>
</tr>
<tr>
<td>Academic Loafing as Accountability</td>
<td>Very High</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Note: Loafing $\propto \frac{1}{\text{Accountability}}$, the values in this table represent Academic Loafing [2,39].

Table 3 summarizes the types of data collected with technological devices in Education 4.0, along with examples and their relationships to hidden parameters, such as participation, awareness, satisfaction, academic loafing, and accessibility.

Achieving complete coverage of all areas of the campus through IoT devices, sensors, and actuators, along with proper connectivity between stakeholders and these devices, can lead to 100% participation under the post-Education 4.0 scenario [41]. On the other hand, accessibility remains challenging under the pre-Education 4.0 scenario, as the mechanism used by apex bodies requires extra effort from stakeholders [42]. Furthermore, accessibility is interrelated with previous parameters, i.e., awareness and participation, and is also influenced by external parameters, i.e., application interface, assessment algorithm and apex body, leading to similar results as earlier parameters. Similarly, under the post-Education 4.0 scenario, 100% accessibility can be achieved by fulfilling the previously discussed conditions [43,44]. The next two parameters, namely satisfaction and academic loafing, are intertwined with a crucial aspect of Education 4.0, which is the real-time irregularity detection and alert generation framework [45]. This framework is a fundamental component of the Education 4.0 environment and is capable of detecting all sorts of irregularities in real-time and generating specific alerts for the respective stakeholders [46,47]. As mentioned earlier, satisfaction is relatively low in the pre-Education 4.0 scenario. However, the implementation of the real-time irregularity detection and alert generation framework has the potential to improve satisfaction levels in the post-Education 4.0 scenario. Additionally, accountability, which is also lacking in the pre-Education 4.0 scenario, can be improved through the aforementioned framework. Any irregularities caused by any stakeholder can...
be detected and reported in real-time, ultimately minimizing such occurrences with time and adaptability.

Table 3. Types of data collected.

<table>
<thead>
<tr>
<th>Types of Data Collected</th>
<th>Examples</th>
<th>Related Hidden Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity Data</td>
<td>Logins, time spent on educational platforms, completion of assignments,</td>
<td>Participation: measures student engagement in educational activities. Accessibility: frequency of access to learning resources.</td>
</tr>
<tr>
<td></td>
<td>and participation in forums.</td>
<td></td>
</tr>
<tr>
<td>Performance Data</td>
<td>Test scores, assignment grades, progress reports.</td>
<td>Awareness: informs students about their progress and areas needing improvement. Satisfaction: higher performance data leads to increased satisfaction.</td>
</tr>
<tr>
<td>Behavioral Data</td>
<td>Attendance records, participation in class discussions, submission</td>
<td>Participation: captures extent and consistency of student engagement. Academic Loafing: indicates irregular participation patterns.</td>
</tr>
<tr>
<td></td>
<td>patterns.</td>
<td></td>
</tr>
<tr>
<td>Biometric Data</td>
<td>Heart rate, skin conductance, facial expressions.</td>
<td>Satisfaction: reflects emotional and psychological state of students. Academic Loafing: changes in biometric data indicate disengagement.</td>
</tr>
<tr>
<td>Feedback Data</td>
<td>Survey responses, feedback forms, peer reviews.</td>
<td>Satisfaction: measures stakeholders’ contentment with educational processes. Awareness: highlights areas needing more information or support.</td>
</tr>
<tr>
<td>Environmental Data</td>
<td>Classroom temperature, lighting conditions, noise levels.</td>
<td>Accessibility: optimal conditions enhance accessibility and comfort. Satisfaction: contributes to higher satisfaction levels.</td>
</tr>
</tbody>
</table>

This part elaborates on the impact of hidden parameters on Education 4.0 and illustrates the elaborative picture of pre and post-Education 4.0 scenarios. Figure 4 illustrates the mathematical model of the pre-Education 4.0 scenario, and Figure 5 illustrates the mathematical model of the post-Education 4.0 scenario. In these two models, \(U\) and \(U'\) define the set of stakeholders in pre- and post-Education 4.0 scenario. \(S_{\text{Awareness}}, S_{\text{Participation}},\) and \(S_{\text{Accessibility}}\) are the set of stakeholders for awareness, participation and accessibility for the pre-Education 4.0 scenario. \(S'_{\text{Awareness}}, S'_{\text{Participation}}\) and \(S'_{\text{Accessibility}}\) represents the same parameters for the post-Education scenario. \(S'_{\text{Present}}\) is the set of present stakeholders at time interval \(\Delta T\). \(\alpha\) and \(\alpha'\) are the sets of unaware stakeholders in pre-Education 4.0 and absent stakeholders in post-Education 4.0 scenario, respectively. The pre- and post-Education 4.0 scenarios are represented by Equations (1) and (2) and Equations (3) and (4), respectively.

\[
U = S_{\text{Participation}} + \alpha \tag{1}
\]

where \(\alpha\) is set of unaware stakeholders in pre Education 4.0 scenario, and \(S_{\text{Awareness}} \cap \alpha = \emptyset \)

\[
S_{\text{Participation}} \in S_{\text{Accessibility}} \in S_{\text{Awareness}} \tag{2}
\]

where \(S_{\text{Participation}} \leq S_{\text{Accessibility}} \leq S_{\text{Awareness}} \)

\[
U'(\Delta T) = S'_{\text{Present}} + \alpha' \tag{3}
\]

where \(\alpha'\) is a set of absent stakeholders in the post-Education 4.0 scenario at time \(\Delta T\)

\[
S'_{\text{Present}} = S'_{\text{Accessibility}} = S'_{\text{Participation}} = S'_{\text{Awareness}} \tag{4}
\]
where $\alpha$ represents the same parameters for the post-Education scenario.

Irregularity is any act or activity executed by any of the stakeholders that crosses the deviation on any parameters in this example is considered an irregularity on account of the stakeholders. Furthermore, accountability is inversely proportional to irregularities among stakeholders. Finally, by improving participation, accessibility, awareness, and accountability; then, the number of unaware stakeholders is greater than the number of absent stakeholders at time interval $T$.

Equation (5) represents the pre- and post-Education 4.0 scenario of a similar institution; then, the number of unaware stakeholders is greater than the number of absent stakeholders at time $\Delta T$.

Equations (1)–(5) are clearly illustrated in Figures 4 and 5. In Figure 4, the impact of awareness and accessibility on participation is clearly visible under the pre-Education 4.0 scenario. Further, Figure 5 clearly illustrates the non-significance of awareness, accessibility and even participation under post-Education 4.0 scenario, and no special efforts are required for participation in the assessment and accreditation process, the required data are automatically acquired under Education 4.0 scenario [39].
Further, academic loafing is inversely proportional to accountability. That means we can reduce academic loafing among stakeholders by improving accountability among them. Furthermore, accountability is inversely proportional to irregularities among stakeholders. Irregularity is any act or activity executed by any of the stakeholders that crosses the defined threshold limits for a particular parameter under evaluation, i.e., to conduct a lecture in any time interval $\Delta T$, the presence of a specific stakeholder $s$ is required on a specific classroom $c$; the deviation on any parameters in this example is considered an irregularity on account of the stakeholder $s$.

\[
S'_{\text{AL}} \propto \frac{1}{S'_{\text{Accountability}}}
\]  

(6)

where $S'_{\text{AL}}$ is academic loafing among stakeholders, and $S'_{\text{Accountability}}$ is accountability.

\[
S'_{\text{Accountability}} \propto \frac{1}{\sum_{i=0}^{n} IR_{\text{Count}}}
\]  

(7)

where $n$ is the number of stakeholders, $IR_{\text{Count}}$ is the irregularity count, and $n \leq U'$.

From Equations (6) and (7)

\[
S'_{\text{AL}} \propto \frac{1}{S'_{\text{Accountability}}} \propto \frac{1}{\sum_{i=0}^{n} IR_{\text{Count}}}
\]  

(8)

Therefore, from Equations (6)–(8)

\[
S'_{\text{AL}} \propto \sum_{i=0}^{n} IR_{\text{Count}}
\]  

(9)

Hence, we can conclude that academic loafing can be reduced by reducing stakeholders’ irregularities. Further, low academic loafing also means high accountability among stakeholders. Finally, by improving participation, accessibility, awareness, and accountability, the satisfaction may be improved. The subsequent section concludes this study and also details some future applications of this study.

4. Conclusions

The culmination of this research underscores the pivotal role played by infrastructure, learning environment, and faculty in delineating the caliber of education, emphasizing their intricate interplay in shaping the educational landscape. Moreover, the study illuminates the significance of numerous latent hidden factors such as awareness, accessibility, participation, satisfaction, and academic loafing, which intricately contribute to the overall educational experience. Through a meticulous placement of these variables within both pre- and post-Education 4.0 scenarios, this study offers a nuanced understanding of their differential impacts across these distinct epochs. By juxtaposing the dynamics of awareness, accessibility, and participation, our research sheds light on the evolving nature of educational excellence, highlighting the shifting paradigms in the post-Education 4.0 era. Furthermore, our investigation establishes a quantifiable correlation between irregularities and academic loafing, unraveling the complexities underlying student engagement and performance. The theoretical and managerial implications of this study provide a pathway for the improvement or the assessment and accreditation process in both pre- and post-Education 4.0 scenarios. By identifying avenues for enhancing satisfaction levels within the post-Education 4.0 paradigm, this study paves the way for targeted interventions aimed at maximizing student fulfillment and academic achievement. The findings of this study are poised to significantly enhance the implementation of Education 4.0 by addressing key aspects of the assessment and accreditation processes within this advanced educational paradigm. Specifically, the mathematical solutions developed and analyzed in this research
offer robust frameworks for the integration and optimization of diverse data acquisition algorithms. These algorithms are crucial for capturing, processing, and analyzing the extensive datasets characteristic of Education 4.0 environments. By providing precise and scalable solutions, this study not only facilitates the seamless integration of data-driven methodologies but also ensures the reliability and efficiency of accreditation systems, ultimately contributing to the broader adoption and success of Education 4.0 initiatives. These findings not only yield actionable insights for optimizing educational efficacy across diverse domains, but also underscore the imperatives of holistic evaluation encompassing hidden parameters. As such, this research serves as a cornerstone for future inquiry, providing a comprehensive framework for understanding and enhancing educational quality in an ever-evolving landscape. While this study has provided valuable insights into the impact of Education 4.0 on educational quality through the lens of hidden parameters, there are several avenues for future research and development that warrant exploration. Expand the scope to include additional hidden parameters that may influence educational quality in Education 4.0 environments. For instance, exploring cultural factors, socio-economic influences, and personal motivations could provide a more comprehensive understanding. Utilize advanced data analytics techniques, such as machine learning and predictive modeling, to extract more nuanced patterns and insights from the vast amounts of data collected by IoT devices and sensors. This could enhance personalized learning experiences and optimize educational interventions. Develop and test strategies to enhance stakeholder engagement and accountability within Education 4.0 environments. This could involve participatory action research methodologies to co-create solutions with students, educators, administrators, and policymakers. By addressing these future research directions, the field of Education 4.0 can continue to evolve, offering transformative opportunities to enhance educational quality, accessibility, and equity in a rapidly changing digital landscape.

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