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Identification of key variables for the integration of a smart schools system and the evolution of local culture in the educational context

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Abstract

The education system faces major challenges due to technological evolution and the changing demands of society. "Smart Schools" is presented as an innovative solution because it integrates information and communication technologies in education. However, its implementation varies and is influenced by contextual factors such as culture and socioeconomic status, highlighting the need for a detailed analysis of these elements. This study mainly aims to explore and classify the variables that affect the implementation of Smart Schools in different local cultural contexts. A mixed and exploratory methodology was used, combining qualitative and quantitative methods. The analysis revealed that key variables such as technological infrastructure, educational policies, and financial resources have a major influence on the implementation of Smart Schools. The research highlights the need to consider both technical and cultural factors to ensure that technological innovations are inclusive and accessible, promoting a more equitable and relevant education for all students.

Keywords: smart schools, cultural adaptation, educational policies, innovative education, technological infrastructure.

Introduction

Education faces significant challenges due to rapid technological evolution and changing societal needs (Subramanya, 2019). The concept of "Smart Schools" has emerged as an innovative response to these challenges, integrating information and communication technologies (ICT) into all areas of the educational environment (Soltani, 2012). These institutions not only use advanced technology to facilitate learning but also promote an approach that includes personalization of learning, efficient management of school resources, and participation of the educational community (Mogas et al., 2022). However, the implementation of Smart Schools is not homogeneous and is influenced by various variables that vary according to the local cultural and socioeconomic context (Mariono, 2023).

Research on Smart Schools has highlighted the importance of several key elements for their success. Among these, adequate technological infrastructure, continuous training of

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educators, and the formulation of favorable educational policies are critical as expressed by Iqbal et al. (2020) and Mogas et al. (2022). Furthermore, studies such as those by Shonfeld et al. (2021) emphasize that the acceptance of technology in schools depends largely on community support and how innovations align with local cultural values and needs. Cultural adaptation is a crucial factor that could determine the success of Smart Schools implementation, as it allows educational technologies and methodologies to be relevant and accessible to all students (Demir, 2021).

As digital technologies continue to transform the educational landscape, it is essential to understand how these changes can be effectively integrated into diverse cultural contexts (Fischer et al., 2020). This study is justified by its focus on identifying key variables that facilitate or hinder the implementation of Smart Schools in different cultural settings. Through this analysis, the aim is to provide a comprehensive framework to guide decision-makers in the adoption and adaptation of educational technologies. Therefore, the main objective of this research was to explore and classify the variables that affect the implementation of Smart Schools in contexts of local cultural evolution.

To achieve this objective, key variables influencing the integration of Smart Schools were identified and the interrelationship between these variables was analyzed using the MICMAC (Matrix of Cross-Impacts, Multiplication Applied to a Classification) technique to determine their level of influence and dependence. The study was based on the following fundamental assumptions: 1. The implementation of Smart Schools is strongly influenced by a set of interrelated variables, including technological, pedagogical, social, and cultural factors. 2. Cultural adaptation is crucial to ensure that educational technologies and methodologies are accepted and useful in a specific context. 3. The existence of adequate technological infrastructure and favorable educational policies are necessary preconditions for the success of Smart Schools.

This study focuses on the identification and analysis of key variables in the implementation of Smart Schools, with a particular focus on how these variables interact in specific cultural contexts. The study is limited to a set of ten predefined variables, selected based on their relevance according to the literature and expert opinion. A major limitation is the reliance on expert assessment, which may introduce subjective biases. Furthermore, cultural and socioeconomic variability across different regions may limit the generalizability of the results to other contexts not directly studied.

Methodology

The present study was designed as a mixed and exploratory research. Mixed because it uses both qualitative and quantitative methods (Sampieri, 2018). Exploratory because the main objective was to explore and understand the interactions between key variables (Swedberg, 2020). In this case, in the integration of Smart Schools and local culture, an area that has not been widely studied using the MICMAC structural analysis (SA) technique. The focus is on understanding the complex dynamics that influence the integration of Smart Schools with local culture. The MICMAC technique is particularly beneficial in this type of research, since it allows, in addition to identifying critical variables, to understand how these interact with each other in a complex system (Arango & Cuevas, 2014).

The sample of participants consisted of 10 experts selected for their experience and expertise in relevant areas such as education, educational technology, school management, and cultural studies. Participants were chosen through purposive sampling, ensuring a diverse representation of perspectives. This group included 3 academics, 2 school administrators, 2 educational technology consultants, and 3 sociologists specialized in cultural studies.

A literature review (LR) was conducted to identify initial variables related to the integration of Smart Schools and local culture. Subsequently, semi-structured interviews were conducted with each expert to validate the variables identified in the literature and to discover new variables from their perspective. Finally, the experts assessed the dependence and influence of each variable using the MICMAC technique. This assessment was conducted through a series of workshops and group discussions, in which a cross-impact matrix was constructed.

For the interviews with the experts, a semi-structured guide was used that included open questions to explore each variable in depth. In addition, the MICMAC software was used for the SA of the variables, facilitating the identification of the motor and dependent variables.

Data acquired from the interviews and the MICMAC workshop were qualitatively analyzed to identify patterns and relationships between variables. Qualitative analysis software was used to code the interviews and classify variables according to their influence and dependence. MICMAC analysis allowed variables to be categorized into four groups: motor, autonomous, dependent, and linking, providing a clear understanding of their role in the system.

The MICMAC technique was implemented in several sequential stages, detailed below:

1. Definition of the context and initial variables: This stage aimed to clarify the research context and select a preliminary list of variables related to the integration of Smart Schools and local culture. To do so, a LR was conducted and initial discussions were held with experts to identify potentially relevant variables.

2. Validation of variables: at this stage, the preliminary variables were confirmed and adjusted. In-depth interviews were conducted with experts to validate the identified variables and to add others that had not been initially considered.

3. Construction of the cross-impact matrix: the objective was to assess the dependence and influence relationships between the variables. A workshop was organized with the experts to discuss and reach a consensus on the influence of each variable on the others. The experts assigned influence values on a qualitative scale, from 0 (no influence) to 3 (strong influence), which were entered into a Cross-Impact Matrix.

4. Matrix Analysis and Influence/Dependence Calculation: This stage consisted of classifying the variables according to their influence and dependence. Influence and dependence indices were calculated for each variable using specialized software tools, which allowed the identification of Driving Variables (high influence and low dependency), Dependent Variables (low influence and high dependency), Autonomous Variables (low influence and low dependency), and Link Variables (high influence and high dependency).

5. Interpretation of results and classification of variables: In this phase, the results obtained from the matrix were analyzed and the variables were classified into meaningful categories.

The results were discussed in another workshop with the experts to interpret the positions of the variables in the influence-dependence map, and the implications for the integration of Smart Schools and local culture were analyzed.

Compliance with all relevant ethical considerations was ensured. Participants were informed about the purpose of the study and their written informed consent was obtained prior to their participation. Confidentiality of their identities and the information provided was assured, and they were offered the possibility to withdraw their participation at any time without any consequences.

Results

This study focused on identifying and classifying the key variables that affect the integration of Smart Schools concepts and local cultural evolution. The identified variables were assessed using the MICMAC technique, based on the opinions of ten experts distributed in four groups: academics, school administrators, educational technology consultants, and sociologists specialized in cultural studies. The results acquired from applying the proposed methodology are presented below.

A preliminary list of variables related to the integration of Smart Schools and local culture was created from the LR. In-depth interviews were also conducted with experts to validate the identified variables and add others that were not initially considered. Ten variables were identified, which can be seen in Table 1. The table is made up of 4 columns. The first shows the variable number, the second corresponds to a code that was assigned to each variable for better management of the information in the implementation of the MICMAC technique. The third deals with the name of the variable and the fourth corresponds to the description of the variable.

Table 1. Variables identified with the LR and expert opinion

#	Code	Name	Description
1	V1	Technological infrastructure	The availability and quality of technological infrastructure are critical to the success of Smart Schools. This includes access to the internet, digital devices, and appropriate educational software (Al-Malah et al., 2020).
2	V2	Teacher training	The preparation and ongoing training of teachers in the use of educational technologies are crucial for the effective implementation of Smart Schools (Mogas et al., 2022).
3	V3	Community support	Local acceptance and support, including parents, students, and community leaders, are essential for the incorporation of new technologies in the educational field (Statti & Torres, 2020).
4	V4	Educational policies	Government policies and regulations to facilitate the implementation of Smart Schools. This includes financing, technology use regulations, and digital inclusion programs (Chohan & Hu, 2022).
5	V5	Cultural adaptation	The ability to adapt educational technologies to the cultural characteristics and specific needs of the local community is a key factor for their acceptance and success.

6	V6	Student participation	The motivation and commitment of learners in the use of technological tools can significantly influence the success of Smart Schools.
7	V7	Assessment and monitoring	The implementation of systems to assess and monitor the progress and results of Smart Schools is essential to make adjustments and continuously improve the process.
8	V8	Financial resources	Adequate funding to develop and maintain the technological infrastructure, support teacher training programs, and other necessary resources.
9	V9	Accessibility and equity	Implementation of policies and practices that ensure the inclusion of all learners, regardless of their socioeconomic background or geographic location, in the educational opportunities offered by Smart Schools.
10	V10	Pedagogical innovation	This refers to the incorporation of new teaching methodologies and practices that take advantage of available technologies to improve the educational experience.

Source: Authors

Once the final list of variables was obtained, a workshop was organized with the experts to discuss and agree on the influence of each variable on the others. The experts rated each variable in terms of influence and dependence, using a scale of 0 to 3. The averages of these ratings were used to build the Cross-Impact Matrix, which shows how each variable influences the others. Figure 1 below shows the matrix, which shows that the variable V1 (Technological infrastructure) has a strong influence relationship (3) with the variable V2 (Teacher training) as well as with the variable V3 (Community support). However, with the variable V4 (Educational policies) it has a weak relationship (1). In this way, the Cross-Impact Matrix in Figure 1 is interpreted.

Figure 1. Cross-impact matrix

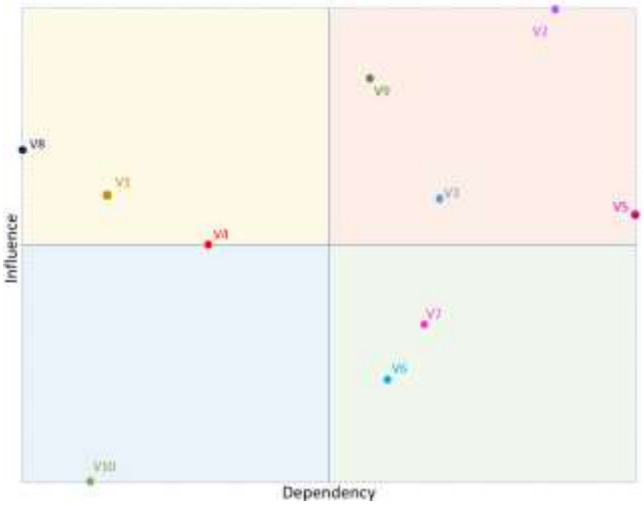
Influence ↱	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
V1	0	3	3	1	2	1	2	3	2	1
V2	3	0	3	1	3	3	3	2	3	3
V3	1	1	0	3	3	3	1	2	2	2
V4	1	3	2	0	3	1	3	1	2	1
V5	0	2	3	3	0	3	3	0	2	2
V6	2	3	1	1	3	0	1	0	1	1
V7	0	2	2	2	2	1	0	1	2	2
V8	3	3	2	2	3	2	2	0	2	1
V9	3	3	2	2	2	3	3	3	0	1
V10	1	1	1	1	1	1	1	1	2	0

Source: Authors

Based on the completion of the cross-impact matrix, the influence and dependence indices for each variable were calculated using specialized software tools, which allowed the identification of driving variables, dependent variables, autonomous variables, and link

variables. The visual representation of this classification is shown in Figure 2, which corresponds to the plane of direct influence/dependence (PDID). In this plane composed of four quadrants, the driving variables are located in the upper left quadrant, the link variables are located in the upper right quadrant, the autonomous variables are located in the lower left quadrant, and the dependent variables are located in the lower right quadrant.

Figure 2. PDID



Source: Authors

To facilitate the analysis of results, Table 2 below presents the classification results of the variables associated with the integration of a Smart Schools system and the evolution of local culture.

Table 2. Results of the classification of the variables associated with the integration of a Smart Schools system and the evolution of local culture

Variable Type	Variable	Code
Link variables	Teacher training	V2
	Community support	V3
	Cultural adaptation	V5
	Accessibility and equity	V9
Driving or "influential" variables	Technological infrastructure	V1
	Educational policies	V4
	Financial resources	V8
Autonomous variables	Pedagogical innovation	V10
Dependent or result variables	Student participation	V6
	Assessment and monitoring	V7

Source: Authors

As can be seen in the table above, the variables Teacher training (V2), Community support (V3), Cultural adaptation (V5), and Accessibility and equity (V9) are linking variables. These have a high influence and dependence, which indicates that they are essential to connect and mediate between different aspects of the educational and cultural system.

The variables classified as driving were: Technological infrastructure (V1), this variable showed high influence and low dependence. It is considered a crucial driving variable for the implementation of Smart Schools since its development significantly impacts other areas, but depends relatively little on them. Educational policies (V4), this variable also stands out as a driver, since the policies dictate the guidelines and regulatory frameworks that govern the adoption of innovative educational technologies and practices, and finally, the variable Financial resources (V8). Its influence and high dependence suggest that it is a crucial variable for the development of infrastructure and training, being a key facilitator in the transformation towards Smart Schools.

On the other hand, only one variable was classified as Autonomous: pedagogical innovation (V10). This variable presents low influence and low dependence, suggesting that its effects are limited and relatively isolated from the other variables of the system studied.

Finally, the variables classified as dependent, Student participation (V6) and Assessment and monitoring (V7), presented low influence and high dependence, which indicates that they are highly affected by other variables, but do not have a dominant role in influencing them.

The results highlight the importance of Teacher training, Community support, Cultural adaptation, Accessibility and equity, Technological infrastructure, and Educational policies as pillars in the implementation of Smart Schools. Comparatively, Financial resources is also identified as a critical variable, although with a slightly higher dependency. Pedagogical innovation, on the other hand, appears as a variable with low influence and dependency, suggesting that although important, it is not the main driver in this context. It is essential to highlight that variables with low influence and dependency, such as Pedagogical innovation, although they appear less critical in this matrix, should not be completely ignored. They can have important roles in specific contexts or in the long term.

On the other hand, the Indirect Influence Matrix (IIM) provides an additional perspective that cannot be obtained solely from the Direct Influence Matrix (DIM). While the IIM is based on the direct influence of some variables on others, the IIM considers second and third-order effects, that is, how one variable can influence another indirectly through other intermediate variables. This allows a more complete view of the structure of interdependencies in the system.

In this sense, regarding dependence, the IIM showed that the variable Assessment and monitoring (V7) has a higher dependency than what was observed in the DIM. This suggests that, although it may initially appear less dependent, Assessment and monitoring is significantly influenced by other variables through indirect routes. Similarly, the variable Pedagogical innovation (V10) also presented a higher dependency in the IIM compared to the initial classification of the DIM. These findings, visualized in Figure 3, highlight how indirect interactions can increase the perception of dependency on certain variables, revealing deeper connections within the system.

Figure 3. Ranking of variables by dependence DIM Vs IIM

Source: Authors

In terms of influence, the IIM revealed that the variable Educational policies (V4) is more influential than what was identified with the DIM. This indicates that Educational policies not only directly affects other variables but also has a significant impact through indirect interactions. In contrast, the variable Cultural adaptation (V5) turned out to be less influential on the IIM, implying that although it has a considerable direct effect, its indirect effects through other variables are less pronounced. These results are stipulated in Figure 4.

Figure 4. Ranking of variables by influence DIM Vs IIM

Source: Authors

These differences between DIM and IIM underscore the importance of considering both direct and indirect influences to gain a full understanding of system dynamics. IIM, by capturing the complex webs of indirect interactions, provides a more detailed view of how variables within the education system interact and affect each other.

The MICMAC methodology allowed to identify the key variables in the integration of Smart Schools with local cultural evolution. The results highlight the need to focus on strengthening the technological infrastructure, developing robust educational policies, and ensuring the availability of financial resources to facilitate an effective transition towards a more innovative educational model adapted to local cultural needs.

Discussions

This study identified and classified the key variables that influence the integration of Smart Schools in contexts of local cultural evolution, using the MICMAC technique. Technological infrastructure (V1), Educational policies (V4), and Financial resources (V8) were determined to be driving variables with high influence and low dependence. Furthermore, Teacher training (V2), Community support (V3), Cultural adaptation (V5), and Accessibility and

equity (V9) were categorized as link variables, essential to mediate between different aspects of the educational and cultural system. Pedagogical innovation (V10) was classified as an autonomous variable, while Student participation (V6) and Assessment and monitoring (V7) were identified as dependent variables.

The findings highlight the importance of the technological infrastructure in the effective implementation of Smart Schools. Specifically, it is noted that this infrastructure is not just an isolated component, but an essential foundation that facilitates and enhances other elements of the smart education system. As mentioned in Omirzak et al. (2022), the proper installation and maintenance of advanced technologies allow for a more effective integration of digital tools in the teaching-learning process, which, in turn, can improve educational quality and access to innovative teaching resources.

These results are consistent with the conclusions presented in the study by Seraji et al. (2020). In their research, both opportunities and limitations in the implementation of Smart Schools projects are identified. The potential for improving academic performance and personalizing teaching through advanced technologies is highlighted. At the same time, various barriers are recognized, such as the lack of adequate infrastructure, resistance to change on the part of teachers, and the need for constant training for educational staff.

In this sense, the Technological infrastructure is not only a fundamental pillar for the functioning of Smart Schools but also a determining factor that influences the effectiveness and scope of these educational innovations. The alignment with the findings of Seraji et al. (2020) reinforces the idea that, for the success of these initiatives, it is crucial to face the opportunities and challenges presented by technological implementation in the educational field.

On the other hand, the strong influence of educational policies underlines the importance of an adequate regulatory framework that facilitates the adoption of educational technologies. Educational policies establish the guidelines and standards necessary for the implementation of Smart Schools, including aspects such as financing, teacher training, and regulation of the use of technologies (Dong et al., 2020). As expressed by Khoyaled (2023), a well-designed regulatory framework can provide incentives for the adoption of new technologies, ensure that resources are distributed equitably, and create a supportive environment for the development of appropriate technological infrastructures.

Furthermore, these policies can include measures for data protection and privacy, which are fundamental aspects of the use of technologies in educational environments. As discussed in Ireri et al. (2020), by establishing clear objectives and providing a supportive framework, educational policies can minimize barriers to technological adoption, ensuring that educational innovations are implemented efficiently and safely and that they are accessible to all learners, regardless of their socioeconomic background. Therefore, the formulation and implementation of effective educational policies are crucial for the success of the transition towards more innovative and technologically advanced educational models.

The availability of financial resources is also a key facilitator in the implementation of Smart Schools, according to Idris et al. (2023) this variable allows the development of the necessary technological infrastructure and the implementation of training programs for teachers and administrative staff. In addition, Animashaun et al. (2024), state that financial resources are

essential to guarantee equitable access to these technologies, ensuring that all students, regardless of their socioeconomic status, have the tools required to participate in the educational process.

Beyond physical infrastructure, financial resources are also critical to the development of ongoing training programs for teachers. Adequate training of educational staff is essential for them to be able to effectively integrate new technologies into their teaching styles as noted by Onyema (2020). This includes not only technical training on the use of devices and software but also the development of pedagogical competencies to apply innovative approaches in the classroom, such as personalized education and project-based learning. Without adequate funding, these training programs could be insufficient, limiting teachers' ability to make the most of the technological tools available (Tomczyk & Walker, 2021).

Finally, the availability of financial resources also facilitates ongoing research and assessment of Smart Schools initiatives. According to Zeeshan et al. (2022), this allows educational institutions to measure the impact of the technologies and methodologies implemented, identify areas for improvement, and adapt their strategies accordingly. In short, financial resources not only enable the acquisition of technology but also ensure effective and sustained implementation, maximizing the potential of Smart Schools to improve educational outcomes.

The classification of Teacher training, Community support, Cultural adaptation, and Accessibility and equity as link variables highlights their critical role in interconnecting key elements of the education system. These variables act as bridges that facilitate the cohesion and harmonious functioning of the system, ensuring that technological and pedagogical innovations are implemented effectively and equitably.

As described in Howard et al. (2021), teacher training is essential to equip educators with the skills and knowledge necessary to integrate educational technologies into their teaching practices. However, the effectiveness of this training depends on the technological infrastructure available and the educational policies that support it, showing how this variable is intertwined with other components of the system. Likewise, Keane et al. (2020) explain that teachers' willingness to adopt new technologies can be influenced by the level of support and acceptance they perceive from the community, including parents, students, and local leaders.

Community support is also an indispensable component for the sustainability and success of Smart Schools. D'Amico et al. (2021) point out that an engaged and well-informed community can facilitate the implementation of technologies by providing a supportive environment and moral and logistical support. This support can manifest itself through active participation in school events, collaboration with schools on technological initiatives, and the promotion of responsible and beneficial use of technologies. According to Díaz et al. (2020), technological integration in schools can strengthen community cohesion and promote a shared sense of progress and modernization.

Cultural adaptation is another vital aspect, as it ensures that educational technologies and methods are relevant and respectful of the specific values and needs of each community. This variable not only influences the acceptance and effectiveness of the implemented technologies but is also affected by factors such as educational policies and the

socioeconomic dynamics of the region. According to Brown et al. (2021), successful cultural adaptation can facilitate the personalization of learning and increase student participation, while failure to consider cultural sensitivities can result in resistance and inefficient use of technological resources.

Finally, accessibility and equity are deeply connected to the financial resources available and the inclusion policies adopted by educational institutions. Lack of accessibility can perpetuate or even widen existing educational gaps, while adequate attention to them can promote a more inclusive and fair learning environment.

Together, these link variables not only exert a significant influence on other elements of the system but are also highly dependent on them. This complex structure of interactions underlines the need for a comprehensive and coordinated approach in the implementation of Smart Schools, where each component is considered in relation to the others to maximize the positive impact on the overall education system.

These results are aligned with previous studies that highlight the importance of a robust technological infrastructure and favorable educational policies for the success of Smart Schools (Al-Malah et al., 2020; Chohan & Hu, 2022). However, the identification of Cultural adaptation as a link variable highlights a less explored dimension in the literature, coinciding with recent research that emphasizes the need to consider local cultural contexts in the implementation of educational technologies (Demir, 2021).

Conclusions

This study contributes to the understanding of how various variables interact to influence the implementation of Smart Schools, highlighting the need for a comprehensive view that considers both technical and cultural aspects. The results suggest that policymakers and educators should focus not only on infrastructure and resources but also on ongoing educator training and community participation.

On the other hand, a key limitation of this study is the reliance on expert assessment, which may introduce subjective biases. Furthermore, cultural and socioeconomic variability across different regions limits the generalizability of the results, making the findings more applicable to contexts similar to those studied. It is recommended that future research explore the integration of Smart Schools in a wider variety of cultural and socioeconomic contexts. Furthermore, it would be valuable to further investigate the interaction between variables identified as link, to better understand how they can be managed to facilitate successful implementation of Smart Schools.

The findings of this study underline the relevance of considering both technical and cultural factors in the implementation of Smart Schools. Technological infrastructure and educational policies emerge as fundamental pillars, while cultural adaptation and community participation are essential to ensure an effective and relevant integration of educational technologies.

The success of Smart Schools depends on a combination of interrelated factors. As digital technologies continue to evolve, it is crucial to adopt an approach that considers local cultural

needs and values, ensuring that educational innovations are accessible and beneficial to all students.

In conclusion, the implementation of Smart Schools is a complex process that requires consideration of a variety of interrelated factors. A solid technological infrastructure, adequate educational policies, and financial resources are fundamental but it is also essential to pay attention to teacher training and community participation to ensure that educational technologies are integrated effectively and meaningfully. Adaptation to local cultural needs is crucial to the success of these initiatives, ensuring that they are inclusive and accessible to all learners.

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