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What kind of VET schools have higher digital capacity? An NCA and QCA study

¿Qué tipo de centros de FP tienen mayor capacidad digital? Un estudio de NCA y QCA

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ABSTRACT

VET institutions are involved in a rapid process of digital transformation, but despite the investments, expected changes have not been achieved. Thus, this study identifies the necessary and sufficient conditions for a high digital capacity of schools. For this, NCA and QCA were conducted from 21 basic VET institutions, analysing data from SELFIE, INCOTIC 2.0 and COMDID A. Considering students' digital competence (SDC) perception, teachers' digital competence (TDC) perception, infrastructure, digital plan and leadership as conditions for a high digital capacity of school, the results revealed that a high level of TDC and digital plan level are necessary for a full degree or digital capacity. According to sufficient conditions, infrastructure is essential for successful digital implementation in schools, but SDC or TDC are also crucial to ensure effective technology use. As a conclusion, the article provides valuable insights into VET institutions' digitalisation to benefit their digital transformation processes.

RESUMEN

Los centros de FP están inmersos en un rápido proceso de transformación digital, pero a pesar de las inversiones, no se han logrado los cambios esperados. Por lo tanto, este estudio identifica las condiciones necesarias y suficientes para una alta capacidad digital de los centros. Para ello, se realizaron NCA y QCA de 21 centros de FP básica, analizando datos de SELFIE, INCOTIC 2.0 y COMDID A. Considerando la percepción de la competencia digital del alumnado (CDA), la percepción de la competencia digital docente (CDD), la infraestructura, el plan digital y el liderazgo como condiciones para una alta capacidad digital de los centros, los resultados revelaron que un alto nivel de TDC y de plan digital son necesarios para un grado completo o capacidad digital. Según las condiciones suficientes, la infraestructura es esencial para el éxito de la implementación digital en las escuelas, pero la CDA o la CDD también son cruciales para garantizar un uso eficaz de la tecnología. Como conclusión, el artículo proporciona valiosas perspectivas sobre la digitalización de los centros de FP para beneficiar sus procesos de transformación digital.

KEYWORDS · PALABRAS CLAVES

Digital transformation, vocational education and training, digital capacity, QCA, NCA.
Transformación digital, educación y formación profesional, capacidad digital, QCA, NCA.

1. Introduction

Digital technologies impact all educational levels and affect all aspects of education and all main actors (Castañeda et al., 2023). Due to its close relation with education and the labour market, vocational education and training (VET) is a key educational level that provides students with the necessary competences and skills for the jobs of today and tomorrow (Kovalchuk et al., 2023). Furthermore, the importance of digital transformation in VET institutions is underscored, as it presents an essential opportunity for fostering employment prospects in the context of the digital transformation of the labour market.

In order to have a successful digital transformation, educational institutions must increase their digital capacity, taking into account the school culture, policies and infrastructure as well as the digital competences of students and staff to support an effective integration of technology (Costa et al., 2021). To accomplish this, one of the strategic priorities is to address the need for effective digital capacity planning and development (European Commission, 2020).

Nevertheless, studies have concluded that, although considerable investment has been made in the integration of technology, schools have not yet achieved the expected transformation (Delgado et al., 2015). Many studies conclude that the integration of digital technologies in education is a complex phenomenon and that many different factors contribute to an effective integration (Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023). Despite these analyses of different factors influencing the digital transformation in education, to the best of our knowledge, there have been no studies to date that address the conditions that must be present for an educational institution to establish an appropriate process for its digital transformation. Therefore, this study aims to analyse the necessary and sufficient conditions for a high digital capacity in basic VET schools in the Basque Autonomous Community (BAC) in order to help them to focus on the key factors to reach their goal and guide them in developing an effective digital transformation process.

2. Theoretical framework

2.1. Digital transformation and the digital capacity of schools

Digital transformation in education is defined as a set of synchronized changes in culture, workforce, technology and educational models that reshapes the institution's processes, strategic plans, and value proposition (Brooks & McCormack, 2020). It is a complex process that requires large-scale transformative changes beyond the technical aspects of technology and infrastructure (Pettersson, 2021).

Digital transformation in education is a priority in Europe since it acknowledges the potential of digital technologies for inclusive and high-quality education (Castañeda et al., 2023). One of the strategic priorities of the Digital Education Action Plan 2021-2027 mentions "the development of a high-performing digital education ecosystem," highlighting the need for effective digital capacity planning and development (European Commission, 2020, p. 10). Nonetheless, although many investments have been made to integrate digital technologies in education, many schools have not yet achieved the expected transformation (Delgado et al., 2015).

For a successful digital transformation in education, schools must increase their digital capacity levels, taking the school culture, policies, infrastructure and digital competences of students and staff into consideration in order to support an effective integration of technology (Costa et al., 2021). Digital capacity refers to the effective integration of technology into teaching and learning processes by a school's cultural environment, policies, and infrastructure as well as the digital competence of its students and teachers (Costa et al., 2021). However, digital capacity is not an issue that involves only the level of implementation; the school's role in the implementation of its digital strategies is essential (Giannoutsou et al., 2023). Hence, for a successful digital education, a culture of bottom-up innovation is needed (Giannoutsou et al., 2023). The incorporation of digital technologies in education depends on each school's characteristics (Castaño Munoz et al., 2023), and it is possible for two schools with the same infrastructure, human resources and students to have wholly different results in their digital capacity (Solar et al., 2013). Therefore, it is crucial for school principals to work with others to establish a digital technology implementation vision (Solar et al., 2013).

The European Commission designed the SELFIE tool based on the DigCompOrg framework (Kampylis et al., 2015) in order to support schools with informed decision-making on the use of digital technologies (Giannoutsou et al., 2023). SELFIE is a self-reflection tool that gathers information about school management team members, teachers and students in order to determine how digitalisation is implemented in the school (Giannoutsou et al., 2023) and provides schools with information on their digital capacity considering the participation of all members (Kampylis et al., 2016). Thus, the main goal of SELFIE is to help schools to obtain a holistic view of organizational strategies for the school's digital transformation (Kampylis & Sala, 2023).

SELFIE is considered a valuable tool to support digital development plans in schools as it provides a good understanding of the conditions and reality of the school and promotes the participation of the whole community when creating the school's digital plan (Castañeda et al., 2023). Schools need a digital plan to achieve the appropriate vision, which must be done based primarily on the school's digital capacity and with the joint reflection and cooperation of the school community (Garcia Grau et al., 2022; Solar et al., 2013). The school's degree of success with regard to digital capacity will depend on the quality and maturity of its plan. Hence, it is important for schools to monitor their digital implementation progress, identifying needs, barriers and opportunities and moving toward a continuous process of evaluation (Solar et al., 2013). The Spanish Ministry of Education, Vocational Training and Sports recommends the use of SELFIE as a preparatory stage for the creation of the digital plan (Castañeda et al., 2023). It is considered a useful tool for schools in order to identify their strengths and weaknesses in the use of digital technologies and it has a recognized impact on the strategic and organizational aspects of the digital transformation of the school (Giannoutsou et al., 2023).

2.2. Factors influencing schools' digital transformation

Many systematic reviews have been conducted to analyse the different interconnected factors that can foster an effective change in the school digital environment (Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023). In those analyses, it was concluded that students' digital competence (SDC), teachers' digital competence (TDC), infrastructure (Garcia Grau et al., 2022; Kovalchuk et al., 2022), leadership and the school's digital vision (Timotheou et al., 2023) are some of the many factors that affect digital transformation in schools; other factors include the teachers' personal characteristics, the students' and schools' socio-economic background and professional development.

2.2.1. SDC and TDC

Technology in education goes beyond the simple use of digital tools in the classroom since being digitally competent consists of a safe, critical and responsible use of digital technologies for learning, working and engaging in society (Castañeda et al., 2023). The process of digital transformation implies a high level of SDC and TDC (Costa et al., 2021; Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023). On the one hand, students need to have sufficient DC regarding how to use digital tools in an appropriate way since they will not be able to take full advantage of the benefits of instruction and the digital environment if they lack digital skills (Higgins et al., 2012). On the other hand, the way that teachers introduce digital technologies in class affects the impact of those technologies (Timotheou et al., 2023) and a study found that there is a strong positive association between TDC and students' use of digital technologies (Delgado et al., 2015).

TDC refers to a set of capabilities, skills and attitudes that educators must achieve in order to best implement digital technologies in their teaching practices and professional development (Lázaro Cantabrana et al., 2019). Limited TDC or familiarisation with technologies can be a barrier to the effective use of digital technologies in teaching and learning processes (Delgado et al., 2015). SDC and TDC are therefore essential for digital transformation since when teachers integrate digital technologies in an appropriate way, students with adequate digital skills are able to take advantage of the digital environment in their learning process (Garcia Grau et al., 2022).

2.2.2 Infrastructure

Technological infrastructure is another factor that impacts the digital transformation of schools (Kampylis & Sala, 2023; Kovalchuk et al., 2022; Timotheou et al., 2023) since appropriate equipment is essential to facilitate students' development and respond to their needs (Garcia Grau et al., 2022). However, schools must consider that, as digital technologies are rapidly developing, constant upgrading is needed (Kovalchuk et al., 2022). Having both the necessary skills and access to high quality equipment promotes students' and teachers' confidence and motivation to use digital technologies (Kovalchuk et al., 2022) since the quality and quantity of educational activities will increase (Timotheou et al., 2023).

Digital infrastructure is often understood as the foundation for the success of digital transformation; that is, without digital equipment, it is not possible to successfully promote digital transformation (Ifenthaler et al., 2021). Nonetheless, infrastructure alone does not automatically lead to the use of digital technologies since, if teachers and students do not consider these technologies useful (Kampylis & Sala, 2023) or if they do not have sufficient digital skills to integrate them in teaching and learning processes (Condie & Munro, 2007), they will not use them to their best advantage.

2.2.3 Leadership and a shared digital vision

Leadership and a shared vision of school digital implementation are factors that affect school digital transformation (Timotheou et al., 2023). In line with this, clear, defined and structurally organized processes are needed for appropriate technology implementation (Solar et al., 2013). Furthermore, in addition to defining a strategy, it is crucial to regularly review and evaluate its implementation (Costa et al., 2021; Solar et al., 2013).

For an efficient digital implementation, a shared and collective strategy is needed (Pulfrey & Caneva, 2022) since to achieve the transformation, all actors need to share a common vision regarding the implementation of digitalisation in education (Timotheou et al., 2023). Teachers who believe that their school has a digital strategy in which they are involved, who receive their principal's support and are encouraged in their digital experiences have stronger collective competence (Pulfrey & Caneva, 2022).

Although many studies have analysed the interconnection of factors that affect schools' digital capacity and transformation (Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023), to the best of our knowledge, there has been no in-depth analysis to date of the relationships among those factors that must be established to reach high digital capacity. It is true that various authors suggest many different strategies to promote digital transformation in schools (Garcia Grau et al., 2022; Timotheou et al., 2023) and discuss the key barriers that could negate it (Kovalchuk et al., 2022). However, no studies have yet addressed the conditions that an educational institution must meet to formulate an appropriate process for its digital transformation. Although each school's characteristics will influence the degree of its digital capacity (Castaño Munoz et al., 2023), it is important to determine the basic requirements, that is, the fundamental conditions and combinations of conditions, for schools to achieve high digital capacity. Understanding the necessary and sufficient conditions for high digital capacity would help schools to focus on the elements that are key to reaching their goal and guide them in developing an effective digital transformation process. Therefore, the present study aims to:

1. identify the necessary conditions for a high DCD in basic VET schools in the BAC; and
2. identify the sufficient conditions for a high DCD in schools.

The related research questions are the following:

R.Q.1: To what extent are SDC, TDC, infrastructure, digital planning and leadership necessary to achieve a high DCD in a school?

R.Q.2: What configuration of SDC, TDC, infrastructure, digital planning and leadership best contributes to a school's DCD?

3. Methodology

3.1. Sample

The data employed to develop the model were obtained from basic VET schools in the BAC, particularly those exclusively dedicated to providing daytime basic VET programs. The sample consisted of 161 teachers and 857 students from 21 schools. Data were collected during April and May of 2023. The conditions and outcome extracted from the questionnaires are listed in Table 1.

Table 1

Description of the conditions and outcome considered in the developed model.

Conditions	
SDC	*Mean of each school's SDC (INCOTIC 2.0 dimensions mean).*
TDC	*Mean of each school's TDC (COMDID A dimensions mean).*
INFRA	*Mean of each school's teachers' vision of infrastructure.*
DP	*Mean of each school's teachers' vision of its digital plan.*
LEAD	*Mean of each school's teachers' vision of leadership regarding digitalisation.*
Outcome	
DCD	*Mean of each school's DCD (SELFIE areas mean).*

3.2. Instruments

3.2.1. SELFIE: Measuring the digital capacity of schools

The SELFIE tool was used to measure the digital capacity of the participating schools. Questionnaires were used to gather information from each school's management team members, teachers and students on their experience of digital implementation in their schools (European Commission, 2022). The questionnaire for the management team members and teachers consisted of 31 items while the students' questionnaire included 18 items. All items used a 5-point Likert scale and included a Not Applicable (N/A) option. Each profile (management team members, teachers and students) answered questions related to 8 different SELFIE areas; hence, the SELFIE tool provided a general view of the implementation of digital technologies in the participating schools (European Commission, 2022). The 8 areas were the following: Leadership; Collaboration and networks; Infrastructure and equipment; Continuing professional development; Pedagogy: support and resources; Pedagogy: implementation in the classroom; Assessment practices; and Student digital competence.

3.2.2. *COMDID A: Measuring TDC*

A validated questionnaire called COMDID A was used to gather TDC perceptions (Usart Rodríguez et al., 2020). The questionnaire consisted of three sections: demographic information, TDC perceptions, and school vision and frequency of use of digital technology. The demographic information included the name of the school, and the teachers' gender, age and years taught at the school. The section on TDC perceptions consisted of 22 items measured by a 5-point Likert scale and divided into four dimensions: Didactic, curricular and methodological aspects; Planning, organization and management of digital technological spaces and resources; Relational, ethical and safety aspects; and Personal and professional aspects.

Three items gathered the teachers' perceptions about school vision (infrastructure, digital plan and leadership) and 17 items addressed the frequency of use of digital technology.

3.2.3. *INCOTIC: Measuring SDC*

A validated questionnaire called INCOTIC 2.0 was used to gather SDC perceptions (González-Martínez et al., 2018). The questionnaire consisted of five sections: demographic information, technological profile, DC perception, attitude toward information and communication technologies (ICTs), and technoethics. The demographic information included the name of the school, and the students' gender and type of studies. The remaining items were answered on a 5-point Likert scale. Four items gathered the respondents' technological profiles. The section on SDC perceptions consisted of 19 items divided into four dimensions:Information; Technology; Multimedia; and Communication

Nine items gathered the students' attitudes toward ICTs and 5 items measured their technoethics perceptions.

3.3. Data collection

The data were collected through online surveys. A direct link was provided to participants for the COMDID-A and INCOTIC 2.0 questionnaires. SELFIE links were provided by the SELFIE coordinator of each school, as each profile (management team members, teachers, students) had its own link (Appendix A: Table A1). . Once the surveys were completed, SELFIE reports were requested from all schools. Informed consent was obtained from all participants, and confidentiality and anonymity were maintained throughout the research process. The study was conducted considering the ethical standards outlined in the Declaration of Helsinki and the guidelines of the American Psychological Association.

3.4. Analysis

First, the conditions for digital capacity were identified from the responses of the questionnaire, and the mean score for each condition was calculated for each school. The conditions analysed were defined as follows:

- SDC: measured through INCOTIC 2.0 and representing students' perceptions about their DC
- TDC: measured through COMDID A and reflecting teachers' perceptions about their TDC
- INFRA, DP, and LEAD: measured through COMDID A and representing teachers' perceptions of the school's context.
- DCD: measured through SELFIE, reflecting students, teachers, and school leaders regarding the overall digital capacity of the institution.

Necessary Condition Analysis (NCA) and Qualitative Comparative Analysis (QCA) were chosen to investigate the key conditions for high digital capacity in schools. NCA identifies the degree to which conditions are necessary for an outcome, indicating the minimum level required to achieve high digital capacity (Dul, 2016), while QCA explores multiple causal paths and identifies sufficient conditions based on fuzzy set membership (Ragin, 2000; Berné-Martínez et al., 2021). In the present study, the model examines the necessary and sufficient conditions for achieving high DCD in schools (DCD = f(SDC, TDC, INFRA, DP, LEAD)). All analyses conducted using R (version 4.4.0).

In this study, all variables (SDC, TDC, INFRA, DP, LEAD) were calibrated using the fuzzy sets direct calibration method, converting data into a 0-to-1 scale for full non-membership, maximum ambiguity, and full membership. Following previous studies, full membership was assigned to values 20% above the mean, the sample mean represented maximum ambiguity, and full non-membership was set at 50% below the mean (Appendix B: Table B1). Means for each school were calculated from the questionnaire responses. Prior to analysis, a skewness check confirmed that data fell within acceptable theoretical ranges, and a crossover point analysis ensured no cases were located at the threshold (Appendix B: Table B2).

After calibration, the necessary condition analysis (NCA) and qualitative comparative analysis (QCA) were conducted using the calibrated data to identify the necessary conditions and explore sufficient combinations leading to high digital capacity (DCD) in schools. In QCA, the intermediate solution was generated considering the directional expectation that infrastructure (INFRA) must be present since without digital equipment it is not possible to reach a digital capacity (Ifenthaler et al., 2021). Additionally, the QCA analysis was conducted with Enhanced Standard Analysis (ESA) in order to improve sufficiency results by dealing more explicitly with counterfactual assumptions. In the sufficient condition analysis in the present study, results derived from the QCA were used (Appendix B: Table B3), excluding the findings from the NCA. The decision was made to maintain analytical coherence within the QCA theoretical framework. Finally, two different analyses were carried out: fit-oriented robustness and case-oriented robustness were performed to determine the robustness of the research results of the QCA.

4. Results

4.1. Necessary conditions results

To analyse the necessary conditions in degree, a ceiling regression with free disposal hull (CR-FDH) was drawn considering the *p*-value (<0.05) and the effect size (> 0.1).

For the high DCD of schools, all the conditions are necessary. Therefore, for a high level of the outcome, high levels of conditions are needed. The effect sizes are large for infrastructure, digital plan, and TDC and SDC perceptions (0.41, 0.33, 0.31 and 0.30, respectively), whereas for leadership it is medium (0.28). The bottleneck table (Appendix C: Table C1) shows the necessary conditions required to achieve a specific degree of high digital capacity of schools. For a level of the outcome of 10% a minimum of SDC perception (1.5) and infrastructure (5.6) are required, while the rest of the conditions are not necessary. Nonetheless, to achieve full digital capacity in schools (100%) the minimum required values for TDC perception and digital plan are 90.4 while those for SDC perception (64.8), infrastructure (84.2) and leadership (73.8) are lower.

4.2. Sufficient conditions results

To analyse the sufficiency of conditions for the outcome, a truth table was constructed listing all possible logical combinations of causal conditions for the outcome (DCD). To ensure the validity of the analysis, the raw consistency ≥0.80, and proportional reduction in consistency (PRI) cutoff ≥0.65 were considered when accepting a combination, before processing with the analysis using Enhanced Standard Analysis (ESA). Next, the Enhanced Intermediate Solution was generated considering the directional expectation that infrastructure (INFRA) must be present. The results indicate the following configuration leading to DCD (Appendix C: Table C2): SDC*TDC*INFRA*~LEAD + SDC*INFRA*DP*LEAD + TDC*INFRA*DP*LEAD -> DCD.

For all causal configurations, the values of the adjustment measurements are considered acceptable as the consistency values exceed the minimum threshold of 0.8. Furthermore, it is concluded that the resulting configurations guarantee strong results since the overall DCD solutions have consistency levels of 0.892. Regarding coverage, although there is no established minimum threshold, the greater the coverage, the greater the empirical relevance of the solution. In this case, the findings indicate that for DCD, 78.1% of the cases with high school digital development include the combinations shown in Table 5 since the global coverage for DCD is 0.781. The causal configuration with greater coverage for a high digital capacity includes TDC*INFRA*DP*LEAD with a coverage of 0.652, which is close to SDC*INFRA*DP*LEAD, which has a coverage of 0.610.

Furthermore, to be able to observe whether the value of incorporating the infrastructure is a must condition, the intermediate solution was compared with the conservative solution; the obtained solution was found to be fully identical. This indicates that empirically derived configurations align closely with theoretical expectations; hence, the presence of infrastructure, together with other conditions, is essential for a high digital capacity of schools.

To determine the robustness of the QCA research results, two different analyses were carried out: fit-oriented robustness and case-oriented robustness. The consistency, frequency parameters and PRI values were varied to perform the analysis and a total of 3 models were created: a model with a consistency of 0.85, a required frequency of 1 and a PRI of 0.51; a model with a consistency of 0.85, a required frequency of 2 and a PRI of 0.51; and a model with a consistency of 0.90, a required frequency of 2 and a PRI of 0.51.

The results of the fit-oriented and case-oriented robustness analyses indicate an appropriate degree of fit (Appendix C: Table C3). Nonetheless, while the raw coverage ratio (RCR_typ) was higher than 0.7, the deviant coverage ratio (RCR_dev) was lower, with a rank of 3.

5. Discussion

This study used NCA and QCA analyses, which differ from conventional quantitative analysis, to explore the complex combinations of conditions that determine high digital capacity in the BAC's basic VET schools. Although the interconnection of different factors for a digital transformation in education has been discussed in previous studies (Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023), the present study provides a more in-depth analysis of the interconnection of different factors to reach a high digital capacity of schools. The results clearly indicate that the digital capacity of a school is a product of a combination of conditions. Considering SDC and TDC perceptions, infrastructure, digital planning and leadership as conditions for a high digital capacity highlighted the complexity of the phenomenon and we were able to reach a deeper understanding than with traditional statistical approaches. Therefore, the contribution of NCA and QCA to the analysis of digital implementation in education is highly relevant.

Regarding the NCA results, it was found that all the conditions are necessary for a high DCD of schools. However, for a school to achieve its full degree of digital capacity (100%), it must have a high level of TDC perception (90.4%) and a solid digital plan (90.4%); in order to reach 100% in digital capacity, it is essential to have these two conditions at very high levels. This does not mean that the rest of the conditions are not important, but it is not crucial to score as highly on them in order to reach the full capacity. From a theoretical perspective, a high level of TDC is necessary since teachers are the key to integrating digital technologies into the teaching and learning process (Delgado et al., 2015; Garcia Grau et al., 2022; Timotheou et al., 2023). Teachers with a low TDC level will not be able to integrate technology appropriately in their practices and this would have a negative impact on their school's digital transformation. According to the digital plan, it is essential to align the resources, objectives and pedagogical practices with appropriate technological implementation (Solar et al., 2013). Without a clear and realistic digital plan, the digital actions of the school could lack coherence, rendering its effort less effective since the digital plan ensures that the whole school works toward the same goals (Pulfrey & Caneva, 2022; Timotheou et al., 2023).

Moreover, the fact that SDC perception (64.8%), infrastructure (84.2%) and leadership (73.8%) have lower levels yet full success remains guaranteed can be understood to mean that, although their presence is important, they do not necessarily have to have high levels. Regarding SDC, even if students may be advanced users of technology, without teachers who know how to teach and guide them strategically, SDC will not evolve and it will not be possible to promote an enriching environment in which digital technologies are used appropriately (Garcia Grau et al., 2022). With respect to infrastructure, even if the school is highly equipped with the latest digital technologies, without a strategy and a certain level of TDC, the infrastructure will not be used to its best advantage (Kampylis & Sala, 2023). Finally, although solid digital leadership creates and promotes an appropriate culture of technological innovation, without teachers who are trained and understand the implications of digitalisation in their school, the vision would be incomplete (Pulfrey & Caneva, 2022).

Regarding sufficient conditions, our results found 3 configurations that lead to a high digital capacity of schools. The first of these configurations includes high TDC and SDC, together with an appropriate infrastructure and a low level of leadership (SDC*TDC*INFRA*~LEAD). This could be interpreted as a strong infrastructure together with a high level of DC of the key actors, which can compensate for the lack of digital leadership. According to the theoretical view, digital leadership is one of the key factors in fostering the use of digital technologies and creating an appropriate culture to promote this use (Timotheou et al., 2023). Nevertheless, the importance of this leadership decreases when SDC and TDC are high, since they are not dependent on a strong digital leadership. After all, teachers with high TDC are able to integrate digital technologies in their teaching practice and students can take advantage of the technological environment and interact with it if they have the necessary level of DC (Condie & Munro, 2007; Kampylis & Sala, 2023). Therefore, the DC of the key actors together with an appropriate infrastructure could mitigate a lack of strategic guidance.

Another configuration includes high SDC perception, a strong infrastructure, a clear digital plan and effective leadership (SDC*INFRA*DP*LEAD). This result suggests that high digital capacity can be reached when a school has strong digital leadership with a defined digital plan. In this scenario, the digital leadership guides and coordinates the effective use of digital infrastructure and follows the digital plan of the school, ensuring that students develop and use their digital competence effectively. As reported in previous studies, if students have appropriate digital skills and their school has a clear digital strategy that is guided by an effective principal (Solar et al., 2013), they will be able to take full advantage of the benefits of instruction and the digital environment (Higgins et al., 2012).

The last configuration includes high TDC perception, a strong infrastructure, a clear digital plan and effective digital leadership (TDC*INFRA*DP*LEAD). When teachers have high DC and access to infrastructure in a school where digital leadership and good digital planning have been established, SDC may be less crucial. If TDC is high and the teachers understand the school's vision of digital implementation, they can guide students in their learning by ensuring a digital environment that promotes learning (Delgado et al., 2015; Timotheou et al., 2023).

The present study highlights the importance of a high level of digital infrastructure as it is found in all sufficient configurations for a high DCD. This suggests that infrastructure is a basic requirement and key enabler for the success of digital implementation in schools. An appropriate infrastructure is fundamental because it makes digital resources available to all members of the school and gives them the opportunity to interact effectively with digital tools. Without a solid infrastructure, schools will not be able to achieve an effective digital capacity (Ifenthaler et al., 2021).

It is also noteworthy that a high TDC or SDC appears in all configurations, highlighting their role in the digital implementation process in a school. The present results showed that when adequate infrastructure is available in schools, the presence of a high SDC or TDC is also needed. In other words, infrastructure alone is not enough; high TDC or SDC is also needed to ensure the proper and effective use of digital tools (Condie & Munro, 2007; Kampylis & Sala, 2023) If teachers do not have enough digital skills or students are not prepared to use these tools, the potential of the infrastructure will decrease, even if the school has a strong infrastructure.

6. Conclusion

The present study makes a significant contribution to the literature on digital transformation and digital capacity in education. In addition to corroborating the results of previous studies in the field (Garcia Grau et al., 2022; Kovalchuk et al., 2022; Timotheou et al., 2023), this study identifies the conditions that are necessary and sufficient for a high digital capacity of schools. Therefore, it provides valuable insights and a comprehensive understanding for policymakers and, more practically, it provides school leaders with knowledge about what aspects to work further to develop their school's digital capacity, and ways to address them and to reflect on how to promote them, as follows.

The findings clearly show that a high level of TDC and the existence of a robust digital plan are necessary conditions for schools to reach a high degree of digital capacity, as well as the presence of the rest of the conditions. At the same time, adequate infrastructure, combined with either SDC or TDC, is an essential condition for effective digital transformation in schools. This means that infrastructure alone is not enough; it must be accompanied by either students' or teachers' digital competence. However, this combination may still require other conditions to fully achieve high digital capacity.

Based on the results of this study, several practical recommendations can be drawn. First, ensuring a high level of TDC is essential. Schools should establish targeted professional development programs that not only provide continuous training but also focus on practical classroom applications of digital tools. In addition, peer mentoring initiatives and collaborative learning communities among teachers can foster a culture of shared expertise and continuous improvement. This approach ensures that TDC development is not perceived as an isolated task but as a collective and ongoing process embedded in everyday practice (Pulfrey & Caneva, 2022; Timotheou et al., 2023).

Second, the development and implementation of a robust digital plan should be prioritised. Such a plan should articulate clear objectives, strategies, and resource allocation for technology integration across all school activities. Importantly, it must be designed and implemented as a collective endeavour, involving teachers, students, and school leaders to ensure shared ownership and a common vision of digitalisation. Schools that promote active teacher participation in the digital strategy and offer principal support create stronger collective competence and more sustainable digital transformation processes (Pulfrey & Caneva, 2022).

Third, while adequate infrastructure is crucial for successful digital implementation, schools should ensure not only the provision of up-to-date equipment but also its continuous renewal and adaptation to emerging technologies (Kovalchuk et al., 2022). Infrastructure, however, should not be treated as an isolated element. It must be complemented with initiatives that strengthen both SDC and TDC, so that technology is effectively integrated into teaching and learning processes (Condie & Munro, 2007; Kampylis & Sala, 2023). This alignment between infrastructure and competences ensures that investments in technology translate into real pedagogical value and sustainable innovation.

Furthermore, this study uses the NCA and QCA methodologies, which are rarely used in the field of education (Cilesiz & Greckhamer, 2020). The application of these methodologies allows us to confirm that the digital capacity of schools is a complex phenomenon and that many different factors affect its development. As we found here, there are multiple factors and combinations of factors that contribute to a school's digital capacity, and the examination of their various configurations adds value to traditional statistical analysis.

However, these results must be interpreted with caution, as this study has certain limitations. First, our data on infrastructure, leadership and digital plan conditions were based on the teachers' perspectives, and the study therefore lacked an overall view of the schools. Additionally, SDC and TDC data were based on the students' and teachers' self-perceptions rather than on objective measurements of their real levels. Additionally, the questionnaires used have inherent limitations, as they do not capture contextual information about the schools, such as the real state of infrastructure, the teaching methodologies applied, or the type of programmes offered. This lack of objective and contextual data may have introduced bias into the analyses and limited the depth of interpretation. Therefore, future studies should complement this study with richer contextual information to provide a more comprehensive understanding of the conditions affecting digital capacity in each school.

Moreover, the present data were quantitative and many results were not interpreted in depth based on real cases. Therefore, it is important in the future to gather qualitative data to enrich the NCA and QCA analyses. Qualitative data could offer a richer and deeper view of the situation of each school, and could perhaps identify conditions that were not taken into consideration here. Furthermore, the present data were collected exclusively from a specific educational level and geographic area and the findings were corroborated with results from other educational levels and regions. It would be interesting to expand the study to other educational levels to extend and validate the results. Further research is needed at all educational levels since, to the best of our knowledge, there has been no other NCA or QCA research beyond the present study on schools' digital capacity and transformation. Further work could examine the differences among different necessary and sufficient conditions at diverse educational levels and identify the key factors of each in order to provide more specific guidance at each educational level.

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Data Availability Statement

The data supporting this study are not publicly available. As such, no datasets have been deposited in a public repository.

Ethics approval

This study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki and the guidelines of the American Psychological Association.

Conflicts of interest

None

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Appendices

Appendix A

Table A1

Sample size for each questionnaire

SCHOOLS	COMDID A	INCOTIC.20	SELFIE		
			Students	Teachers	Leaders
1	6	34	43	4	2
%	100%	56,67%	71,67%	66,67%	100%
2	2	26	26	2	1
%	66.67%	92.85%	92.85%	66,67%	100%
3	7	78	131	9	3
%	46,67%	52,70%	88,51%	60%	75%
4	7	35	33	6	1
%	100%	64,81%	78,57%	85,71%	100%
5	5	47	47	5	1
%	71,42%	82,45%	82,45%	71,42%	100%
6	7	34	48	7	1
%	70,00%	52,30%	73,84%	70,00%	50%
7	8	55	69	8	2
%	88,88%	47,82%	60%	88,88%	100%
8	5	45	45	6	3
%	83,33%	100%	100%	100%	100%
9	14	63	63	12	1
%	93,33%	54,78%	54,78%	80%	100%
10	6	19	23	6	1
%	100%	36,53%	41,07%	100%	100%
11	9	27	33	9	2
%	100%	31,39%	38,37%	100%	100%
12	9	41	49	10	1
%	90,00%	56,16%	67,77%	100%	50%
13	12/15	37	42	13	1
%	80,00%	30,83%	35,00%	86,66%	50%
14	9	49	61	11	3
%	75,00%	51,04%	63,54%	91,66%	100%
15	9	56	61	12	3
%	75,00%	62,22%	67,77%	100%	75%
16	15	87	92	17	2
%	83,33%	65,90%	69,69%	94,44%	100%

SCHOOLS	COMDID A	INCOTIC.20	SELFIE		
			Students	Teachers	Leaders
17 %	2 66,66%	13 43,33%	14 46,66%	2 66,66%	1 100%
18 %	13 86,67%	58 41,42%	65 46,42%	12 80%	1 100%
19 %	4 80%	12 35,29%	12 34,29%	5 100%	1 100%
20 %	6 85,71%	24 42,85%	26 46,42%	7 100%	1 100%
21 %	7 100%	17 36,17%	29 61,70%%	7 100%	1 50%

Appendix B

Table B1
Calibration

Condition/Outcome	Fully in	Crossover point	Fully out
SDC	3.907 (20% above the average)	3.256 (average)	1.628 (50% of the average)
TDC	50.374 (20% above the average)	41.979 (average)	20.989 (50% of the average)
INFRA	4.147 (20% above the average)	3.456 (average)	1.728 (50% of the average)
DP	3.3636 (20% above the average)	2.803 (average)	1.4015 (50% of the average)
LEAD	3.168 (20% above the average)	2.64 (average)	1.32 (50% of the average)
DCD	3.133 (20% above the average)	2.611 (average)	1.305 (50% of the average)

Table B2.
Calibration of conditions for each school

	SDC	TDC	INFRA	DP	LEAD	SDL
1	0.6673714	0.85224054	0.83106591	0.87298285	0.99180390	0.9702467
2	0.9082482	0.98631386	0.54672213	0.34602034	0.42255612	0.9026672
3	0.7491750	0.91442319	0.94852284	0.99959457	0.99744450	0.7707027
4	0.5551636	0.54929331	0.74687477	0.12119446	0.3849870	0.4870343
5	0.4490835	.29592499	0.39264366	0.10839681	0.13311027	0.2162187
6	0.7491750	0.28465493	0.98446705	0.85446076	0.77326670	0.9474776
7	0.6948566	0.54294691	0.67726293	0.59975084	0.79222363	0.5477812
8	0.7753737	0.99455201	0.64872165	0.99470952	0.47770843	0.9822704
9	0.7753737	0.25007021	0.16396965	0.89451244	0.31416420	0.2785263
10	0.5806768	0.95478300	0.44653057	0.15616570	0.14102352	0.3309950
11	0.5938275	0.99599018	0.99861030	1.00000000	1.00000000	0.9978505
12	0.4625414	0.08941798	0.24014669	0.08468405	0.23465024	0.2458371
13	0.6292551	0.95205790	0.98380202	0.99814313	0.99180390	0.9657099

	SDC	TDC	INFRA	DP	LEAD	SDL
14	0.4114178	0.43362172	0.03121395	0.05398493	0.06435854	0.1131271
15	0.4477415	0.35879193	0.44653057	0.31807470	0.33370013	0.5796644
16	0.7533993	0.75207925	0.99674823	0.99470952	0.99895135	0.9207630
17	0.4158043	0.97645879	0.98842574	0.99814313	0.99949182	0.3041240
18	0.2643110	0.29879730	0.17352825	0.13527379	0.07916846	0.2302952
19	0.2332457	0.01125710	0.02277773	0.06079659	0.04308319	0.1224992
20	0.6851859	0.22226009	0.54672213	0.20917885	0.33370013	0.7843541
21	0.2211802	0.77468303	0.36854807	0.45130842	0.31416420	0.3017427

Table B3.

Analysis of necessary conditions with QCA for DCD

Conditions	inclN	RoN	CovN
SDC + TDC	0.939	0.623	0.754
SDC + INFRA	0.952	0.675	0.786
SDC + DP	0.965	0.663	0.785
SDC + LEAD	0.949	0.686	0.790
TDC + INFRA	0.948	0.674	0.784
TDC + DP	0.901	0.664	0.759
TDC + LEAD	0.922	0.693	0.784

inclN, Inclusion cut-off; RoN, Relevance necessity; CovN, Coverage.

Appendix C

Table C1.
Bottleneck table for the necessary conditions for DCD.

Y (DCD)	SDC	TDC	INFRA	DP	LEAD
0	NN	NN	NN	NN	NN
10	1.5	NN	5.6	NN	NN
20	8.5	NN	14.3	NN	NN
30	15.6	NN	23.1	4.5	6.3
40	22.6	10.8	31.8	16.8	15.9
50	29.7	24.0	40.5	29.0	25.6
60	36.7	37.3	49.3	41.3	35.2
70	43.7	50.6	58.0	53.6	44.9
80	50.8	63.8	66.8	65.9	54.5
90	57.8	77.1	75.5	78.1	64.1
100	64.8	90.4	84.2	90.4	73.8

Y: outcome; NN: not necessary.

Table C2.
Analysis of sufficient conditions for DCD.

	inclS	PRI	covS	covU
SDC*TDC*INFRA*~LEAD	0.937	0.815	0.319	0.088
SDC*INFRA*DP*LEAD	0.978	0.965	0.610	0.040
TDC*INFRA*DP*LEAD	0.904	0.857	0.652	0.083
S	0.892	0.833	0.781	

inclS: Inclusion cut-off; PRI: proportional reduction in consistency; covS: Coverage; CovU: Unique coverage.

Table C3.
Robustness analysis.

Robustness parameter	
Fit-oriented	RF_cons: 0.932 RF_cov: 0.78 RF_SC_minTS: 0.728 RF_SC_maxTS: 0.728
Case-oriented	RCR_typ 0.71 RCR_dev: 0.5 Rank: 3
Performing models	
SDC*TDC*INFRA*DP*LEAD+SDC*TDC*INFRA*~DP*~LEAD (1)	RCC_Rank: 3 SC: 0.728
SDC*TDC*INFRA*DP*LEAD+SDC*TDC*INFRA*~DP*~LEAD (2)	RCC_Rank: 3 SC: 0.728
SDC*TDC*INFRA*DP*LEAD+SDC*TDC*INFRA*~DP*~LEAD (3)	RCC_Rank: 3 SC: 0.728