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Sustainable Participatory Governance: Data-Driven Discovery of Parameters for Planning Online and In-Class Education in Saudi Arabia During COVID-19

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Everything about our life is complex. It should not be so. New approaches to governance are needed to tackle these complexities and the rising global challenges. Smartization of cities and societies has the potential to unite us, humans, on a sustainable future for us through its focus on the triple bottom line (TBL) – social, environmental, and economic sustainability. Data-driven analytics are at the heart of this smartization. This study provides a case study on sustainable participatory governance using a data-driven parameter discovery for planning online, in-class, and blended learning in Saudi Arabia evidenced during the COVID-19 pandemic. For this purpose, we developed a software tool comprising a complete machine learning pipeline and used a dataset comprising around 2 million tweets in the Arabic language collected during a period of over 14 months (October 2020 to December 2021). We discovered fourteen governance parameters grouped into four governance macro parameters. These discovered parameters by the tool demonstrate the possibility and benefits of our sustainable participatory planning and governance approach, allowing the discovery and grasp of important dimensions of the education sector in Saudi Arabia, the complexity of the policy, the procedural and practical issues in continuing learning during the pandemic, the factors that have contributed to the success of teaching and learning during the pandemic times, both its transition to online learning and its return to in-class learning, the challenges public and government have faced related to learning during the pandemic times, and the new opportunities for social, economical, and environmental benefits that can be drawn out of the situation created by the pandemic. The parameters and information learned through the tool can allow governments to have a participatory approach to governance and improve their policies, procedures, and practices, perpetually through public and stakeholder feedback. The data-driven

parameter discovery approach we propose is generic and can be applied to the governance of any sector. The specific case study is used to elaborate on the proposed approach.

INTRODUCTION

Everything about our life is complex. It should not be so, but this is the reality now. Perhaps, the blame for this exponential rise in the complexity of life should be on us. This is because of our increasing desire to do more, produce more, and innovate more in each and every moment of our life. We wish to find new ways of living, we wish to find new planets for living, and all this has increased the complexity of everything we do. Such increasing complexity requires new ways of "governing" our life and the various complex systems around us that support us to live a complex, "modern" life.

The word "governance" is increasingly common in many sectors and contexts these days, corporate governance, global governance, transnational governance, urban governance, risk governance, sustainable governance, and more. Bevir (2011) states, "at the most general level, governance refers to theories and issues of social coordination and the nature of all patterns of rule". The traditional methods and modes of governance are considered to be monolithic, formal, and hierarchical and are no more seen as sustainable for managing the complex world of today. The contemporary use of the word "governance" refers to and emphasizes "various new theories and practices of governing and the dilemmas to which they give rise" and "draws attention to the complex processes and interactions that constitute patterns of rule" (Bevir, 2011). Governance involves in its decision-making process institutions that are not necessarily from the government (in its traditional, formal, sense) but include various stakeholders from the public, industry, voluntary sectors, and others. Therefore, decisions are made both autonomously and collectively by different actors, rendering the boundaries and responsibilities of governance to become blurred. Participatory governance has become common because "the formal state apparatus has frequently proved to be inadequate in dealing with growing social complexities" and "actors from the voluntary and private sectors have become increasingly involved in the governance process" (Chhotray and Stoker, 2009). The government is more seen as a facilitator, integrator, or coordinator, that is "able to use new tools and techniques to steer and guide" (Stoker, 1998). The asynchronous nature and blurriness of responsibilities of contemporary governance, hence, have given rise to several dilemmas including the difficulties associated with blame avoidance and accountability and risks of governance failure, among others (Stoker, 1998).

A critically important area where the role of governance is crucial is the education sector (Burns and Köster, 2016). Education governance has been a subject of much investigation, debate, controversy, and polyvalence (Wilkins and Olmedo, 2019). This is due to the complex and the rapidly evolving nature of the education sector involving many government levels (national, regional, local, etc.) and stakeholders including all public segments, and more importantly, due to the role that education plays in developing theories, practices, and social and economic capacities for all forms, disciplines, and domains of governance. The education sector is going through rapid transformations due to social, economic, and technological reasons such as the availability of free and paid massive open online courses (MOOCs), the industry gradually prioritizing labor skills over university degrees, the education sector facing new economic challenges, the increasing demands by modern learners for any time, anywhere learning, the need of educational institutions to keep abreast of the rapidly changing technology and knowledge and accordingly adjust their content and content delivery systems up to date, the need to use many new sources of data in education-related decision making, and more (Mehmood et al., 2017a). The changes in global political ideologies and environments have also transformed education governance, making it a decentralized, complex, multi-level, and multi-stakeholder sphere subject to *ad hoc*, autonomous, and participatory decision-making. Education governance is seen as polyvalent because it is "experienced by some as a part of the dangerous and mischievous practices of the 'hidden hand' of the market or neoliberalism more generally, while those who fear the tyranny of hierarchies and are distrustful of top-down systems celebrate it as an empowering tool for democratic change, innovation and improved effectiveness or transparency" (Wilkins and Olmedo, 2019). Saguin (2019) emphasizes that education governance "should be seen as establishing a specific type of relationship between governmental and non-governmental actors that often involves a mix of legal, market, network, and corporatized approaches". Researchers have also warned against the risks of governance failures in education that can "occur when private actors 'capture' the government to channel public resources to pursuing private interests" (Saguin, 2019). The complexity of education governance has also led to the development of new disciplines such as the sociology of disciplines that studies the effects of public institutions and individual experiences on education and its outcomes (Raab, 1994; Davies and Guppy, 2014).

Knowledge and human and social capital are fundamental to human progress. However, the mainstream role of education is increasingly seen and adopted as "education for employment". Rather, the role of education should extend to "the notion of social and collaborative governance where the society will collaborate to train each other in maintaining its knowledge, moral fiber, good practice, resilience, competitiveness, and for bringing innovation and becoming a knowledge-based economy" (Mehmood et al., 2017a). This will require a

converged ubiquitous infrastructure comprising many systems that allow information sharing, collaboration, and decision-making between different stakeholders, as necessary, for defined objectives including the triple bottom line (TBL).

The challenges facing governance have been further exacerbated by the COVID-19 pandemic that has affected many things in our lives including restrictions on being in physical spaces leading to our accelerated transition to being in digital spaces. Governance for many sectors has been affected, including the education sector with teaching and learning moving to and from between online and physical learning spaces. These pandemic-related challenges are here to stay and, therefore, new approaches are needed to address the governance-related challenges. Both theoretical and practical contributions are required from the community to education and general governance.

The complex challenges mentioned above, we believe, can be addressed by *smartization* of our societies and living spaces, enabling a sustainable future for us humans, due to its data-driven analytics approach and its focus on TBL—social, environmental, and economic sustainability. Precisely, smartization relies on collecting data and making informed decisions on policy and action using cutting-edge technologies such as the internet of things (IoT), big data, artificial intelligence, and large-scale distributed computing. Our research aimed to explore this smartization concept and develop methods based on data-driven analytics for informed decision-making and governance.

To accomplish this objective, this study provides a case study on sustainable participatory governance using a data-driven discovery of parameters for planning online, in-class, and blended learning in Saudi Arabia evidenced during the COVID-19 pandemic. The data-driven parameter discovery approach we propose is generic and can be applied to the governance of any sector. The specific case study on education is used to elaborate on the proposed approach. A high-level framework depicting our proposed data-driven approach for participatory education governance is provided in **Figure 1**. It shows that various actors work to achieve certain educational objectives using a range of data sources. The triple bottom line is shown at the bottom that could be considered as the high-level or ultimate objectives of the education governance. Examples of actors include people, government, the voluntary sector, social enterprises, and others. The data sources include, without the intention to be exhaustive, -social media, government, institutional, academic and scientific literature, industrial, and other data. The data sources are modeled and analyzed using machine learning to discover education governance parameters and macro parameters. The parameters are evaluated, validated, and improved using national and international good governance parameters. Good governance parameters, for instance, can also be included in the design of the data-driven governance parameter discovery system, such that automated comparison and evaluation of a government's services are made against established standards of good governance. The good governance parameters themselves can be improved using the data-driven self-improving approach. The improved

education governance parameters are applied and tested in real environments that create effects on data sources, objectives, actors, and sustainability. This process is repeated iteratively and continuously to dynamically improve education governance. The government could use the knowledge gained through this data-driven discovery process to develop better governance apparatuses, and this whole process could be implemented as a perpetual loop for real-time or dynamic governance with much finer levels of engagement with the public and other stakeholders.

To investigate the proposed approach and framework, we developed a software tool comprising a complete machine learning pipeline and used a dataset comprising around 2 million tweets (1,878,993 tweets, to be precise) in the Arabic language collected during the 14-month period, i.e., 1 October 2020 to 17 December 2021. We discover fourteen governance parameters including, among others, Pandemic Measures, Digital Services, Nurturing Positive Behavior, Exam Procedures, and International Collaborations. These fourteen parameters are grouped into four governance macro-parameters, namely, Success Factors, Challenges, Socioeconomic Sustainability, and Accountability and Transparency.

This study makes important and significant theoretical and practical contributions to the literature. First, we proposed a novel data-driven parameter discovery approach for governance applicable to any sector, and, to elaborate on the proposed approach, we provided a case study in education governance. A theoretical framework for data-driven participatory education governance is developed and provided in this work. Second, we developed a complete case study and software for the data-driven discovery of parameters from social media (Twitter) data for planning and governance of learning during COVID-19. The practical contributions that we provide in this paper are novel, and completely different from any of the other works because it attempts to comprehensively grasp and discover governance parameters related to the education sector from Twitter data using unsupervised machine learning. Third, the research provides evidence to support the general literature on data-driven smart cities research and reinforces that policy and action on smart cities should be supported with data (Liu et al., 2017; Yigitcanlar et al., 2020; Bibri, 2021a) and that social and digital media provides a convenient and important source of such data (Alomari et al., 2021b). The literature review section discusses the related works and establishes the research gap in detail.

This work is an extension of our earlier work that had considered 128 thousand tweets for a 66-days period from October 2020 to December 2020 (Alswedani et al., 2022). The work presented in this study makes substantial improvements to the data collection process and overall methodology, including the collection of around 2 million tweets for a period of 14 months (October 2020- December 2021). The period has undergone significant public and governance-related changes due to the evolving situation of the pandemic and education, and therefore, this study reports new parameters, insights, and findings compared to the previous paper. Also, it extends the data analysis content presented in the earlier
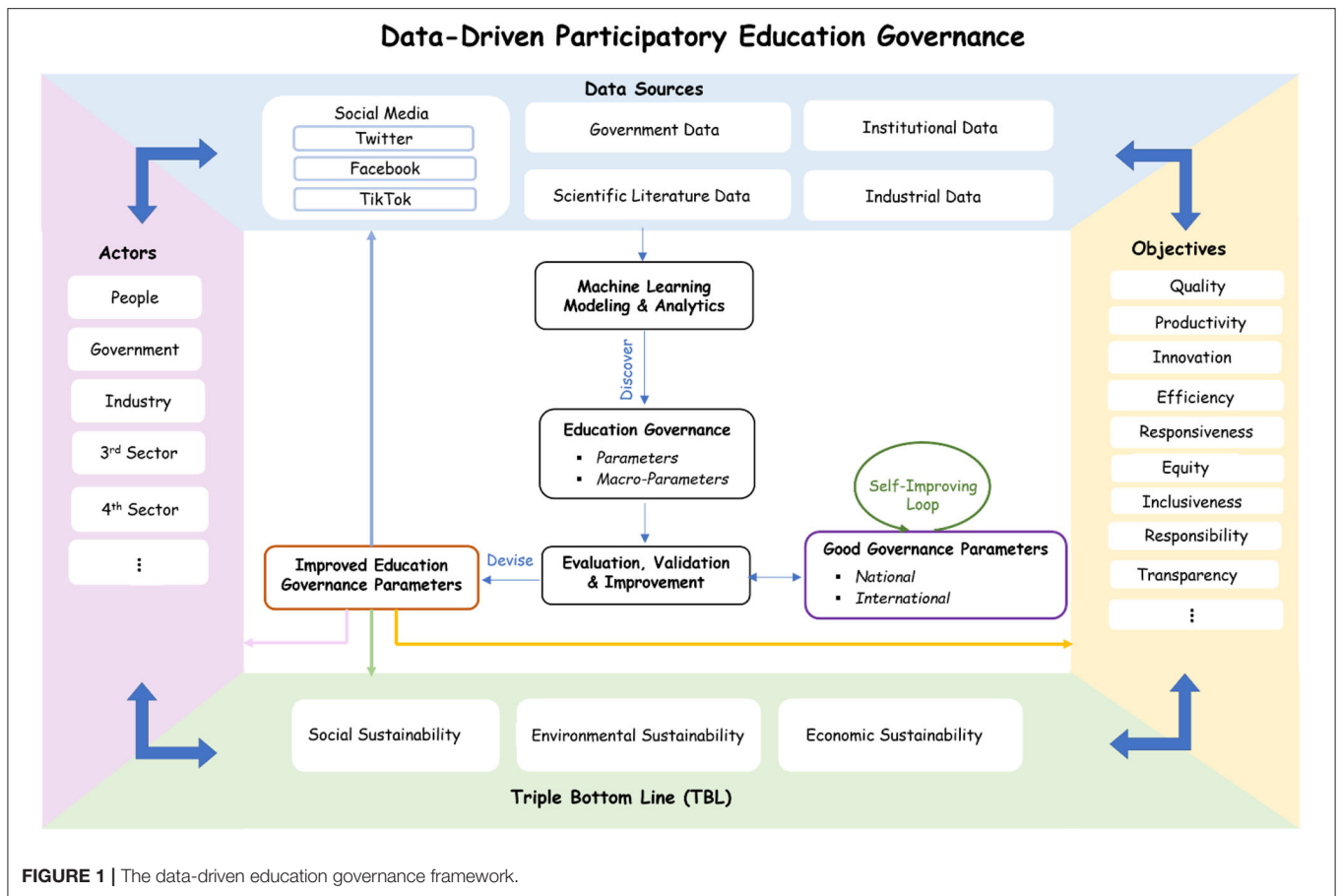
FIGURE 1 | The data-driven education governance framework.

work. We have performed a temporal analysis of each parameter and provided visualizations for all the parameters. Moreover, we provide in this study a theoretical framework for data-driven governance.

The particular aspect in which we propose the use of machine learning for urban planning and governance is expected to be a trendsetter for future works and provide a significant impact on research and practice in this area. The discovered parameters by the tool demonstrate the possibility and benefits of our sustainable participatory planning and governance approach, allowing the discovery and grasp of important dimensions of the education sector in Saudi Arabia, the complexity of the policy, procedural and practical issues in continuing learning during the pandemic, the factors that have contributed to the success of teaching and learning during the pandemic times, both its transition to online learning and its return to in-class learning, the challenges public and government have faced related to learning during the pandemic times, and the new opportunities for social, economic and environmental benefits that can be drawn out of the situation created by the pandemic. The parameters and information learned through the tool can allow governments to have a participatory approach to governance and improve their policies, procedures, and practices, perpetually through public and stakeholder feedback.

Note that, in this study, we made contextual translations of the Arabic words and tweets for the sake of the English reader. The tweets in many cases were not provided in full to preserve the privacy of the tweeters.

The rest of the article is organized as follows. Section Literature Review provides a review of the relevant literature. Section Methodology and Design introduces the methodology and describes the tool design. Section Parameter Analysis and Findings explains the discovered parameters. Section Discussion gives additional insight into the results. Section Conclusions and Future Work concludes the paper.

LITERATURE REVIEW

We provide here in this section a review of works related to the study. The focus of the study is Twitter data analytics for urban governance of the education sector during the COVID-19 pandemic; hence, we first review works on smart cities followed by reviews of works on education and smart cities, social media analytics in general and during COVID-19, Twitter data analytics in education, and topic modeling in Twitter data analytics.

Smart societies and cities are driven by objectives such as triple bottom line, innovation, and efficiency optimization through data-driven computing (Bulkeley and Castán Broto, 2013; Mehmood et al., 2017a; Ahmad and Mehmood, 2020;

Cugurullo, 2020; Yigitcanlar et al., 2020; Bibri, 2021b). Data-driven machine learning is at the heart of it (Yigitcanlar et al., 2021b). The terms such as "data-driven", "data-intensive", etc., are used with machine learning to highlight that machine learning methods are driven by or use large amounts of data, see e.g., (Jordan and Mitchell, 2015) for machine learning trends, perspectives, and prospects. Many bodies of literature have been proposed to investigate and advance data-driven computing for cities and urbanization such as the use of big data for planning smart cities (Batty, 2013), sustainable, smart, resilient, low carbon, knowledge cities (De Jong et al., 2015), urban computing (Zheng, 2017), the cases of London and Barcelona as data-driven smart cities (Bibri and Krogstie, 2020), energy planning with big data (Estiri, 2017), intelligent urban computing with big data (Liu et al., 2017), geospatial data in urban studies (Sun and Du, 2017), and datafication of urban society (Calvo, 2020). Several studies have sought to contribute to the computational aspects of big data analytics to improve the speed of analytics such as road traffic prediction (Aqib et al., 2019b), metro urban transportation systems (Aqib et al., 2019a), detection of diseases in cities (Alotaibi et al., 2020), logistics (Suma et al., 2017), detection of events for urban management (Alomari et al., 2019), collaboration among autonomous vehicles (Alam et al., 2019), and more.

The education sector is going through rapid transformations due to social, economic, and technological reasons. There is an increasing interest in education in smart cities. Molnar (2021) discussed the shortcomings of educational initiatives in smart cities and how to address them. Sadeh et al. (2020) looked into the technological aspects of learning in smart cities. Kwet and Prinsloo (2020) examined developments in the "smart classroom" for higher education. They present the scope and limitations of smart classrooms in the context of university initiatives in smart cities. Some researchers have looked into proposing educational applications with immersive technologies. For example, Gnanadurai et al. (2022) proposed a learning system (AstroSolar) with immersive technology to help students in the primary school develop a better understanding of the solar system. They utilized augmented reality (AR) and virtual reality (VR) to combine the physical environment with digital information. Many VR-based tools were proposed to help students with various subjects in space (Mintz et al., 2001; Yair et al., 2003), mathematics (Hwang and Hu, 2013), medicine (Elliman et al., 2016), and engineering. Mehmood et al. (2017a) propose teaching and learning big data framework to improve lifelong learning in smart societies. They used eleven widely used datasets to evaluate various functions of the proposed framework. Reviews on education in smart cities can be found, for example, in the studies of Mehmood et al., 2017a and Molnar, 2019.

Many COVID-19-related studies which are utilizing Twitter data have been proposed. Some researchers have explored the thematic analysis of Twitter data. For example, Samuel et al. (2020) analyzed Twitter data to discern sentiment related to the COVID-19 pandemic. The authors extended their previous study of Samuel et al. (2020) to identify the major themes on Twitter posts that are associated with the debate on reopening the US economy during the pandemic. The impact of COVID-19 on society was studied by Duong et al. (2020a,b) using sentiment analysis of Twitter data. Abdulaziz et al. (2021) examined the sentiment of the COVID-19 tweets, as well as the extracted topics. Sentiment analysis was conducted by Abd-Alrazaq et al. (2020) to capture the major trends in Twitter posts related to Coronavirus disease. A number of other studies examined a thematic analysis of COVID-19-related tweets, including Jimenez-Sotomayor et al. (2020) as well as Das and Dutta (2020). A review of some other COVID-19-related studies on social media data analysis including Twitter was published in Alomari et al. (2021a).

Few studies have focused on COVID-19 data analytics using social media in the Arabic language. Essam and Abdo (2021) analyzed Arab communities' reactions to the pandemic of COVID on Twitter. Alsudias and Rayson (2020) analyzed Arabic tweets associated with COVID-19 to detect rumors. Alanazi et al. (2020) studied Arabic tweets to identify the most common syndromes associated with COVID-19 cases and the order in which they appear. Researchers have also analyzed Twitter data in Arabic to examine government measures and public concerns about COVID-19. A sentiment analysis study was presented by Alhajji et al. (2020) to explore the effects of closing public and private facilities in Saudi Arabia in response to the COVID-19 outbreak. In a study published in Alomari et al. (2021a), researchers analyzed Arabic Twitter data to detect public concerns and the Saudi Arabian government's pandemic response to COVID-19. (Alomari et al., 2021a) present a review of other literature related to COVID-19 using Twitter data in Arabic.

Several studies have investigated teaching and learning through the use of social media and machine learning (Alsulami and Mehmood, 2018). For example, an analysis of students' learning using social media data was provided by Verma et al. (2016). An analysis of Twitter data related to engineering students was conducted by Lande and Dalal (2016) to explore issues that affect student learning as well as to help improve the educational system. A number of studies have focused on using social media applications such as Twitter and Facebook to enhance learning (Kechaou et al., 2011; Chen et al., 2014; Verma et al., 2016).

Some researchers have also looked at learning during the COVID-19 pandemic. Some have focused on studying students and their attitudes while others have focused on teachers and other stakeholders. These include the view toward online learning of people in Saudi Arabia (Aljabri et al., 2021), higher education students in Pakistan (Adnan and Anwar, 2020), high school students in Indonesia (Bestiantono et al., 2020), primary school teachers (Rasmitadila et al., 2020), and K-12 teachers (Harron and Liu, 2020).

Several studies have focused on studying Twitter data analytics using topic modeling based on the Latent Dirichlet Allocation (LDA) algorithm. These include the work by Zahra (2020) on finding semantic relations related to COVID-19 in Twitter data, a supervised model for regression and classification by Korshunova et al. (2019), detecting public concerns and pandemic measures from Twitter data (Alomari et al., 2021a) and evaluating LDA performance for sentiment classification by Onan et al. (2016).

Alomari et al. (2021a) provided a relatively detailed review of topic modeling using LDA.

The literature review establishes that currently there are only three studies that can be considered remotely related to the practical side of our research due to their focus on sentiment analysis of social media for learning during the COVID-19 pandemic. However, these studies focus on sentiment analysis of specific education issues during the pandemic as opposed to the discovery of education governance parameters provided in our research. These include a study on the pandemic response of university students in the US (Duong et al., 2020a), an exploration of public sentiments on closures of private and public facilities in Saudi Arabia (Alhajji et al., 2020), and an analysis of peoples' sentiments on distance learning in Saudi Arabia using Twitter data (Aljabri et al., 2021). Our research is completely different from any of these studies because of its specific focus and in terms of the dataset (the nature of the data due to data collection parameters, the time period of the collected data, the data size, language, and geography), methodology and design (the overall design of the machine learning method and pipeline), our innovative approach of using AI to discover governance parameters, and our findings (Success Factors, Challenges, Socioeconomic Sustainability, and Accountability and Transparency).

METHODOLOGY AND DESIGN

This section describes the design and methodology of our proposed tool. **Figure 2** shows the architecture of the proposed system which involves five modules, including data collection and storage, data preprocessing, parameter discovery (Education Governance), validation, and visualization and reporting. Section System Overview presents an overview of the proposed system. The architecture's modules will be presented in Sections Data Collection and Storage, Data Preprocessing, Parameters Discovery (Education Governance), Validation, and Visualization and Reporting. Additional details about the general methodology related to this study can be found in the study of Alswedani et al. (2022).

System Overview

The system was designed to discover education governance parameters using Twitter data analytics. It focuses on learning in Saudi Arabia during the COVID-19 pandemic using Twitter data in the Arabic language. The proposed system is composed of five components: data collection and storage, data preprocessing, education governance parameters discovery, validation, and reporting and visualization. First, we downloaded public tweets in Arabic by using a carefully designed script with a set of predefined parameters such as search keywords and Twitter hashtags related to learning in Saudi Arabia (See Section Data Collection and Storage, and **Table 1**). We used the Twitter REST API and the Tweepy library to collect the data. Tweets obtained from Twitter API were in JavaScript Object Notation (JSON) format. Then, we used a Python parser we developed to convert and save the JSON data to XLXS format. The preprocessing component cleans and preprocesses the acquired data in order

to prepare it for analysis. We removed stop words from text using the Natural Language Toolkit (NLTK) library with a dialectical Arabic stop word list (see details in Section Data Preprocessing). Subsequently, the discovery module was built using Latent Dirichlet Allocation (LDA) with the scikit-learn Python library. We then provide visual representations of the discovered parameters through an intertopic distance map, the keywords frequency diagrams (the corpus-wide and the cluster-specific), and parameters temporal progression. The PyLDAvis tool (Sievert and Shirley, 2014; Mabey, 2015) has been used to compute and plot the map and term frequency diagrams. Last, the results were validated using internal and external validation techniques. To validate the discovered parameters internally, we found tweets supporting those findings. For external validation, online newspapers and reports are found to validate the parameters.

Data Collection and Storage

Twitter is among the most widely used social networking media at present. It has 436 million monthly active users worldwide. There are 436 million active Twitter users every month around the world (Statista, 2022). Saudi Arabia has the eighth largest number of Twitter users (14.1 million, around 40% of its population) according to a Statista report in January 2022 (Statista, 2022). People use Twitter for discussing various issues, forming opinions, and gaining knowledge about different issues. Twitter is used to communicate with the general public, improve products, strategies, and services, and gather feedback on government issues (Alotaibi et al., 2020). Researchers have increasingly used Twitter to study different topics across many application domains and sectors including education. For instance, Twitter has been used to examine different aspects of education such as analyzing students' attitudes (Adnan and Anwar, 2020) and discovering users' perspectives, viewpoints, and sentiments toward online learning (Al-Rubaiee et al., 2016; Bestiantono et al., 2020; Rasmitadila et al., 2020). Due to social isolation and limited mobility during COVID-19, the use of social media increased during that time (Alomari et al., 2021a; Bichara et al., 2022). Twitter has been a rich source for capturing information about education, which was one of the top discussed issues among stakeholders during the pandemic (Alsudias and Rayson, 2020; Zhu et al., 2020). It is a convenient source for capturing timely and large-scale data (Alomari et al., 2021a).

We collected the Arabic tweets using Twitter REST API during the period from 1 October 2020 to 17 December 2021. The total number of collected tweets is ~1,878,993 tweets.

The collected tweets are related to education and learning systems in Saudi Arabia including online, in-class, and blended learning. The tweets were collected using a set of key terms and hashtags related to virtual, in-class, and hybrid learning in Saudi Arabia during COVID-19. Initially, we used a set of key terms for data collection. Subsequently, we clustered data using Latent Dirichlet Allocation (LDA). Then, from the clustered data, we selected key terms and hashtags and we added them to the data collection script to get more data. This process was carried out iteratively. We used a total of twenty-seven key terms in this study. We used the key terms "التعليم المدمج"
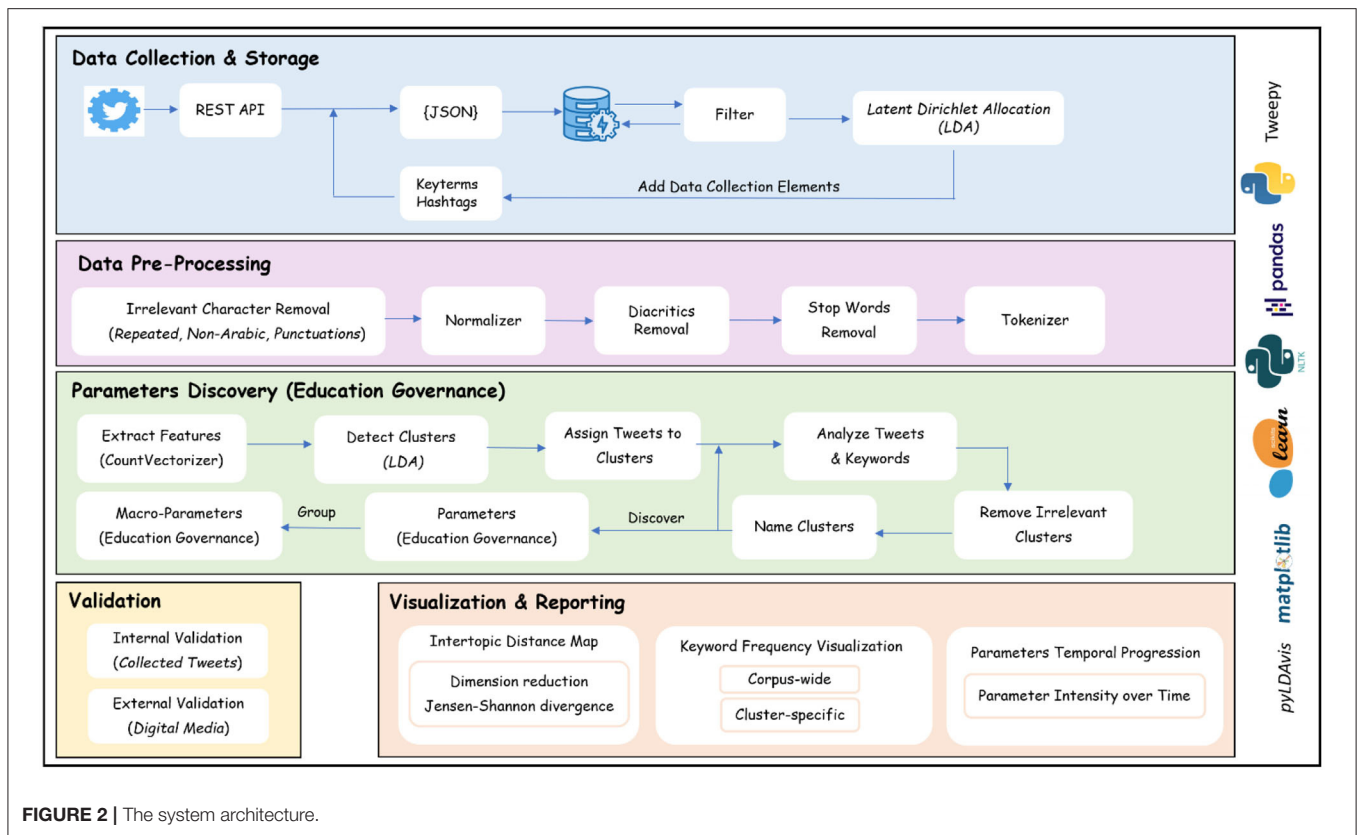
FIGURE 2 | The system architecture.

TABLE 1 | Data collection: keywords and hashtags.

Keywords

التعليم حضوري، التعليم عن بعد، التعليم الإلكتروني، الدراسة عن بعد، التعليم المدمج، التعليم المتزامن، وزارة التعليم، الاختبارات، الاختبارات النهائية، الدراسه منصه، منصة مدرستي، الطالب، الطلاب، الجامعات، المدارس، التعليم، الدراسه

In-Class Learning, Distance Learning, E-Learning, Distance Education, Blended Learning, Simultaneous Learning, Ministry of Education, Exams, Final Exams, Platform, Madrasti Platform, Student, Students, Universities, Schools, Education, Studying

Hashtags

التعليم_المدمج#، التعليم _الحضوري#، التعليم_عن_بعد#، التعليم الإلكتروني#، الدراسه_عن_بعد#، مانفهم_عن_بعد#، نطالب_بالدراسة_حضوري#، تاجيل_العوده_الحضوريه#، الإختبارات_النهائية#، الغاء_الاختبارات_الحضوريه#، وزارة_التعليم#

Blended Learning, In-Class Learning or Face-to-Face Learning, Distance Learning or Online Learning, E-Learning, We Don't Understand Online Learning, We Request In-Class Learning, Postpone In-Class Return, Final Exams, Canceling In-Class Exams, Ministry of Education

(Blended Learning), "وزارة التعليم" (Ministry of Education), and others. We considered different variations for some key terms. For instance, we used the key terms "وزارة" and "وزاره"; both these words mean ministry but the first one is more formal writing compared to the second one. Moreover, we used several hashtags (around fifteen) that were raised and used by the Ministry of Education, students, teachers, and other stakeholders such as "الدراسه_عن_بعد#" (Distance Learning), "التعليم_حضوري#" (E-Learning), "التعليم الإلكتروني#" (In-Class Learning). A selection of the hashtags and key terms that were used for data collection is provided in **Table 1**.

The collected tweets were retrieved from Twitter in JSON format. Each tweet contains several attributes. Among these

attributes are "created_at" which shows when the tweet was posted, "text" which provides the actual tweet message, and other attributes related to the location, such as "geo", "place", and "coordinates". We used "extended" mode to extract the full (untruncated) text of tweets. The JSON format for tweets creates certain coding and computational challenges. To address this issue, we developed a Python parser algorithm to extract the important attributes from JSON format such as the tweet id, text, date, and time and then store the results in an XLSX file. The filter is used to remove irrelevant data or create a subset of data, as needed. We removed duplicate tweets using the Panda package and that is based on the "Id" attribute for the tweets.

Data Preprocessing

Data preprocessing is an essential step for data analytics. It involves several techniques for cleaning, removing noise, enhancing quality, and, ultimately, improving accuracy. The Natural Language Toolkit (NLTK) library is one of the libraries available for preprocessing textually based data.

There are several preprocessing tasks, such as removal of irrelevant words and characters, tokenization, normalization (replacement of letters), and removal of stop words.

Irrelevant Characters Removal

We started preprocessing by removing irrelevant words and characters. We removed URLs, numbers, whitespaces, mentions (@), hashtag symbols (#), emojis and smiley faces, and English alphabets. We also removed the repeating characters such as (ا)in لماذااااا. Furthermore, we removed the non-Arabic alphabets and kept only the Arabic letters. We removed all punctuations including:

- The various types of brackets such as {}, [], and ().
- Colons and semi-colons (: ;).
- Exclamation marks and Arabic and English question marks (؟ ?).
- Mathematical notations such as ÷, , −, +, and %.
- Slashes and ad symbols such as *, &, ∧, \$, >>, <<, |, and ∼.

We replaced the colon symbols (:) as well as the new lines with whitespaces for readability.

Tokenization and Normalization

Tokenization is important in the preprocessing phase. Split () is an available method in python and it was utilized for this task.

Normalization is another preprocessing task. We removed all the forms of diacritics:

- Single marks including Fatha (ﹷ), Damma (ﹹ), Kasra (ﹻ), Tashdid (ﹽ), and Sukun (ﹿ).
- Double marks include Tanwin Damm (ﹲ), Tanwin Kasr (ﹴ), and Tanwin Fath (ﹰ).

Furthermore, we normalized the letters in the words into a consistent form. For example, "Taa marbutah" (ة) was replaced with "haa maftohah" (ه), "Alif" with three shapes (آ، إ، أ) to "bare Alif" "Yaa" (ي) to "dotless Yaa" (ى).

Stop Words Removal

The Natural Language Toolkit only provides a list of stop words for modern standard Arabic. However, a list of words in dialectical Arabic is needed. Therefore, we used the NLTK library with some modifications that suit the needs. We extended the list of stop words supported by the (NLTK) and added a new list for stop words that are usually used in dialectical Arabic. The new list of stop words which are usually used in dialectical Arabic was created based on manual observation of the tweets, such as in the following list: "ايش"، "ليش"، "وش"، "شى"، "الي"، "على"، "والله"، "اللهم"، "اللى"، "احنا"، "مو"، "علا"، "لكن"، "لاكن"، "اللي"، "الله". Furthermore, we added additional stop words (750 stop words) in dialectical Arabic (Alrefaie and Bazine, 2019).

Parameters Discovery (Education Governance)

In this section, we describe the approach to discovering education governance parameters by analyzing Twitter data using topic modeling. Modeling of topics is an AI technique that is commonly used for data analysis and discovery of topics. It involves a set of algorithms that discover themes and patterns among a collection of documents through clustering word terms (Mortenson and Vidgen, 2016). Latent Dirichlet Allocation algorithm (LDA) is a frequently used unsupervised learning algorithm for topic modeling. It is a statistical method of identifying the topics that appear most frequently within a collection of documents. It maps a collection of documents (in this case tweets) to a collection of topics or clusters in which each document is given a certain probability of being associated with a particular topic. The scikit-learn Python library was used for implementing the education parameter discovery module using LDA.

We explored different numbers of clusters (10, 15, 20, and others) to find a reasonable balance between the number of clusters and the quality of clusters and found that 20 clusters identify the best outcomes for detecting important urban governance parameters. After extracting the clusters, we assigned each tweet to its cluster based on the highest probability of the tweet association with a cluster. Then, we did an analysis of the keywords and tweets in which we examined each cluster's key terms and looked at the context of the key terms in each cluster. This process enabled us to give appropriate names to each cluster based on the tweets and keywords within each cluster and our domain expertise. The process was repeated iteratively to improve cluster names. The process also allowed us to remove irrelevant clusters and merged similar clusters, finally finding a total of 10 clusters that we call urban governance parameters. We grouped these ten governance parameters into four governance macro-parameters that represent higher-level governance areas.

For example, we noted that, in topics 7 and 12, the keywords and tweets point to the government's decisions, strategies, and efforts to continue online learning during COVID-19. Some of these keywords are as follows: "Continuation," "Announce," "Preparation," and "Training Course." Therefore, these two topics have been merged into one governance parameter, Supporting Online Learning. Since these topics are some of the factors to assure teaching and learning continue and stay effective during pandemic times, these topics were included under the first macro-parameter, Success Factors.

Validation

In the proposed system, the detected parameters were validated by two different approaches: internal and external validation. We used news publications, academic papers, and online reports for external validation of the information and parameters discovered from the Twitter data. Internal validation was conducted using tweets from the collected dataset to examine the credibility of the discovered information and parameters. For example, for the governance parameter "Digital Services," we found that all the tweets belonging to this parameter that were detected by our

tool are about digital platforms and services for learning (e.g., "Madrasati" platform, Ain Educational Channel) (See Section Digital Services). However, for external validation, we found various international organizations acknowledged the success of the digital learning services. For instance, a book published by UNESCO cites the success of "Madrasati" as an educational model that was globally innovative and distinguished during the COVID-19 pandemic (Reimers and Opertti, 2021; Saudi Press Agency, 2021). Furthermore, the Saudi educational systems were evaluated by six international organizations in two different studies [Saudi National eLearning Center (NELC), 2020]. Education experts in international organizations [e.g., the Organization of the E-Learning Consortium (OLC), UNESCO, and others] have applauded the success of the distance education experience in the Kingdom.

Visualization and Reporting

In this study, we present various visual representations of the discovered parameters. These include keyword frequency diagrams (both corpus-wide and cluster-specific), intertopic distance maps, taxonomy, and temporal progression diagrams. For example, the terms frequency diagrams and distance maps were computed and plotted using the Python pyLDAvis library (Sievert and Shirley, 2014; Mabey, 2015). Jensen-Shannon divergence was used to compute the intertopic scaling and distances. The diagrams of keyword frequency present the frequency distributions at the topic level and the corpus level, which is characterized by the width of the bars. We used other python libraries such as Matplotlib.

PARAMETER ANALYSIS AND FINDINGS

In this section, we discuss the results of our proposed system. Section Parameters and Macro-Parameters: An Overview provides an overview of the macro-parameters and parameters extracted from Twitter data using LDA. Sections Success Factors, Challenges, Socioeconomic Sustainability, and Accountability and Transparency provide a detailed explanation for every urban governance parameter with examples from the collected data.

Parameters and Macro-Parameters: An Overview

This section explains the detected urban governance parameters and macro-parameters. We discuss the approach used to discover the urban governance parameters from Twitter data. We discovered 14 topics using LDA-based topic modeling. The key terms such as cluster, topic cluster, and governance parameter will be used interchangeably. We have grouped these fourteen parameters into four macro-parameters.

Table 2 provides a list of the urban governance parameters along with their data. Column 1 lists the governance macro-parameters. There are four macro-parameters including Success Factors, Challenges, Socioeconomic Sustainability, and Accountability and Transparency. Column 2 provides the fourteen urban governance parameters. For example, In-Class Pandemic Measures, Awareness Activities, and others. Column 3 gives the topic numbers. Column 4 lists the percentage number of keywords for each topic. Column 5 provides the keywords

for each urban governance parameter. A taxonomy for the detected parameters and macro-parameters that we extracted from Twitter is depicted in Figure 3.

Figure 4 presents the temporal progression for each parameter. The *x*-axis gives the timeline of the detected parameters during the data collection period, October 2020 to December 2021. The *y*-axis represents the intensity of the collected tweets. The tweets' intensity has changed over time for the seventeen detected urban parameters. We will present the temporal progression for each macro-parameter in separate figures for clarity and elaborations in the next sections.

Success Factors

We begin discussing the parameters related to the first macro-parameter, Success Factors, which covers the factors to assure teaching and learning continue and stay effective during pandemic times. It also involves strategies for improving the educational outcomes by providing support to students, teachers, families, and other stakeholders. It includes six parameters that are discussed in the next six subsections In-Class Pandemic Measures, Awareness Activities, Supporting Online Learning, Commending Stakeholders, Digital Services, and Nurturing Positive Behavior.

In-Class Pandemic Measures

The first parameter is In-Class Pandemic Measures, represented by the keywords including Visit, Follow up, Health, Precautionary, Procedures, School, and Progress. Figure 5 plots the top 30 most relevant keywords (*or key terms*) for this parameter (Topic 4). The English translation of these keywords is available in Table 2. The government's decision for people to return to in-class learning in physical learning spaces (schools, universities, etc.) was accompanied by various precautionary measures to ensure the health and safety of students, teachers, and others. For example, the government prohibited anyone who did not take the required COVID-19 vaccine doses (according to age) from entering the physical learning spaces. Students in schools are divided into two groups, each group going to school on alternate days except for schools where there is sufficient capacity for the institution to accommodate all its students without violating the distancing measures. Moreover, wearing masks, applying social distancing, disinfection and sterilization of buses and learning environments, preventing sharing of teaching consumables, utensils, and meals, and other precautionary measures were also applied. The key terms in this parameter such as "Follow up" show that periodic supervision is conducted to ensure that the recommended safety measures are applied. The tweets related to this cluster were posted by official accounts, news media accounts, and people. For example, the following tweet was posted by a school in Riyadh city.

"تشرفت الثانوية . . . بزيارة المشرفة. . . في أول يوم للإختبارات النهائية للفصل الدراسي الأول لمتابعة سير الاختبارات الحضورية وعن بعد وتطبيق الإجراءات الاحترازية." #الاختبارات_النهائية

"The [school] was visited by the [supervisor]… on the first day of the final exams for the first semester, to follow up on the progress

TABLE 2 | Urban governance parameters (online learning during COVID-19, October-December 2020).

Macro-Parameters	Urban governance parameters	Topics	Keywords (%)	Keywords
Success factors	In-class pandemic measures	4	6.2%	بزیاره، الصحه، لمتابعه، الصحه، الاحترازیه، الاجراءات، المدرسیه، للشؤون، سر، التعلمیه Visit, Healthy, Follow up, Health, Precautionary, Procedures, School, Affairs, Progress, Educational
	Awareness activities	5	6.2%	ومبادرات، العالمی، المجتمع، الاعاقه، بمناسبه Initiatives, International, Community, Disability, Occasion
		18	3.1%	ومهاراته، قدراته، الاحتفال، حقه، مدرستی، الطفل Skills, Abilities, Celebration, Right, Madrasati, Child
	Supporting online learning	7	6%	العوده، استمرار، الطلاب، جهود، الالكترونی، تعلن، للعام، الفصل، المدارس، الدراسی Return, Continuation, Students, Efforts, Electronic, Announce, Year, Class, Schools, Academic
		12	3.8%	الرابط، وزاره، التسجیل، الطلاب، اعداد، المعلم، شهادات، درس، دوره، معتمده، شهاده Hyperlink, Ministry, Registration, Students, Preparation, Teacher, Certificates, Lesson, Training Course, Accredited, Certificate
	Commending stakeholders	10	4.6%	العمله، وزاره، لدعم، وتحقق، التعلمیه، الوطن، استمرار، نجاح، شكرا، الطلاب Process, Ministry, Support, Achieve, Educational, Homeland, Continuation, Success, Thanks, Students
	Digital services	13	3.5%	بث، الیوتوب، وفرت، الاسبوع، مباشر، جدول، رابط، الحصص، دروس، الساعه، وزاره Broadcast, YouTube, Offered, Week, Live, Schedule, Hyperlink, Classes, Lessons, Hour, Ministry
	Nurturing positive behavior	16	3.2%	التعاون، ونشر، المجتمع، القیم، مدرستی، منصه، تعزیز، الانسانیه، الخبر، طلاب، دور Cooperation, Dissemination, Community, Values, Madrasati, Platform, Promotion, Humanity, Goodness, Students, Role
Challenges	Educational system	3	7.8%	جامعه، الحضوری، الدراسه، قرار، الثالث، الدوام، افضل، وزاره، المدارس، المعلم، السنه، الطلاب University, In-Class, Studying, Decision, Third, Work, Better, Ministry, Schools, Teacher, Year, Students
	In-class vs. online	6	6.1%	العام، استمرار، الدراسه، والثانویه، بدایه، حضوریا، للمرحله، المتوسطه، الابتدائیه، الفصل Academic Year, Continuation, Studying, High School, Beginning, In-Class, Level, Intermediate School, Elementary School, Semester
	Exam procedures	1	11.3%	الوضع، كورونا، قرار، اختبارات، وزیر، الترم، حضوری Situation, Corona, Decision, Exams, Minister, Term, Physical Attendance
		9	5%	الطلبه، الصحه، جامعه، نطالب، وزاره Students, Health, University, Request, Ministry
Socioeconomic sustainability	School timings	2	8%	وقت، المدارس، الجامعه، تجربه، نظام، التواصل، الطلاب، الالكترونی Time, Schools, University, Experience, System, Communication, Students, Electronic
	Benefits	20	2.9%	الكفاءه، التشغیلیه، متمیز، الوصول، تحسین، فرص، رفع، لتعلم، سیسهم، المدارس، الدراسه Efficiency, Operational, Distinguished, Access, Improvement, Opportunities, Raising, Education, Contribute, Schools, Study
	New economic opportunities	8	5.4%	بوربوینت، تصمیم، خدمات، خاص، بحوث، للتواصل، واجبات، عمل، عروض، حل PowerPoint, Design, Services, Private, Research, Communication, Assignments, Work, Presentations, Solution
& Accountability transparency	PIRLS	14	3.3%	بمشاركه، تبدا، تهئیه، استعدادات، بجهود، الاف، برامج، الوطن، ابنائهم، الاسر، وزاره، واولیاء، كتاب، طالب، المدارس، والمعلمین Participation, Start, Preparation, Arrangements, Efforts, Thousands, Programs, Homeland, Their Children, Families, Ministry, Parents, Book, Student, Schools, Teachers
	International collaborations	17	3.1%	المحتوى، الرقمی، مسؤول، وزاره، انجازا، حققت، زیارته، تعلمیه، عالمیا، المملكه، وزیر Content, Digital, Responsible, Ministry, Achievement, Achieved, Visit, Educational, International, Kingdom of Saudi Arabia, Minister

of the in-class and online exams, and to apply precautionary measures." #Final exams

Awareness Activities

The governance parameter **Awareness Activities** relates to the recommendations and observance of the Ministry of Educations in Saudi Arabia to observe various international days such as International Children's Day and International Day of Disability. These activities were used to increase awareness of the importance of education for children and all and to motivate everyone to continue and excel in education during the pandemic. These international days were supported by the Ministry with various education initiatives. For example, International Children's Day was celebrated on 20 November 2021, through the digital learning platform "Madrasati". Among the objectives of celebrating this event was to raise awareness about the rights of children and highlight the government's efforts in ensuring children's protection and rights. The Ministry also developed several programs related to these themes to create awareness of issues related to children's education. For example, Early Childhood Initiative is one of the important projects of the Ministry which aims to raise the rate of enrollment in the primary classes by assigning teaching of boys and girls in elementary school levels to female teachers alone. The National Family Safety Program is another project which aims to create programs for the community to protect and defend the rights of individuals, reduce the incidence of abuse through training and awareness, and provide helpline services for children. The detected tweets related to this parameter were about these international days, the activities associated with them, and the government's efforts to increase awareness of education in general and children's education-related and other national and international issues in particular. For example, the following tweet was posted by the Ministry of Education.

"#وزارة_التعليم تشارك في الاحتفال بــ
#اليوم_العالمي_للطفل، وإبراز جهود المملكة بدعم القيادة
الرشيدة ـحفظها اللهـ في تمكين الطفل من حقه في التعليم،
وتنمية قدراته ومهاراته للمستقبل."

"#The Ministry of Education is participating in the celebration of the #InternationalChildren's Day and highlighting the Kingdom's efforts with the support of the wise leadership - may God protect it - in empowering the child with his right to education and developing his abilities and skills for the future."

Supporting Online Learning

The urban governance parameter **Supporting Online Learning** (see **Table 2**) relates to the government's decisions, strategies, and efforts to continue online learning for all the school and university levels in Saudi Arabia. The selected keywords in Column 5 of Row 4 (Topic 7) and Row 5 (Topic 12) characterize the governance parameter. It is discussed in Section In-Class vs. Online that education in Saudi Arabia for all educational grades and institutions had shifted from physical to online learning since the beginning of the pandemic (since August 2021, it is gradually being brought back to physical spaces).

Stakeholder training was one of the strategies to support online learning. The lack of technical and digital skills among stakeholders was some of the challenges associated with the migration to online learning and enhancing these skills had been a key element for a successful transition to online learning. Therefore, one of the strategies applied by the Ministry of Education was to equip teachers, students, and other stakeholders with the essential skills to access and use the digital teaching and learning platforms. For this objective, the ministry has conducted various courses, programs, and workshops for training the stakeholders. Moreover, public and private organizations (training institutions, academies, etc.), coaches, tutors, and others have also provided certain training courses for strengthening stakeholders' skills. Some of the offered courses and programs are accredited by the Ministry of Education and provide certificates to the trainees and that is why the "Accredited" and "Certificate" key terms are detected in this parameter.

For example, the English translations of some tweets include excerpts, *"A course, 'Teaching practices for primary grade teachers, to help address the shift towards distance education during the COVID-19 pandemic is offered on… with accredited certificates from King Saud University,* and *"The Schools Development Unit in #education_Majmah city, in cooperation with the e-learning unit at the Community College of the #University…, invites you to attend a two-day training program, 'Preparing Computerized Tests Using Electronic Forms'…"*. Another such tweet follows.

"هام لجميع المعلمين والمشرفين :وزارة_التعليم تدعوكم
غداً الثلاثاء الساعة ٨ مساءً لحضور التدريب الإلكتروني
المباشر بعنوان (الفصول الافتراضية الجاذبة) ضمن سلسلة
البرامج التدريبية لـ #منصة_مدرستي وذلك على الرابط
التالي."

"Important… Ministry of Education invites you… to attend live electronic training, 'Attractive Virtual Classes' within the series of training programs for #Madrasati platform… https://t.co/YgkFDfNtzp"

The government's efforts to continue online learning in Saudi Arabia were seen as praiseworthy by people and its evidence is found in a large number of tweets from the public included in this cluster. Here are some examples.

"التعليم_عن_بُعد؛ قدمت فيه المملكة . . . سرعة الاستجابة
لتحديات الجائحة، وتعدد الخيارات التعليمية، والتطوير
المستمر للمنصات التقنية؛ بدعم من قيادتنا . . . و
#وزارة_التعليم وجهود مخلصة بذلها المعلمون والمعلمات
والأسر لضمان رحلة النجاح …"

"Distance education, in which the Kingdom provided… the speed of response to the challenges of the pandemic, the multiplicity of educational options, and the continuous development of technology platforms; with the support of our leadership… and the Ministry of Education and sincere efforts made by teachers and families to ensure the journey of success…"
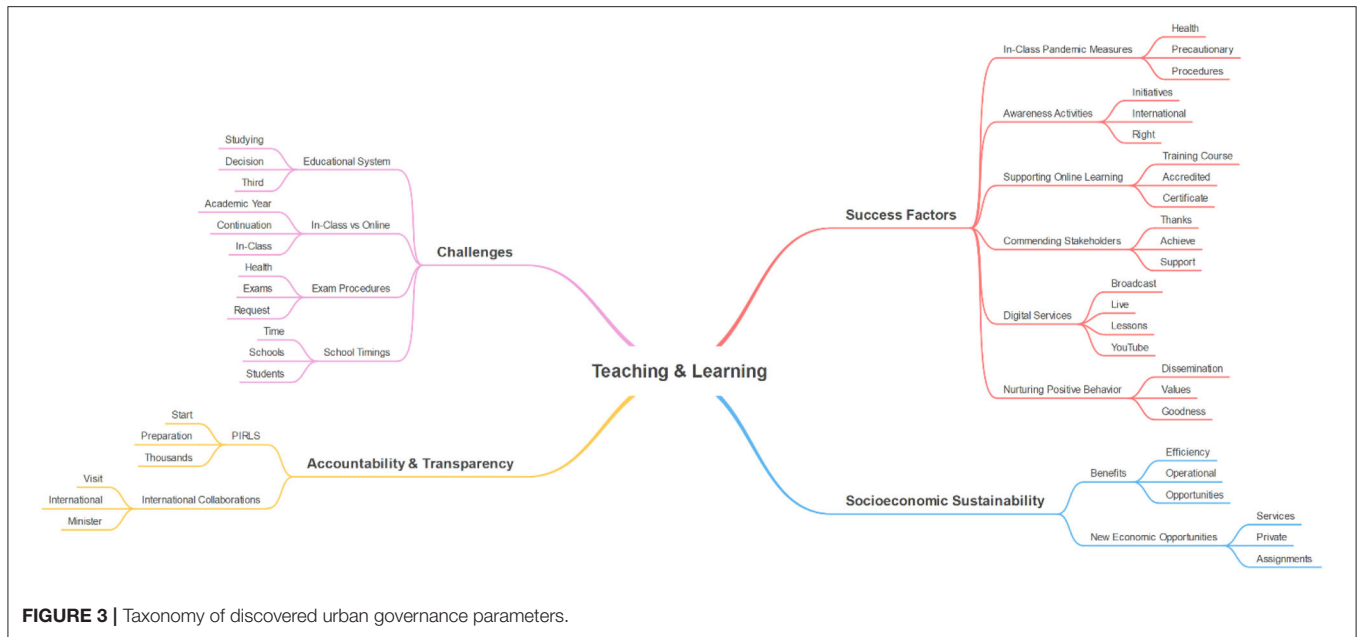
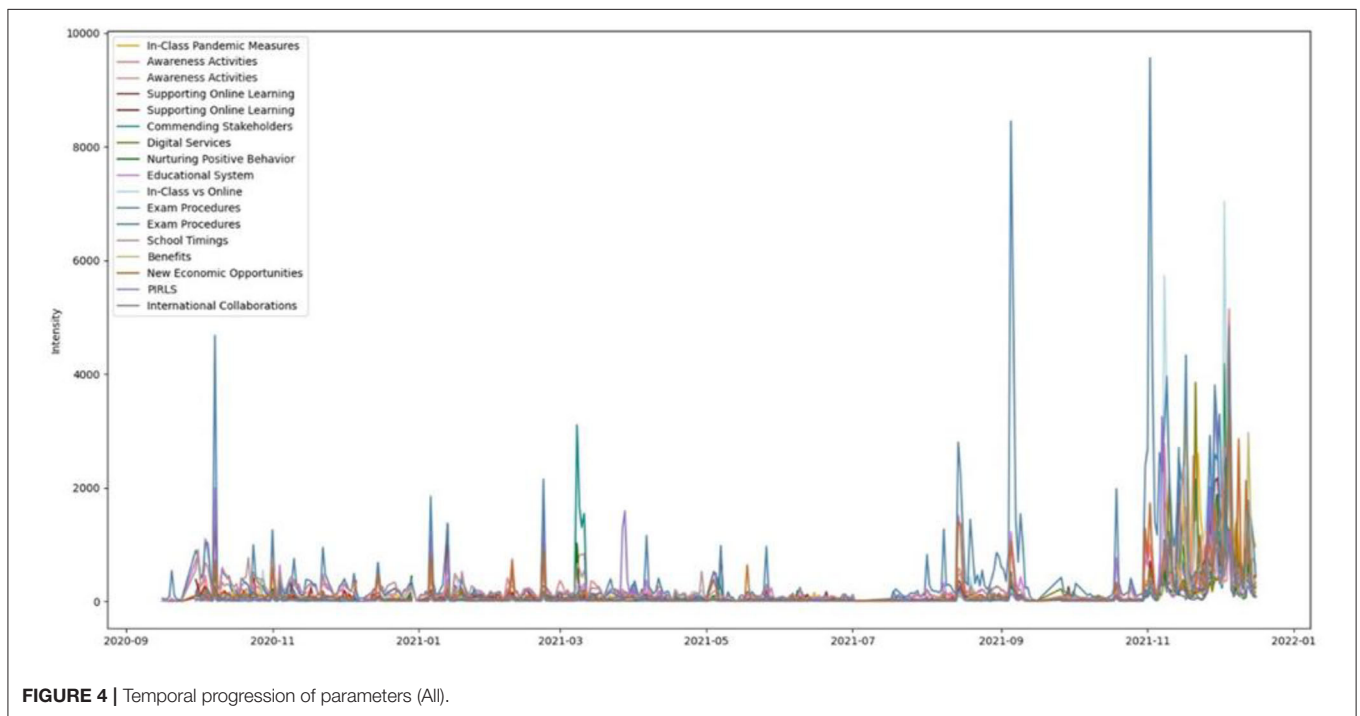**FIGURE 3 |** Taxonomy of discovered urban governance parameters.

FIGURE 4 | Temporal progression of parameters (All).

"… the Kingdom's success in e-education and the provision of vaccines to all for free for nationals and residents as well as free treatment and medical follow-up …"

The government's educational efforts to continue online learning in Saudi Arabia were acknowledged by various international organizations. For instance, recently Microsoft applauded the Kingdom's success in the continuity of education (Official Twitter Account of Saudi Press Agency, 2022; Saudi Press Agency, 2022). Furthermore, a book published by UNESCO cited the success of "Madrasati" as an educational model that was globally innovative and distinguished during the COVID-19 pandemic (Reimers and Opertti, 2021; Saudi Press Agency, 2021). Furthermore, the Saudi educational systems were evaluated by six international organizations in two different studies
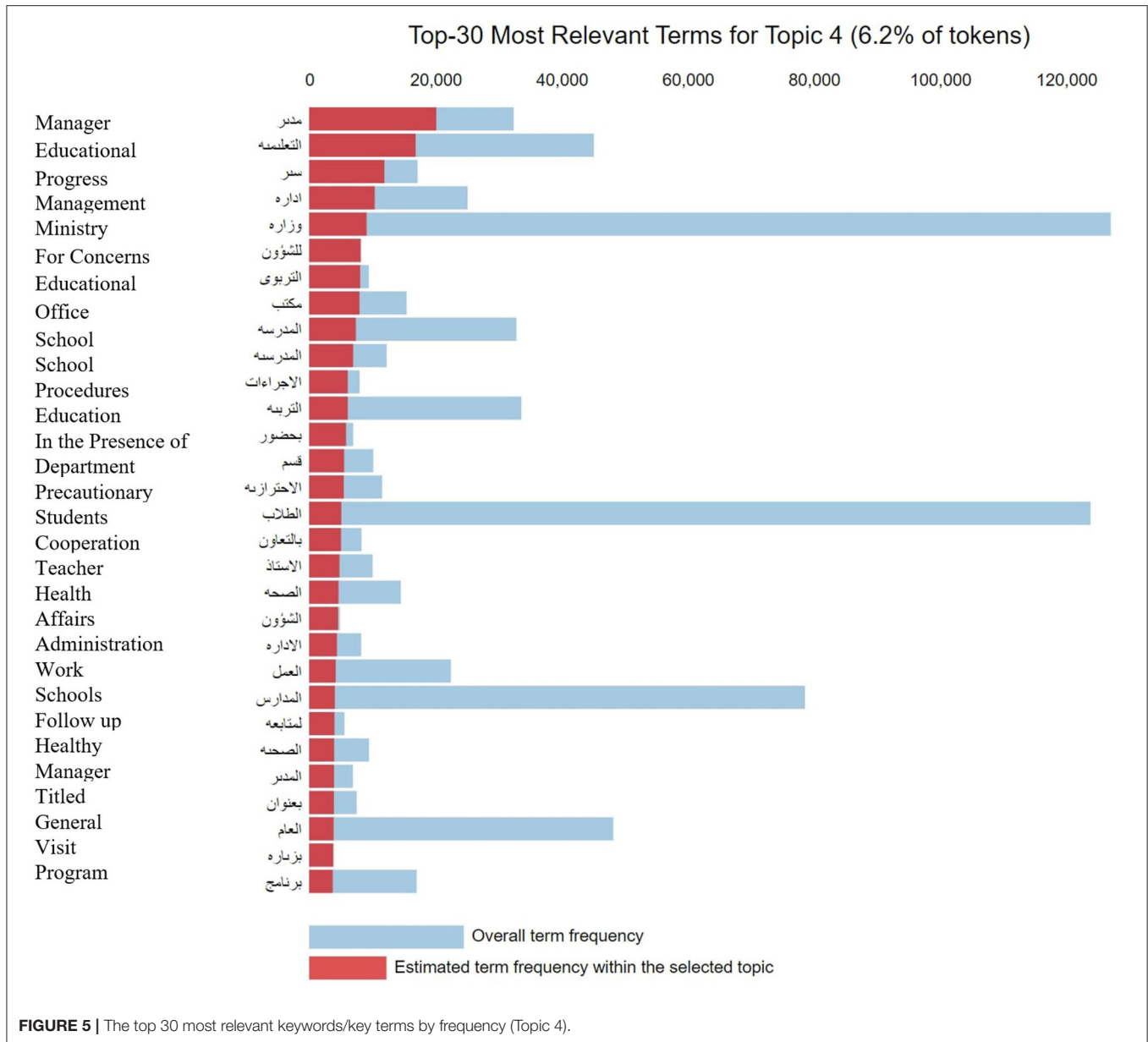
FIGURE 5 | The top 30 most relevant keywords/key terms by frequency (Topic 4).

(Saudi National eLearning Center (NELC), 2020). Education experts in international organizations [e.g., the Organization of the E-Learning Consortium (OLC), UNESCO, and others] have applauded the success of the distance education experience in the Kingdom.

Commending Stakeholders

The fourth governance parameter is **Commending Stakeholders** (see Row 6, **Table 2**). COVID-19 caused teachers' efforts to become more apparent because parents and other stakeholders realized the teachers' commitment to teaching the kids despite the many challenges they faced throughout the pandemic, including migration to online learning. This cluster reflects society's thanks and appreciation for teachers, parents, and other

stakeholders. For example, the following tweets show the thanks and appreciation for teachers.

"#شكراً لمنسوبات متوسطة وثانوية . . . لــ الجهود
المبذولة في إنجاح سير #اختبارات نهاية الفصل الدراسي
الأول والتعاون وإنجاز الأعمال بكفاءة وإخلاص
#تعليم_نجران#وزارة_التعليم"

"#Thanks to the [intermediate and high school's] teachers... for the efforts made in making the end-of-semester exams run successfully, cooperating and completing work efficiently and faithfully." #Najran_Education #Ministry of Education

The following tweet highlights the appreciation to the parents.

"شكر وامتنان لشركاء التعليم أولياء أمور طالباتنا في
مدرسة. . . لمتابعتكم ودعمكم لأبنائكم في استمرار رحلتهم
التعليمية عن بعد للفصل الدراسي الأول لعام:١٤٤٣هـ."

"Thank you and gratitude to the education partners, the parents of our students in the school... for your follow-up and support for your children in continuing their distance educational journey for the first semester of the year 1443 AH."

Digital Services

The governance parameter **Digital Services** relates to matters such as internet access and digital platforms for virtual, in-class, and hybrid learning. People initially, in the early days of online learning due to the COVID-19 pandemic, had concerns about the quality of internet and digital learning platforms. However, these were resolved mostly and people reported satisfaction overall with the digital services for online learning, manifested also in the government's accomplishment reported by the studies carried out by six international organizations (Saudi National eLearning Center (NELC), 2020). Provisioning high-speed, low-latency internet connections, convenient access to online platforms, and other digital resources are important for the success of both online and in-class learning. It could also improve distance, lifelong, anytime, anywhere learning opportunities for the society. Therefore, the Ministry of Education had launched several learning resources (Ministry of Education, 2020).

For example, Ain Educational Channel (قناة عين التعليمية) is a group of Saudi channels offered by the Ministry of Education (Ministry of Education, 2022a; Saudi Ministry of Education, 2022). It provides various information from the Ministry of Education and broadcasts lessons on the "Madrasati" platform through more than twenty educational channels. In addition, the Ain Channel owns a platform that broadcasts lectures and information *via* YouTube. The Ain channels are available on Arabsat satellite, and the channels are classified based on the educational stages. Each channel is allocated to a certain study stage, with an average of 5 h per day, repeated several times daily, to increase availability for families with children studying for different educational levels and allow learning at their convenience. The aim of providing Ain Educational Channel was to strengthen the online and distance learning system, increase the achievement of students by providing repetition for learning materials taught by different instructors using different teaching methods, and compensate for the disadvantages of online learning, such as for children who find it difficult to focus for long hours on their own during online lessons.

The Ministry of Education posted several tweets related to the weekly schedule of the lessons available on the Ain channels and about other digital platforms and services.

"#التعليم_عن_بعد #الأسبوع_الخامس جدول دروس
الحصص اليومية للمرحلة الثانوية (المستوى السادس) عبر
#قنوات_عين على تردد عربسات. . . ، فى بث مباشر من
الساعة ٩ صباحاً، ويُعاد طوال اليوم، أو عبر رابط القناة على
اليوتيوب".

"Distance education #fifth_week, Daily classes for secondary school (level six) are available via #Ain_channels on Arabsat frequency …, in a live broadcast from 9 a.m., and it is repeated throughout the day, or via the channel link on YouTube." (Feb 13, 2021).

". . . المملكة. . . في التعليم عن بُعد من خلال منصة
#مدرستي و ٤٢ قناة تعليمية"

"… The Kingdom …has provided convenient access to distance education through the #Madrasati platform and twenty-four educational channels."

"قدم أكثر من (30000) عملية دعم فني و (250) ساعة
تدريبية مركز دعم التعلم الإلكتروني بـ #تعليم_جازان …
جهود تقنية عبر #منصة_مدرستي لدعم المجتمع التعليمي
تفاصيل أوسع https://t.co/RDlDB4fl3i #وزارة_التعليم
https://t.co/cshG8xlg9t"

"The E-Learning Support Center in the Jazan region provided more than (30,000) technical support operations and (250) training hours … Technical efforts via Madrasati (digital platform) to support the educational community. Further details …"

The government's efforts with Digital Services are evidenced in the public tweets, international evaluations, and outcomes, i.e., "Madrasati" platform was identified as a global innovation and a distinguished model of education during the COVID-19 pandemic in a book published by UNESCO (Reimers and Opertti, 2021; Saudi Press Agency, 2021). NELC Saudi Arabia was commended by the OLC for offering a variety of options to students and stakeholders (e.g., several digital platforms, free lecture broadcasts *via* satellite TV, stakeholder training, etc.) and the speed with which the transition to online learning was accomplished (Saudi National eLearning Center (NELC), 2020).

The following tweets reflect the public's expression that they were satisfied with the digital services provided for education.

". . . ْتعددت الخيارات التعليمية، عبر المنصات التقنية . . .
وجهود مخلصة بذلها المجتمع التعليمي والأسر نحو نجاح
رحلة الأبناء الطلاب والطالبات في التعليم عن بعد"

"… there are many educational options, through technical platforms … and sincere efforts made by the educational community and families towards the success of the journey of children, male and female students, in online education."

"الجهود التي بذلها وزيرنا … حول (منصة مدرستي) أصبحنا
نستشعر نجاحها الآن … فالتعامل مع المنصة للمعلم والطالب
أصبح أمرا سهلا."

"Now we feel the success of the efforts made by our Minister... for (Madrasati Platform) … dealing with the platform for the teacher and the student has become easy."

Nurturing Positive Behavior

The sixth governance parameter is **Nurturing Positive Behavior**. Creating and nurturing positive attitudes among students is a key strategy for the success of the online learning process. There are several issues associated with online learning, for example, the motivation of the children and their honesty when the teacher

is not physically present to supervise them. The Ministry of Education aimed to strengthen the positive values and behaviors among students. One of the strategies applied by the Ministry of Education to strengthen good attitudes in students was through activating various programs and competitions (Saudi Ministry of Education, 2020a,b; Alatiq, 2021). For example, the guidance and counseling departments organized a one-week program called "Schools Promoting Positive Behavior" (Alyaum Newspaper, 2020; Alhadwari, 2021). The following tweet is an example.

"برنامج #تعزيز_السلوك_الإيجابي (التسامح والمسؤولية) عن بعد عبر #منصة_مدرستي #وزارة_التعليم"

"Promoting Positive Behavior Program (Selected Values: Tolerance and Responsibility) is remotely activated via #Madrasati_Platform#Ministry of Education"(Dec 16, 2021).

Figure 6 shows the tweets intensity for the macro-parameter **Success Factors**. The urban governance parameters in this macro-parameter are In-Class Pandemic Measures, Awareness Activities, Supporting Online Learning, and others. There are various peaks. For example, the Awareness Activities parameter which is represented in a light coral color has a peak in November and another peak in December. We found that various hashtags were launched related to international days such as the International Children's Day (e.g., #اليوم_العالمي_للطفل), which was on 20 November 2021, and the International Day of Persons with Disabilities, which was on 3 December 2021 (e.g., #اليوم_العالمي_للإعاقة). The line plot for the In-Class Pandemic Measure parameter is shown in orange color. The Twitter posts related to the pandemic measures had increased before the official announcement of the decision to return to in-class learning in physical learning spaces for primary and kindergarten schools.

Challenges

Now, we discuss the second macro-parameter **Challenges**. The global pandemic of COVID-19 has created many challenges for education such as school closure and transition to online learning, lack of clarity on examinations, etc. This macro-parameter includes four urban governance parameters, **Educational System**, **In-Class vs Online, Exam Procedures**, and **School Timings**.

Educational System

The governance parameter **Educational System** (see **Table 2**) relates to the recent changes being introduced in Saudi Arabia by the Ministry of Education under the umbrella of the Saudi 2030 vision. The ministry has introduced major reforms in the education system. These changes aim to improve the performance of the education system and assure that students receive maximum benefit from the learning process. The reforms include dividing the academic year into three semesters (earlier it was a two-semester system), introducing new curricula, implementing the new curricula and systems during this ongoing academic year (Saudi Ministry of Education, 2021a), cancellation of the preparatory year (foundation year) in universities, and providing the options of blended learning methods for students. These changes were discussed on Twitter by students, parents,

instructors, news media accounts, and other stakeholders. An example tweet is given below.

". . . سعت وزارة التعليم بدعم سخي من قيادتنا الرشيدة -يحفظها الله – لتطوير الخطط الدراسية في الفصول الثلاثة بإضافة مقررات جديدة، تلبي الاحتياجات التربوية وتحسّن من نواتج التعلّم في مختلف البرامج والأنماط التعليمية المقدمة للطلبة."

"The Ministry of Education has received generous support from the government to develop the study plans by adding new courses that meet educational needs and improve learning outcomes in various programs and educational patterns given to students."

The following tweet was posted by a news media account.

"#عاجل #وزير_التعليم: سنستخدم التعليم المدمج إذا تطور الوضع الصحي – متفائلون بأن الفصل القادم سيكون حضوري – الاستغناء عن السنة التحضيرية في الجامعات – نعمل على زيادة أيام الدراسة والإجازات المطولة مستمرة – المناهج الحالية مفترض أن تطور منذ زمن بعيد #صحيفة_هام *https://t.co/C7fAObRp94*"

"#Urgent #Minister of Education: - We will use blended learning if the coronavirus situation gets better - We are optimistic that the next semester will be present - Dismissal of the preparatory year in universities - We are working to increase school days and extended vacations continue - The current curricula are supposed to develop long ago #Ham newspaper…"

Dividing the academic year into three semesters is one of the major changes in the Saudi Education system. It aims to maximize students' benefits from the learning process, enhance the performance of the education system, and meet the government's goals for development. The ongoing academic year (August 2021–July 2022) is divided into three semesters, and each semester consists of 13 weeks. After each semester, there are 7 days of break. For example, the following tweet was posted on 26 May 2021. It highlights some of the expected benefits of introducing the three-semester academic year.

"#عاجل وزير التعليم: التعليم عن بُعد سوف يستمر حتى مع التعليم الحضوري بطرق مختلفة. قد نستخدم التعليم المدمج في حال تطور الوضع الصحي. الفصول الثلاثة يُقدم فيها التعليم بشكل مفيد، وتكسر الجمود في الرحلة التعليمية."

"#Urgent Minister of Education: Distance education will continue even with attendance education in different ways. We may use blended learning if the health situation evolves. The three chapters teach usefully and break the deadlock in the educational journey."

In-Class vs. Online

The next governance parameter is **In-Class vs. Online**. It is represented by keywords such as Academic Year, Continuation, Studying, High School, Beginning, In-Class, Level, Intermediate School, Elementary School, Semester, and Academic. The learning process during COVID-19, should it be in-class or online, has been the subject of major discussions on Twitter during the pandemic by all stakeholders including teaching staff, families, and students. Since the beginning of the pandemic,
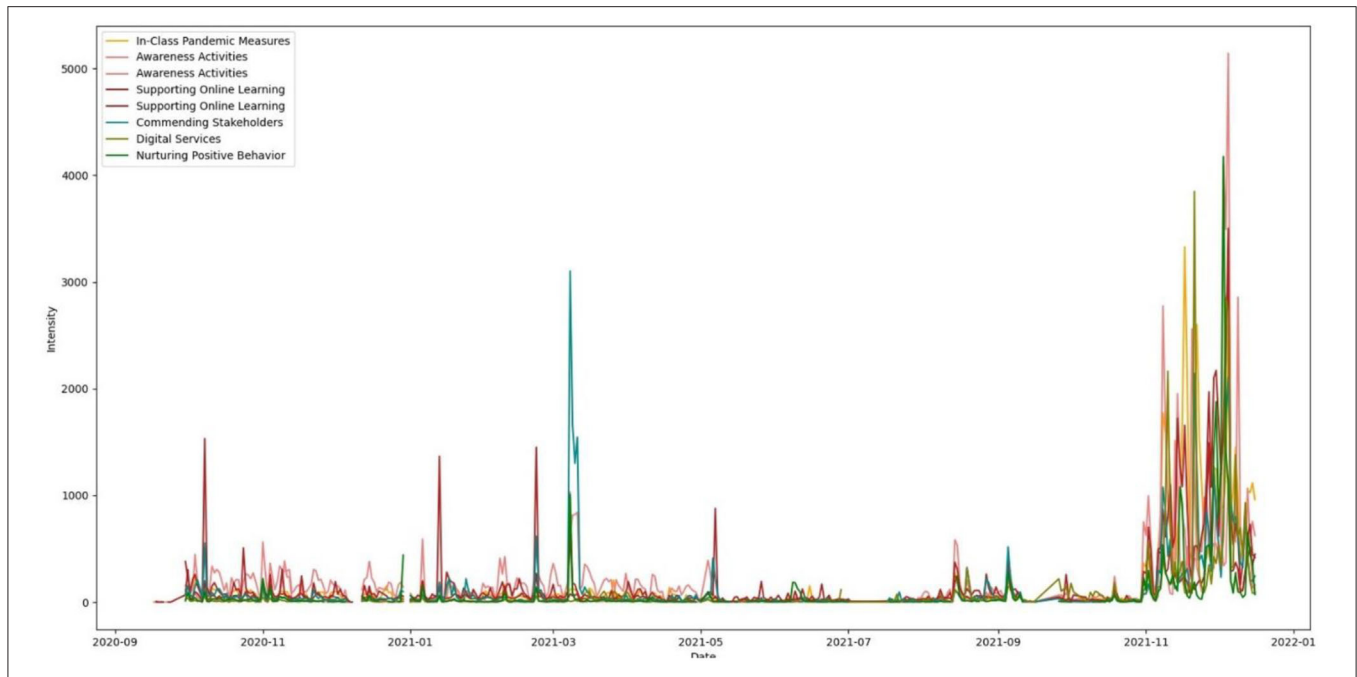
FIGURE 6 | Temporal progression of parameters (macro-parameter: success factors).

the learning process has been online for all the educational grades and types of educational institutions (university, technical, training, etc.). However, with the pandemic situation beginning to improve, the Saudi government has gradually started to bring learning to the physical spaces. For the academic year (August 2021), the learning process was determined based on the educational level. Different educational levels were directed to follow different learning schedules and plans.

"وزارة التعليم (آلية الدراسة للفصل الثاني): تعلن
#وزارة_التعليم استمرار الدراسة حضورياً للمرحلتين
المتوسطة والثانوية و (عن بعد للمرحلة الابتدائية) للفصل
الثاني ٣٤٤١هـ. ١. حضوري: للمتوسطة والثانوية. ٢ عن بعد:
للابتدائي ورياض الأطفال..."

"The Ministry of Education (the study mechanism for the second semester): The #Ministry_of_Education announces the continuation of the study in attendance for the intermediate and secondary stages and (remotely for the primary stage) for the second semester 1443 AH. 1. In-Class: for middle and high school. 2. Online: for primary and kindergarten."

For universities, high schools, and intermediate schools, the learning process was decided to be a mix of in-class and online learning (blended learning) and the students are required to take the COVID-19 vaccine as a condition to attend physical classes. However, for young children (elementary and kindergarten), the government decided to continue the online mode of learning (note the keywords related to this parameter, e.g.,

"Continuation") throughout the semester (First Semester, 2021–2022)[1]. The keywords "High School," "Intermediate School," and "Elementary School" represent the educational grades engaged in these conversations. For example, the following tweet was posted on 19 October 2021 by a news media account:

"عاجل#التعليم: تأجيل العودة الحضورية للطلبة لمن هم
أقل من 12 عاماً إلى حين استكمال الدراسات العلمية
المرتبطة بالمخاطر الوبائية على هذه الفئة حفاظاً على
سلامتهم وسلامة أسرهم. استمرار تقديم التعليم عن بعد من
خلال منصة #مدرستي للمرحلة الإبتدائية ومنصة
#روضتي لمرحلة رياض الأطفال."

"Urgent #Education: Postponing the attendance of students under 12 years of age until the completion of scientific studies related to epidemiological risks for this category in order to preserve their safety and the safety of their families. Continuing the provision of online learning through the #Madrasati platform for the elementary stage and the #Rawdati platform for the kindergarten stage."

Exam Procedures

The next governance parameter is **Exam Procedures** (see **Table 2**). The selected keywords in Column 5 of Row 11 (Topic 1) and Row 12 (Topic 9) characterize the governance parameter. The keywords include Corona, Decision, Exams, Term, Physical Attendance, Health, University, Request, and Ministry. The procedures of exams during the pandemic including whether the exams should be taken in-class or online were among the

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[1] The government announced on 9th January 2022 its decision to open primary and kindergarten schools with in-class learning beginning from 23 January 2022. This is not covered in the time period of the dataset we have used.

major concerns and were vigorously discussed on Twitter by students, parents, teachers, and other stakeholders. Some higher education institutions and universities demanded students attend final exams in-person, so this created concerns, and people feared an increased risk of infection during the exams. The keyword "Health" reflects people's concerns about students' health. The following tweet is an example.

> "... الاختبارات حضورية. . . تهيئ بيئة خصبة لانتشار #فيروس-كورونا. خيار الاختبارات #عن-بعد أصبح مطلباً في التعليم. . ."

"...in-class exams... creates a fertile environment for the spread of #CoronaVirus. The option of online examinations has become a requirement in education..."

Even though the public concern was valid, universities also appear to have a valid viewpoint related to physical attendance in final exams due to the lack of cheating detection tools in the current eLearning systems that can enforce honesty among students. This challenge creates an opportunity for developing learning systems with better assessment capabilities.

The following tweets reflect the public views related to Exam Procedures.

> "#وزاره-التعليم احسنت بقرار الاختبارات الورقية الحضورية لمراحل المتوسطة والثانوية فالاختبارات الحضورية كفيلة بضخ الجدية . . . في . . . المدارس وهي القياس الصحيح لجودة عملية الاختبارات ومصداقيتها. . ."

"The Ministry of Education did well in deciding to hold in-class exams for the intermediate and secondary levels ... these are necessary to maintain quality and credibility of the testing process ..."

School Timings

The next governance parameter is **School Timings**. With the transition to online learning during the COVID-19 pandemic, the school timings for online learning were determined based on the school level. For example, the students in intermediate and high school classes attend classes in the mornings, while elementary school students attend classes in the afternoons. Families faced difficulty in coping with this, particularly mothers who had children at multiple school levels and had to supervise them all day. Tweets that highlight the concerns of working parents about school timing for online learning were detected by the tool.

> "#منصة-مدرستي...وقت-الابتدائي ضغطٍ كبير جداً على الأسرة والأطفال واستهلاك لطاقتهم المُستنفذة من الصباح وتأخر في إتمام متطلباتهم والواجبات في المنصة لأوقات متأخرة ليلاً #التعليم-عن-بعد"

"#Madrasati Platform... school time for elementary stage puts pressures on the family and children and consumes their energy ... and completing children's requirements and duties on the platform requires working whole day until late night"

> "سؤال مهم لو التعليم عن بعد للابتدائي. . . كيف المفروض الأم تتابع اطفالها في المنصة وتروح الشغل فنفس الوقت؟ . . ."

"An important question: if the learning is online for the elementary stage... how does a working mother follow her children on the platform and go to work at the same time? ..." (August 18, 2021).

Although the parents and mothers had valid reasons for being exhausted, we believe that the timing of school was determined by a variety of factors. The senior school students were scheduled for the morning because older kids do not require as much supervision, allowing working parents to do their jobs in the morning. Having the school hours divided into the mornings and afternoons also allowed for the sharing of resources such as smartphones, TVs, and tablets.

Figure 7 depicts the Twitter activity for the parameters associated with the **Challenges** macro-parameter. The tweets related to exam procedures including whether the exams should be taken in-class or online were vigorously discussed and it has several peaks between October 2020 and December 2021. The parameter In-Class vs. Online is displayed in light blue color. Note in the graph that the tweets about whether the learning process should be in-class or online started to increase at the beginning of the academic year (August 2021) and reached a peak on 5 September 2021. There were a number of trending hashtags on the 5 September, including #التعليم-الحضوري (In-Class Learning) and #نطالب-الملك-بالدراسه-عن بعد (We Demand Online Learning).

Socioeconomic Sustainability

We now discuss the parameters related to the third macro-parameter, **Socioeconomic Sustainability**. This macro-parameter includes two governance parameters.

Benefits

Benefits (eleventh governance parameter) reflect the advantages of online learning from a socioeconomic perspective. It is represented by keywords such as Efficiency, Operational, Distinguished, Access, Improvement, Opportunities, Raising, Education, Contribute, Schools, and Study. The benefits of online learning include efficiency, economic benefits, equity, and operational efficiency. Online learning contributes to avoiding the operating costs of small and remote schools, ensuring the availability of education for all students through its various tools and services, and improving equality and equal access to education.

> "#وزير-التعليم :التعليم-عن-بُعد سيسهم في تحسين تكافؤ فرص الوصول لتعليم متميز، كما سيسهم في رفع الكفاءة التشغيلي. #ملتقى-ميزانية 2022"

"#Minister of Education: Distance education will contribute to improving equal access to distinguished education, and will also contribute to raising operational efficiency. #Budget 2022 Forum"

The following tweets reflect the public views related to Benefits.

> ". . . لتعليم عن بعد الذي اثبت نجاحه وانه افضل من التعليم العادي مما يوفر جهد وكوادر اداريه ويصقل في الطالب ان يكون سوي وقيادي."

"... distance education has proven to be successful and is better than in-class education, as it saves efforts and numbers of
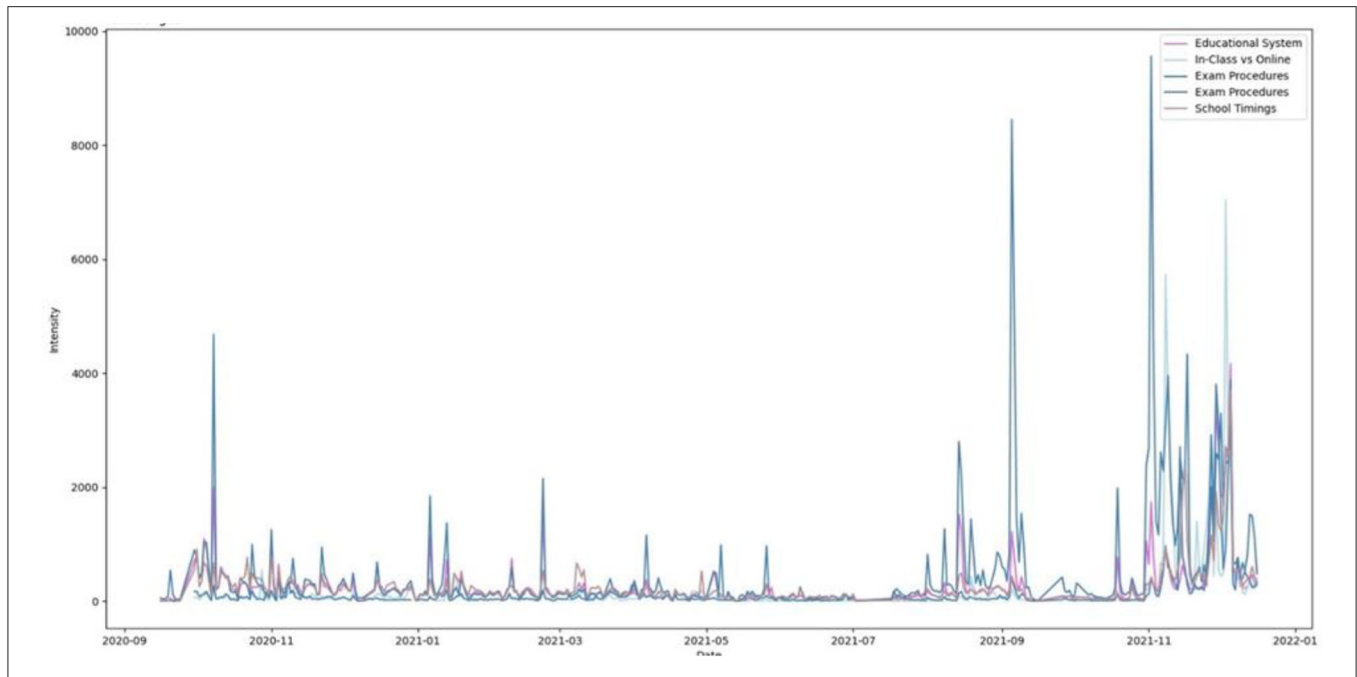
FIGURE 7 | Temporal progression of parameters (macro-parameter: challenges).

administrative staff, and teaches the student to be independent and responsible."

> "... جهود الطلاب معنا جبارة أفضل من قبل لأن... التعليم عن بعد نحن نوجه وهم يبحثون والمعلومة اذا بحث عن الطالب أرسخ من تلقينه وحشوه"

"... the independence that the students get through online education can make them better learners as opposed to in-class learning where students might overly follow teacher instructions, limiting their independent learning and creativity"

> "... نطالب الوزاره بتحويل التعليم عن بعد لصحه وسلامه الطلاب ولان التقنيه تخدمنا بالبيت فماله داعي التعب والمصروف... نستغل التقنيه بالتوفير والصحه"

"... we demand the ministry to transform education to be online for the health and safety of students, and because technology serves us at home, there is no need for fatigue and expenses ... we use technology to save money and health."

New Economic Opportunities

The next governance parameter is **New Economic Opportunities**. It is represented by the keywords from Topic 8 such as PowerPoint, Design, Services, Private, Research, Communication, Assignments, Work, Presentations, and Solution. **Figure 8** plots the top 30 most relevant keywords for Topic 8. This governance parameter reflects the new opportunities that have become available during COVID-19. Among the new economic opportunities, a variety of educational services for students, instructors, and other stakeholders are available. Individuals and small businesses offer these services by providing tuition and other services to help students with research papers, solving assignments and exams, designing logos

and photos, developing interactive maps and portfolios, and creating CVs and PowerPoint presentations. A number of other services were also made available to the other stakeholders such as teachers, parents, and management staff for the purpose of facilitating the transition to online learning. An example tweet is given below.

> "... لدينا... حل واجبات، بحوث، تقارير، بوربوينت، خرائط تفاعليه، وحقائب تفاعليه، وغيره الكثير للتواصل واتس... "

"...we provide ... solving assignments, research, reports, PowerPoint, interactive maps, interactive portfolios, and many more. Contact us on WhatsApp [number]" (Dec 7, 2021).

Figure 9 depicts the intensity of tweets for the macro-parameter **Socioeconomic Sustainability**. For the parameter New Economic Opportunities (see chocolate color), the intensity of the tweets shows a continuous increase over time.

Accountability and Transparency

Now we discuss the governance parameters that are associated with the fourth macro-parameter Accountability and Transparency. It involves the tweets and clusters that are related to the evaluation or accountability of in-class and online learning. It includes two parameters.

PIRLS

The first parameter (the thirteenth overall) is **PIRLS**. The Progress in International Reading Literacy Study tests (PIRLS) are designed by the International Education Agency to evaluate the reading and comprehension skills of students (fourth grade) and to compare the results with those of other countries. This parameter shows the government's efforts to improve the teaching and learning process in the country. The exams were
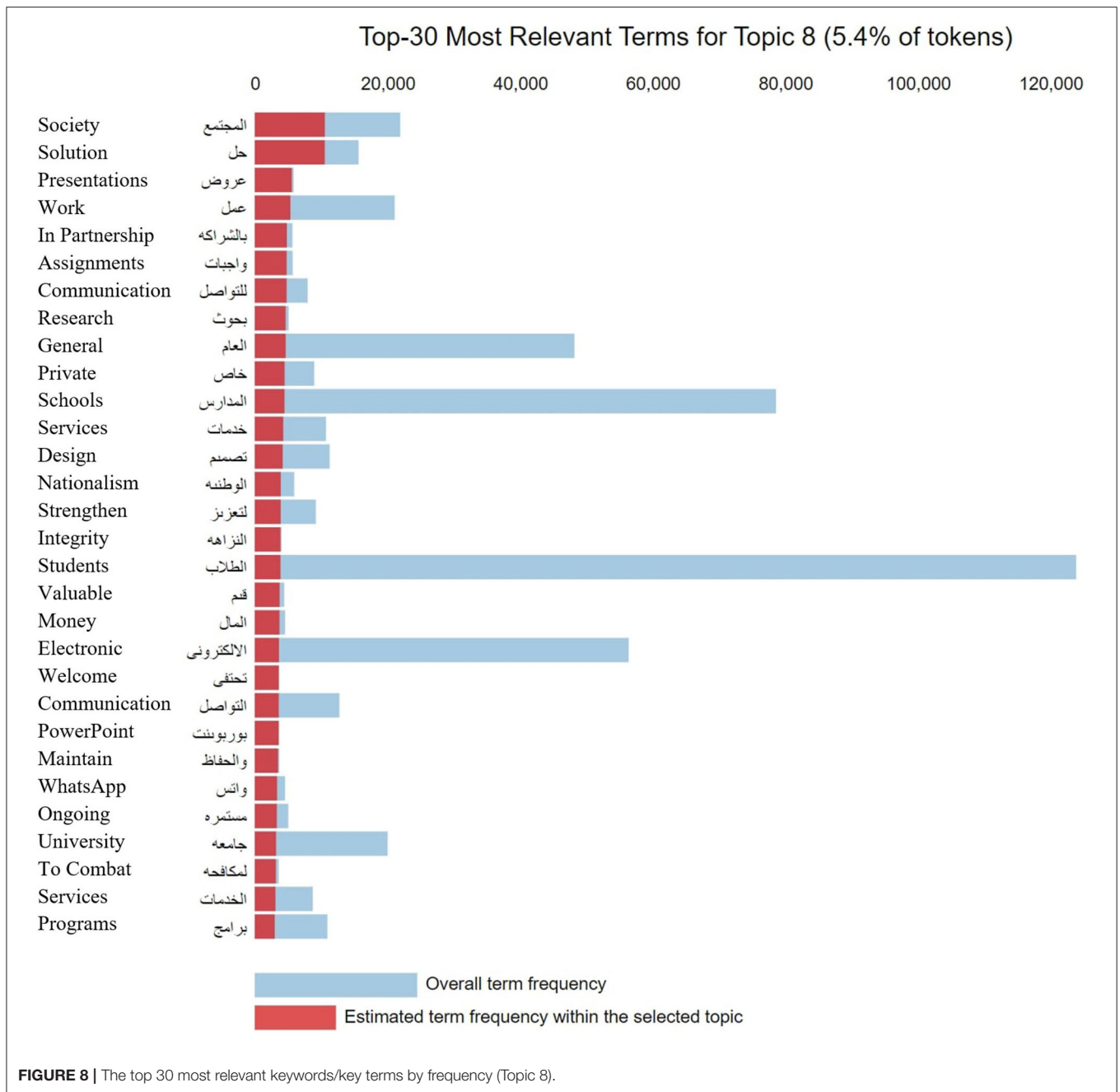
FIGURE 8 | The top 30 most relevant keywords/key terms by frequency (Topic 8).

conducted during the period 8–10 November 2021, through the "Madrasati" platform. The tweets provide information about the PIRLS tests such as their objectives, importance, the dates of the exam, and the family role in motivating children to participate in the exam. For example, the following tweet was posted by the Ministry of Education on 7 November 2021, and it was retweeted by schools, teachers, and other stakeholders.

"#نائب-وزير-التعليم . . . يلتقي عن بُعد بمديري التعليم؛ للاطلاع على استعدادات المدارس لــ #اختبارات PIRLS التي تبدأ غداً، بمشاركة 7 آلاف طالب وطالبة يمثلون الوطن،

وينوّه بجهود الأسر وأولياء الأمور في تحفيز أبنائهم والمعلمين والمعلمات في تهيئة طلابهم نفسياً ومعرفياً."

"#Deputy_Minister_of_Education ... meets remotely with education directors; To see the schools' preparations for the #PIRLS_exams that start tomorrow, with the participation of 7,000 students representing the country, and he notes the efforts of families and parents in motivating their children and teachers in preparing their students psychologically and cognitively."

International Collaborations

The last governance parameter is **International Collaborations**. We mentioned earlier that the parameters can be seen, for
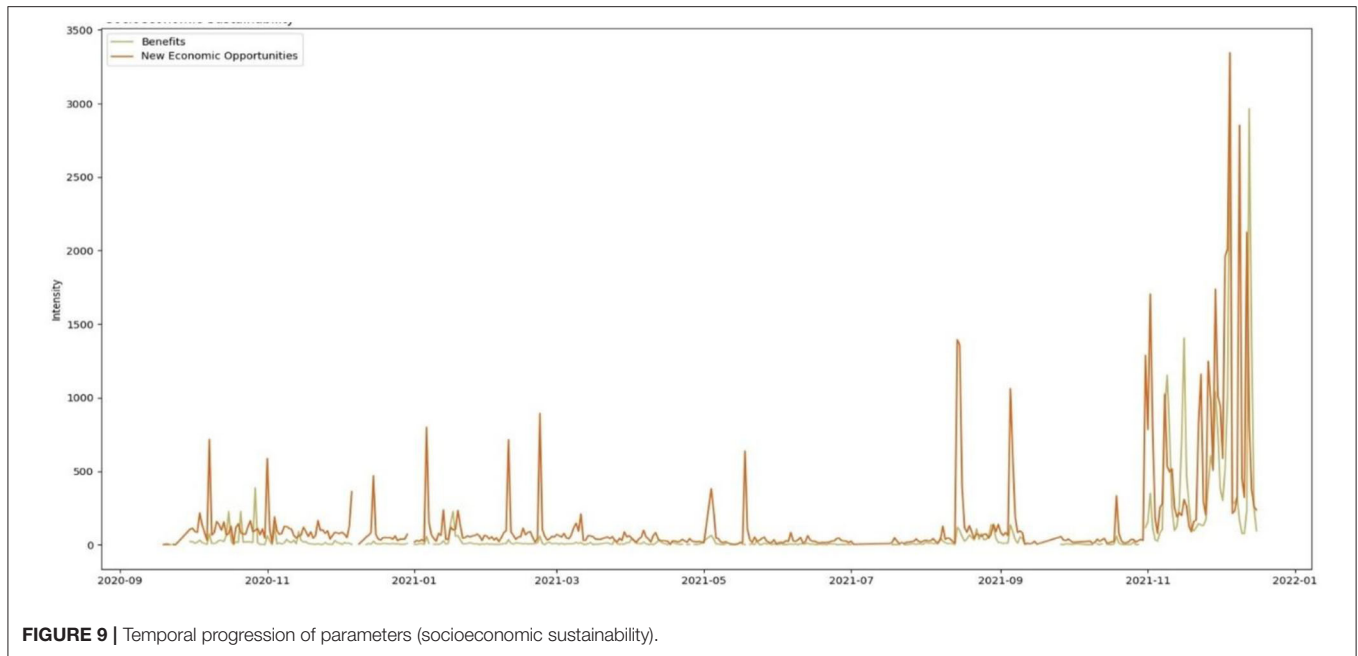
FIGURE 9 | Temporal progression of parameters (socioeconomic sustainability).

example, in the context of what was detected in relation to the practices or actions of the Saudi government or as a general parameter that is required by governments or institutions to create successful governance policies, instruments, and outcomes. Discussing in the context of the detected actions, this governance parameter relates to the international collaboration in education as well as the evaluation and commendation of the online learning programs in Saudi Arabia. This international cooperation aims to build a more flexible, sustainable, and inclusive education system. The cooperation also aims to build and implement better digital strategies for education, achieve sustainable development goals for education, and bridge the gaps between different educational systems. The government signed various cooperation agreements and executive programs in the field of higher education and scientific research with a number of countries, including Japan. This reflects the government's keenness to strengthen the relationship with the various international and regional organizations related to education through the National Committee for Education, Culture and Science. These cooperation activities involved international visits of some Education ministers. For example, the following tweet was posted on 30 November 2021 by a news account.

"سيكون هناك تعاون بين وزارة التعليم SA وزارة التعليم اليابانية JP في مجال الثقافة، الرياضة، التقنية"

"There will be cooperation between the Saudi Ministry of Education (SA) and the Japanese Ministry of Education (JP) in the field of Culture, Sports, and Technical"

Effective collaborations between organizations and governments naturally help improve transparency, processes, and outcomes. Moreover, the Saudi educational programs were evaluated by six international organizations in two different studies (Saudi National eLearning Center (NELC), 2020). Education experts in international organizations [e.g., the Organization of the E-Learning Consortium (OLC), UNESCO, and others] have applauded the success of the distance education experience in the Kingdom for the comprehensive, diverse, and equitable access to distance learning opportunities and resources available to the students, teachers, and other stakeholders [free access to learning contents and lectures through Internet and Satellite TV Channels, access to numerous digital platforms (e.g., Madrasati platform), and exceptional and sufficient support to provide stakeholders with the required skills, among others and the speed of response in ensuring a successful transition to online learning. Furthermore, recently Saudi education received three international awards from the Microsoft Global Experience Exchange Conference 2022, which was held in the United States (Ministry of Education, 2022b). The tweets related to this governance parameter included reports about the results of learning evaluation studies as well as responses from the public and institutions. For example, a newspaper in Makkah posted the following tweet on 7 May 2021.

"خبراء تعليم في منظمات دولية يشيدون بنجاح تجربة المملكة في التعليم عن بعد"
https://t.co/2sQz0yw9Ug

"Education experts in international organizations praise the success of the Kingdom's experience in distance education"

Figure 10 depicts the tweets' intensity for the macro-parameter **Accountability and Transparency.** The parameter PIRLS, which is represented in medium purple color has some peaks and the highest peak is on 8 November 2021, which is the day when the exam was conducted for students. The line plot for the International Collaborations parameter is displayed in slate
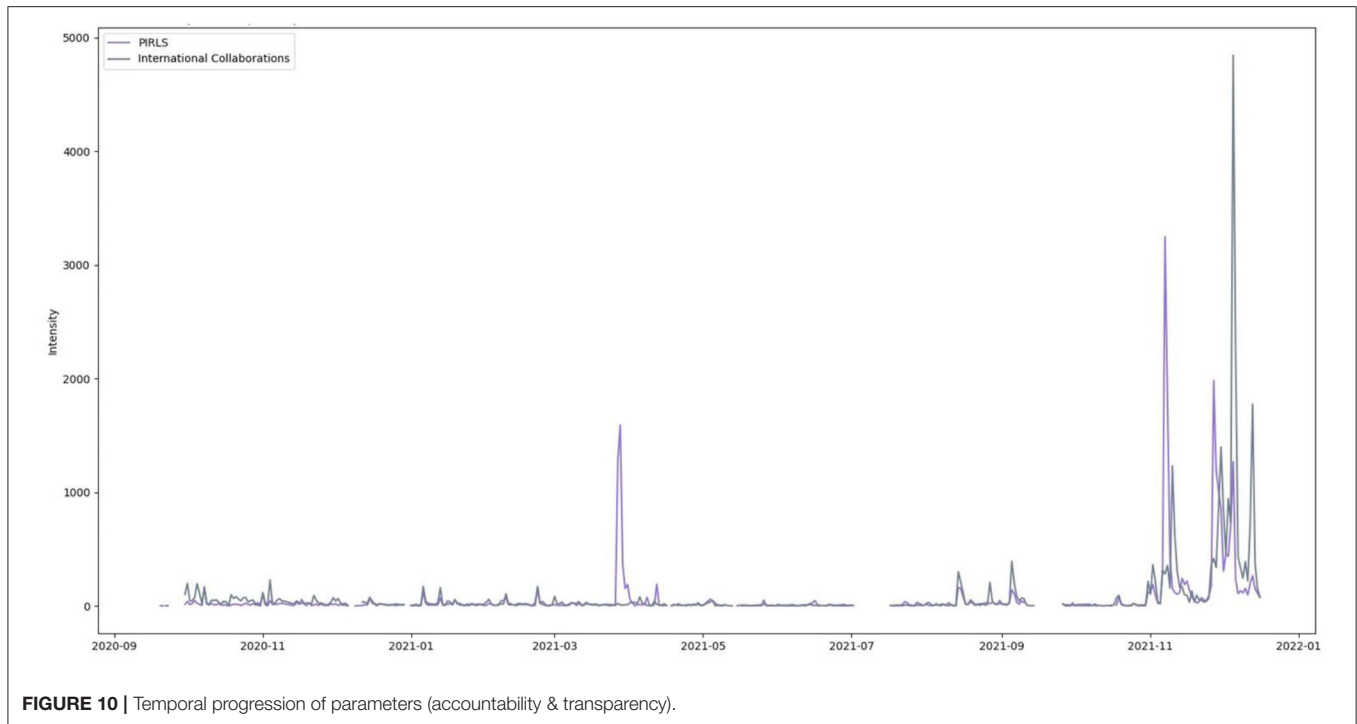
FIGURE 10 | Temporal progression of parameters (accountability & transparency).

gray color. Note in the figure that there is a peak in December 2021. Our tool detected that there was an international visit for collaboration in education on 5 December 2021.

DISCUSSION

We provided a case study on sustainable participatory governance using a data-driven parameter discovery approach for planning online, in-class, and blended learning in Saudi Arabia evidenced during the COVID-19 pandemic. The data-driven parameter discovery approach we propose is generic and can be applied to the governance of any sector. The specific case study is used to elaborate on the proposed approach. We discovered fourteen governance parameters grouped into four governance macro-parameters. The first macro-parameter Success Factors includes the governance parameters that have enabled the continuation and effectiveness of teaching and learning during pandemic times. The success factors included effective implementation of pandemic measures to control the potential increase in infection rates due to in-class learning, activities to increase awareness about the importance of education and to motivate everyone to continue and excel in education during the pandemic, supporting online and hybrid learning through training, praising, and championing teachers and others, high-speed internet access, effective digital learning services and platforms, and positive behavior nurturing such as honesty and community care. To elaborate, for example, the government developed strategies for improving educational outcomes by providing support to students, teachers, families, and other stakeholders. Training courses were provided to equip teachers, students, and other stakeholders with the essential skills

to access and use the digital teaching and learning platforms. The Ministry of Education had launched several learning resources including providing free access to lectures through Satellite TV (e.g., Ain Educational Channel) and YouTube. The government's decision to return to in-class learning in physical learning spaces was accompanied by various precautionary measures to ensure the health and safety of students, teachers, and others. For instance, anyone who did not take the required COVID-19 vaccine doses was prohibited from entering the physical learning spaces.

The macro-parameter Challenges embodies issues that have been challenging for people to adopt as well as the government's strategies to help manage the difficulties people have faced. These include the changes in the Saudi education systems developed to improve teaching and learning in the country, the government's decision to shift in-class learning to online learning (in the early days of the pandemic, early 2020) and *vice versa* (since August 2021), the changes in the specific procedures of exams during the pandemic, and the difficulties and benefits of morning and afternoon school schedules. The third macro-parameter Socioeconomic Sustainability has detected and captured social and economic benefits of the transitions in teaching and learning during (and necessitated by) the pandemic. It was experienced that online learning allows operational efficiencies, allows better accessibility to learn across urban and rural geographies and different social classes, and provided new economic opportunities for people. The fourth macro-parameter Accountability and Transparency includes government activities related to the transparency, international collaboration, and evaluation of educational policies, systems, and practices in Saudi Arabia. These aspects of learning were experienced by tweets

on activities such as international visits by foreign education officials, engagement of Saudi students in PIRLS tests through digital platforms, and evaluation of online learning in Saudi Arabia by international organizations. The Parameter analysis and findings section provides a detailed discussion of these issues along with supporting references and tweets.

This study makes important and significant theoretical and practical contributions to the literature. First, we proposed a novel data-driven parameter discovery approach for governance applicable to any sector, with a case study in education governance to elaborate on the proposed approach. A theoretical framework for data-driven participatory education governance was developed and provided in this literature. The contribution of our study to theory is that it provides a framework in which data-driven governance can be developed for any sector. It identifies actors, data sources, and objectives and provides a pathway (comprising machine-learning-based analytics, governance parameter discovery, and improvements in relation to established good governance parameters) to develop better governance parameters and apparatuses. This whole process could be a perpetual loop for real-time or dynamic governance with much finer levels of engagement with the public and other stakeholders.

Second, our research provides novel practical contributions. We developed a complete case study and software for the data-driven discovery of parameters from social media (Twitter) data for planning and governance of learning during COVID-19. The practical contributions that we provide in the present study are novel and completely different from any of the other literature because it attempts to comprehensively grasp and discover governance parameters related to the education sector from Twitter data using unsupervised machine learning. Moreover, the findings of our study (specific parameters, experiences, opinions of people, etc.) provide specific insights into education governance, particularly in a time of disruption (the COVID-19 pandemic).

Third, the research provides evidence to support the general literature on data-driven smart cities research and reinforces that policy and action on smart cities should be supported with data (Liu et al., 2017; Yigitcanlar et al., 2020; Bibri, 2021a) and that social and digital media provides a convenient and important source of such data (Alomari et al., 2021b). The parameters detected by the system clearly show the possibility and benefits of our tool, allowing the discovery and grasp of important dimensions of the education sector in Saudi Arabia, the complexity of the policy, procedural and practical issues in continuing learning during the pandemic, the factors that have contributed to the success of learning during the pandemic times, both its transition to online learning and back to in-class learning, the challenges public and government have faced related to learning during the pandemic times, and the new opportunities for social, economic, and environmental benefits that can be drawn out of the situation created by the pandemic. The parameters and information learned through the tool can allow governments to have a participatory approach toward governance and improve their policies, procedures, and practices perpetually through stakeholder feedback. Earlier studies on

data-driven smart cities have discussed the benefits of data-driven approaches in smart city design and operations; however, none of the earlier studies have proposed a theoretical framework to develop data-driven governance similar to ours and practical contributions to how data-driven governance can be built into existing systems. Moreover, none of the existing bodies of literature have provided a theoretical framework and practical system prototype for education governance. Our research, therefore, advances the existing theory and practice on data-driven smart cities.

Certainly, many more efforts are needed by the community to advance what we have proposed here in both the theory and the practice. First, the proposed approach, both its theory and practice, needs to be investigated further. For example, there is a need to understand the type of data sources that can be used for the governance parameter discovery process. What is the relationship between the type of data sources and the discovered parameters? What different analytics methods can be used to discover parameters. What is the relationship and the effect of these discovered parameters with actual governance? What policy and practice apparatuses can be developed from this parameter discovery and improvement processes. While new theories need to be developed for data-driven policy and action development, there is also a need to look at how these new developments and theories contribute to the existing theories of governance and education, theories such as system theory, constructivism, postmodernism, and critical theory. Moreover, further research is needed to improve the proposed framework to establish deeper comprehension of the practical work on data-driven policy and action.

We evaluated the Saudi government's performance in planning and governance of education in the country during the pandemic against well-known good governance international standards (ESCAP, 2009) and evidenced high achievements in terms of its participatory approach (Ministry of Education, 2020), speed of responsiveness (Algaissi et al., 2020; Hassounah et al., 2020), transparency (Saudi National eLearning Center (NELC), 2020), accountability, inclusivity, equity, and social sustainability (Saudi Ministry of Education, 2020b). This could be seen in the outcomes, e.g., low infection rates and deaths (Worldometer, 2022), sustained attendance and performance in schools (Official Twitter Account of Saudi Press Agency, 2022; Saudi Press Agency, 2022), collaborations and commendations from international institutions for effective education delivery in Saudi Arabia during the pandemic (Saudi National eLearning Center (NELC), 2020; Reimers and Opertti, 2021; Saudi Press Agency, 2021), etc. As we have discussed in the Parameter analysis and findings section in detail, the government provided all the citizens access to online learning through free TV lectures (Ministry of Education, 2022a; Saudi Ministry of Education, 2022) and other incentives such as financial subsidies for internet access (Saudi Ministry of Education, 2020a) to maintain equity and social sustainability. The government designed several initiatives and programs to nurture responsibility, honesty, and positive behavior among students (Madrastati, 2020; Saudi Ministry of Education, 2020c, 2021b). The government also made efforts to create understanding, empathy, compassion,

appreciation, and harmony among teachers, families, and other stakeholders (Saudi Ministry of Education, 2020b). No issues were discovered from the Twitter data by our software concerning the lack of equity in the provision of access to online educational resources, lack of food, security, or other basic needs of people. The provision of free COVID-19 treatment and vaccination allowed people to focus on education without worrying about food, healthcare, and vaccinations (Unified National Platform GOV.SA, 2022).

The government implemented effective pandemic measures that allowed successful transitions between online and in-class learning (Saudi National eLearning Center (NELC), 2020) without affecting the educational goals while keeping people safe through physical distancing and other pandemic measures (Alomari et al., 2021a). Saudi Arabia was ranked number 6 in the world in March 2022 in "Covid Resilience" by Bloomberg (Lew et al., 2022) (earlier it was ranked number 3 in the world). They considered, in this ranking, various factors related to "Reopening Progress," "Covid Status," and "Quality of Life". For evaluating the overall Saudi management of the COVID-19 pandemic that helped with the transitions between online and in-class learning, we also considered the Eurasia Group's methodology for evaluating and ranking international pandemic responses; the methodology focused on three key dimensions: healthcare management, financial policy response, and political response (Bremmer, 2020; Alam et al., 2021). The Saudi government has acted well in all these three areas (see, for example, Alomari et al., 2021a). The government was efficient and effective in healthcare management during the pandemic (Leaders Mena Magazine, 2020; AlFattani et al., 2021). For example, the government implemented quick measures to contain and control the spread of the virus (e.g., quarantines, physical distancing, etc.), provided free treatment to all citizens, residents, and even to the residents who violated the regulations of residency (Ministry of Health, 2020; Saudi Press Agency, 2020), and launched a range of telehealth applications to suit different public segments (Algaissi et al., 2020; Alghamdi et al., 2020; Hassounah et al., 2020). Saudi government acted well in maintaining physical distancing in daily life (Alomari et al., 2021a) as well as a successful Hajj season that involves a large gathering of people with zero COVID-19 cases in 2021 (El-Ziq, 2021; Saudi Gazette, 2021). There was sufficient availability of and operational access to the COVID-19 vaccines in the country (Bell, 2021). The government provided various financial initiatives and incentives to support businesses during the COVID-19 pandemic in order to mitigate the negative financial and economic impacts of the pandemic (Saudi Ministry of Investment, 2020). For example, a financial incentive of nine billion Saudi riyals was provided to the private sector employees in the country to contribute toward 60% of their salaries by the government (Saudi Ministry of Finance, 2020; WAS Saudi Press Agency, 2020). Another financial package of 6 billion Saudi riyals was provided to allow delaying mortgage payments and rescheduling loans (Saudi Ministry of Investment, 2020). Moreover, the government had allocated a sum of 47 billion riyals to the healthcare sector to improve the sector's readiness (Saudi Ministry of Investment, 2020).

The benefits and limitations of social and digital media-based research and practice have been a subject of much discussions such as data ownership (Montgomery, 2017), difficulty in enforcing ethical compliance (Sparks et al., 2016), people's safety (Huang et al., 2016; Facca et al., 2020), privacy (Al-Dhubhani et al., 2018; Editorial, 2020), security (Terzi et al., 2016; Carter, 2019), and more. However, non-digital methods for policy and action research are too limited, slow, and practical. Alam et al. (2021) provide in their study a concise summary of the limitations and solutions of digital data in research and the references therein for further details. There are rising and important concerns related to green, explainable, AI (Yigitcanlar et al., 2021b), and responsible innovation (Yigitcanlar et al., 2021a), and these must be addressed should we expect to reap the benefits of data-driven (sustainable) smartization. Continued research and awareness of the limitations of digital, data-driven, and AI methods will lead to improvements in methods and reduction of risks and we will continue on this mission in the future.

CONCLUSIONS AND FUTURE WORK

We live in a complex world comprising many complex systems. New approaches to governance are needed to tackle the global challenges. Smartization could deliver a sustainable future for us due to its underpinning of data-driven analytics-based policy and action for social, environmental, and economic sustainability. This study sought to provide a case study on sustainable participatory governance using a data-driven discovery of parameters for planning physical and digital learning in Saudi Arabia during the ongoing pandemic. We developed a software tool comprising a complete machine learning pipeline and used a dataset comprising around 2 million tweets collected from October 2020 to December 2021 and discovered fourteen governance parameters grouped into four governance macro-parameters.

The results clearly demonstrated the possibility and benefits of our sustainable participatory planning and governance approach, allowing the discovery and grasp of important dimensions of the education sector in Saudi Arabia; the complexity of the domain, stakeholders, and decision making; and the challenges and opportunities offered by the evolving national and international landscape. The tool allows governments to have a participatory approach toward governance and improve policy and actions perpetually through feedback from all parties.

We have built significant capacity in data-driven urban computing research such as our research on improving machine learning-based methods, and application of these methods, and the use of emerging technologies in smart societies and several urban sectors (Mehmood et al., 2017b, 2020; for example, see Alam et al., 2017; Alyahya et al., 2020; Arfat et al., 2020; Ahmad et al., 2022; Alahmari et al., 2022; Janbi et al., 2022). We will continue to build this capacity further with our mission of contributing to the international efforts on developing smarter sustainable societies.

DATA AVAILABILITY STATEMENT

AUTHOR CONTRIBUTIONS

SA and RM conceived, developed, analyzed, and validated the study. SA developed the software. SA and RM prepared the initial draft, and RM and IK reviewed and edited it. RM and IK supervised funds and resources and contributed to the article editing. All authors contributed to the article and approved the submitted version.

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