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Simulation Model for Face-to-Face and Distance Education Options Post-COVID-19

Modelo de simulación para las alternativas educativas presencia-distancia pos-COVID-19

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Abstract

This study aimed to simulate school dropout in preschool, basic, and upper secondary education in Colombia following the COVID-19 pandemic, based on face-to-face and distance education scenarios. A two-stage methodological approach was employed, consisting of a meta-analysis of 25 articles (2020-2022) and a simulation of scenarios using system dynamics. "Teachers" and "curriculum matrix," which were part of the academic determinant, were found to be the most relevant variables. The model showed that dropout is highly sensitive to the percentage of virtual education, with over one million students dropping out in 100% virtual scenarios. By contrast, dropout was not sensitive to an increase in teacher training hours within the limits set by education policy. We conclude that virtual education calls for comprehensive measures that go beyond teacher training and ensure minimum technological conditions to prevent school dropout.

Keywords: simulation model, dropping out, basic education, distance education

Resumen

Este estudio tuvo como objetivo simular el comportamiento de la deserción escolar en los niveles de preescolar, básica y media en Colombia tras la pandemia de COVID-19, considerando alternativas educativas entre presencialidad y virtualidad. Se aplicó una metodología en dos fases: metanálisis de 25 artículos (2020–2022) y simulación de escenarios con Dinámica de Sistemas. Los resultados muestran que las variables más relevantes son "docentes" y "matriz curricular", pertenecientes al determinante académico. El modelo reveló que la deserción es altamente sensible al porcentaje de virtualidad, alcanzando más de un millón de estudiantes desertores en escenarios de 100% virtualidad. En contraste, la deserción no fue sensible al aumento de horas de capacitación docente dentro de los márgenes establecidos por las políticas educativas. Se concluye que la virtualidad exige acciones integrales que superen la capacitación docente y garanticen condiciones tecnológicas mínimas para prevenir el abandono escolar.

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Palabras clave: modelo de simulación, deserción escolar, educación básica, educación a distancia

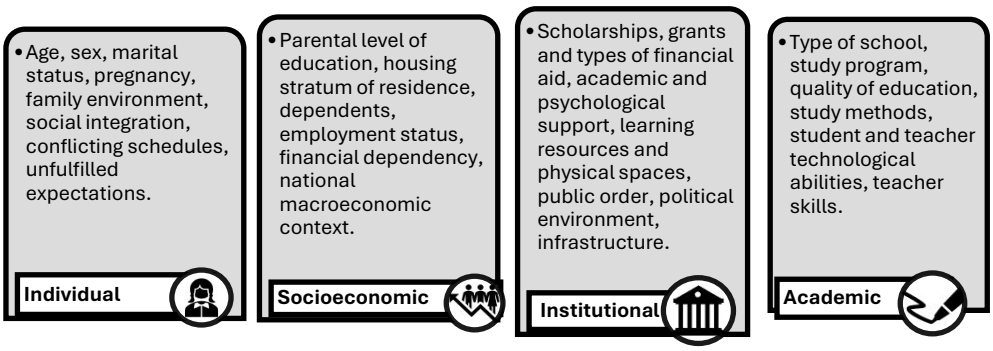
I. Introduction

The United Nations (2020) has reported that the COVID-19 pandemic affected 1.6 billion students from 190 countries: "Closures of schools and other learning spaces have impacted 94 per cent of the world's student population, up to 99 percent in low and lower-middle income countries" (UN, 2020, p. 2). The World Bank (2021) has indicated that the short-term challenge is to reopen schools with the appropriate health and safety measures and ensure student retention, while stressing that girls are at greater risk of school dropout. The UN and World Bank agree that in the long term, the challenge is to reverse learning losses (World Bank, 2021; UN, 2020), taken to mean a decline in average overall learning; countries responded to the crisis differently and faced massive school dropout (Iqbal et al., 2020).

School dropout behaves like a dynamically complex system (Barragán, 2015) that should be frequently monitored to strengthen school retention plans. This monitoring, which was already important prior to the pandemic, gained new significance during and after the COVID-19 lockdowns. Explanatory variables can be monitored by adapting Tinto's (1993) model, accepted by Colombia's Ministry of National Education (MEN) to diagnose, address, and monitor dropout in higher education as a consequence of the interaction between students and institutions. Diagnostic and analytical reports on school dropout show that the explanatory variables most frequently used to compare determinants of dropout, across different approaches, are those outlined by Tinto in early work in 1975 (Ministry of National Education, 2009).

Tinto's (1993) integration model categorizes variables into determinants that are endogenous to the education system (academic and institutional determinants) or exogenous (individual and personal determinants); it is therefore useful to apply this model to school dropout by grouping the explanatory variables (see Figure 1) as appropriate for the relevant levels of education and ages. For clarity, and in light of the differences between countries, in the Colombian education system early childhood education is between the ages of 0 and 5 years; primary education is for children from 6 to 10 years of age; lower secondary education is from 11 to 14 years of age; and upper secondary (known as *educación media*) is for 15 and 16-year-olds.

Figure 1. Determinants and explanatory variables of school dropout



Note: Adapted from Tinto (1993).

As Barragán-Moreno and Lozano-Galindo (2022) have noted, Tinto's (1993) model makes it possible to identify and monitor at least 44 direct and indirect variables that affect student retention and school dropout at pre-higher education levels, to varying degrees depending

on student age. For example, the parenthood variable is weighted 0 at young ages, but more heavily in adolescence.

The most predictable explanatory variables of school dropout during lockdowns include those in the socioeconomic determinant, given the challenges of the economic downturn and the preexisting economic vulnerability that exacerbated significant differences in the ability to cope with isolation (World Bank, 2021), in addition to child marriage, teenage pregnancy, and gender-based violence, which affect girls and young women (UN, 2020). Meanwhile, Ramírez and Hernández (2021) highlighted how the mandatory use of online learning for preschoolers demonstrated inequalities in access to this form of education, with preschool serving as the foundation for socioemotional and intellectual development through face-to-face interaction. It is against this backdrop that the following guiding research questions were formulated.

RQ1: What are the main explanatory variables of school dropout in preschool, basic, and upper secondary education in Colombia during the COVID-19 lockdown?

RQ2: What is the long-term behavior of the variables under the different education options – lying on a continuum between face-to-face and distance learning – for reducing school dropout in preschool, basic, and upper secondary education in Colombia, in the aftermath of COVID-19?

This article aimed to simulate the behavior of school dropout in preschool, basic, and upper secondary education in Colombia in the aftermath of COVID-19, based on the degree of online instruction under various alternatives on a continuum between face-to-face and distance learning.

1.1 Emergency changes, responses, and options

García (2021) has noted that the pandemic forced a drastic change in the provision of education services due to the mandatory closure of facilities. Governments found themselves compelled to turn to digital distance learning, using available information technologies, to prevent interruptions in education. This resulted in distinct responses both between and within countries due to limitations in technological infrastructure and planning within education systems (Herrera, 2021), coupled with the challenge of preparing teachers and students required to deliver and receive a "digital distance education" or "remote emergency education" that emerged as a solution to address the need for educational continuity, maintaining physical distance and enabling synchronous and asynchronous interaction.

One response to the change was to adjust the student-teacher ratio to monitor student progress, adapting in-person activities to the virtual classroom. This demanded a change in teaching and learning methods, with proposals for flexible teaching approaches adapted to the health and safety measures, student group sizes and readiness, and teacher readiness and attitudes. Teachers were quick to incorporate information and communication technology (ICT) and learning and knowledge technologies (LKTs) (Latorre et al., 2018) to support their work. In response to uncertainty about an unknown virus and the potential emergence of other viruses, schools underwent a transition from face-to-face learning ("normal" conditions) to hybrid learning (with some students attending in person, and others remotely with digital support), with a fully remote option.

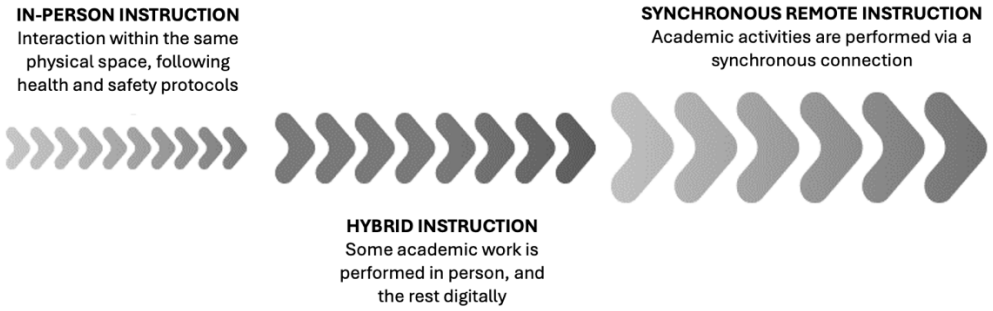
Distance education has been recommended in higher education and has posed challenges for curricular adaptation and for evaluation in these new environments. In higher education, a lack of student and teacher readiness became clear and revealed huge differences in

access to hardware, software, and connectivity, coupled with a poor ability to use educational platforms despite the users being digital natives (Díaz Barriga & Barrón, 2022; Guevara, 2021). These differences were shown more acutely in a georeferenced analysis of external test results, which found better outcomes in areas with better infrastructure and connectivity (cities), as opposed to more remote locations away from urban areas (Arias-Velandia et al., 2021).

Distance education is scarcely recommended in preschool, basic, and upper secondary education, where teacher-student and student-student relationships are key to furthering the education process, as it is through these relationships that affective and emotional bonds are developed that influence knowledge appropriation. Health and safety protocols and lessons learned made it necessary to consider flexible learning scenarios during lockdown and post-lockdown periods to reduce school dropout, maintain levels of quality, and mitigate the effect of economic or geographic variables or any other circumstance that may impede access to official education (Barragán-Moreno & Lozano-Galindo, 2022; García, 2021).

Figure 2 illustrates the range of options that were implemented, or which could be implemented, as ways to adapt the teaching-learning process and pedagogical approaches, in line with learning outcomes, the pedagogical model, and the school's education plan. These alternatives depend on the contexts in which teaching practices take place, the availability of technological resources, and teachers' and students' technological skills and abilities, to limit the likelihood of reproducing the current disparities in education and dropout (Herrera, 2021).

Figure 2. Range of education options from in-person to synchronous remote instruction



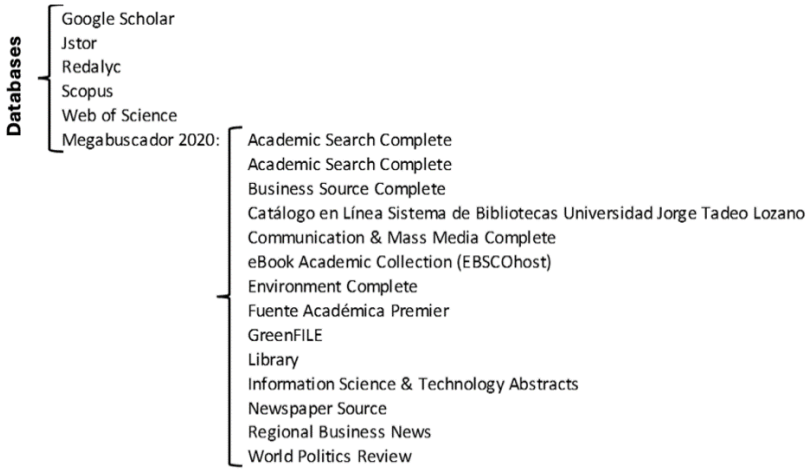
Note: Adapted from García (2021).

II. Method

The methodology consisted of two phases, which were carried out consecutively:

Phase 1: Meta-analysis. Analysis of 21 research articles published in 2020-2021, retrieved by searching 19 databases (see Figure 3), with 24 specific search strings related to student persistence and dropout. The sample of articles was obtained after identifying, selecting, screening, and excluding related documents, as per the PRISMA 2020 guidelines (Page et al., 2021).

Figure 3. Research databases searched



Phase 2: Scenario modeling and simulation. For this phase of the research, a systemic approach was employed given the complex nature of the basic education system in Colombia, which comprises multiple stakeholders and countless interactions that can be distilled into two subsystems: educational demand and supply. It is the interaction between these two subsystems that determines the behavior of the education system as a whole.

In this phase, it is very important to view the feedback and effects that arise from the changes in the key variables in the system over time (see Appendix I). There is therefore a need to present the results of the system's performance when social interventions (simulations) are performed, which can be designed and implemented with the support of computer tools, based on the historical context and future projections of the impacts of public education policy measures on the system (Bianchi & Salazar, 2020; Senge, 2010; Williams & Hummelbrunner, 2011). For this, we described the behavior using a causal loop diagram, in order to identify the hypotheses and roles played by the various elements in the subsystems.

The causal loop diagram shows both the system's reference mode and the dynamic hypotheses and feedback structure. The interactions between the system's variables are represented by arrows marked with positive or negative signs. A positive sign indicates a positive relationship between the variables (when one increases, the other also increases), while a negative sign indicates an inverse relationship (when one variable increases, the other decreases) (Bala et al., 2017). Lastly, a stock-and-flow model was used as a system dynamics simulation model, combining modeling as a scientific practice, modeling as model progression, and the instrumental dimension of modeling (Oliva, 2019).

In line with the model progression approach, the model designed by Serna and Flores (2015) to study educational policies in Peru was employed as a starting point. For the model progression, we included variables that were found in phase 1 to be related to the teacher's role, the percentage of online instruction in the various educational modalities available following the COVID-19 lockdown, and the effects of the variables in the individual, institutional, and socioeconomic determinants, with the aim of leveraging the similarities between the Peruvian model and the dynamics of dropout in Colombia within this new context. Similarly, studies were included that reported multiple factors in the causes of dropout, such as COVID-19 infection, a rural education model ill-prepared for remote education, a lack of continuity in the inclusion processes of migrant students, and inequality

in terms of technology access and availability to educate the population, both in Colombia and across Latin America (Mauris & Domínguez, 2022; Pérez, 2022; Rodríguez-Lizarralde et al., 2022; Sañudo, 2022). Then, as a scientific practice, the model was parameterized both to validate its operability and to perform simulations; this was done with data on preschool, basic, and upper secondary education in Colombia available in public databases. The simulation recorded behavior in three scenarios, revealing the effect on student dropout of different alternatives falling between in-person and fully remote instruction (Figure 2).

III. Results

The phases of research described above identified variables that were incorporated into the model and yielded results from the system dynamics model.

3.1 Variables that explain dropout

Initially, our systematic review located 77,700 records in the 19 databases, with 24 specific search strings related to student persistence and dropout. Of these, 75,809 records were eliminated as duplicates, leaving 1,891 for screening in the title and abstract to determine eligibility for processing with Atlas.ti. A sample of 25 research articles published between January 2020 and December 2022 was included in the qualitative synthesis of the review (Figure 4).

Figure 4. Sample of research articles

2020		2021		2022	
Educación inclusiva en contexto: reflexiones sobre la implementación del Decreto 1421 de 2017	Díaz, A., Bravo, C., y Sierra, G.	Uso de las Tecnologías de Información y Comunicación como Valor Pedagógico en Tiempo de Crisis	Avendaño, W., Hernández, C., y Prada, R.	A feedback view of behavioural distortions from perceived public service gaps at 'street-level' policy implementation: The case of unintended outcomes in public schools	Bianchi, C., & Salazar, R
Universalización de la educación media de calidad: el reto sigue para llegar a ser "Colombia la mejor educada"	García, S., & Maldonado, D.	Diferencia de logro geolocalizado en educación presencial y a distancia en Colombia	Arias-Velandia, N., Rincón-Báez, W. U. y Cruz-Pulido, J. M.		
We should avoid flattening the curve in education – Possible scenarios for learning loss during the school lockdowns	Iqbal, S., Azevedo, J., Geven, k., Hasan, A., & Patrinos, H.	Desafíos del currículo en tiempo de pandemia: innovación disruptiva y tecnologías para la inclusión y justicia social	Díaz Barriga, F. y Barrón, M. C.	Los Efectos De La Crisis Sanitaria Del Covid-19 En La Educación Rural De Colombia	Mauris, L., y Domínguez, B.
		School reorganization reforms: the case of multi-site schools in Colombia.	Elacqua, G., Sánchez, F., & Santos, H.		
Educación Rural y Dispositivo Evaluación en Tiempos de COVID-19: Voces de Profesores de Matemática	Martínez, D., Serna, J., y Arrubla, J.	Estudio del Sector Educativo Colombiano	Findeter	Educación, Desigualdad Sociodigital en Pandemia	Pérez, A
		COVID-19 y educación a distancia digital: preconfinamiento, confinamiento y posconfinamiento	García, L.	Inclusión educativa en pandemia: interseccionalidad y situación de menores venezolanos en Bogotá	Rodríguez-Lizarralde, C., López-Villamil. S., y Barrera-García, A.
Understanding Latin America´s Educational Orientations: Evidence from 14 Nations	Osiobe, E.	El modelo de la alternancia y la desigualdad educativa territorial en la educación en Colombia	Herrera, D.		
Un Marco para Guiar una Respuesta Educativa a la Pandemia del COVID-19	Reimers, F., y Schleicher A.	Las Organizaciones de la sociedad civil en época de pandemia. Reflexiones hacia una nueva normalidad: ¿Nuevos desafíos o mismas realidades?	Maroscia, C., y Ruiz, P.	Del abandono a la permanencia escolar en secundaria	Sañudo Guerra, L.
Pruebas de Evaluación Saber Y PISA en la Educación Obligatoria de Colombia	Sanabria, L., Pérez, M., y Riascos, L.	Una Mirada a la Educación Preescolar desde la Diversidad en Pandemia Covid-19 y sus Afectaciones.	Ramírez, G., y Hernández, S.		
Efectos de las tecnologías de la información y las comunicaciones en la educación en Colombia	Sánchez, P., Saavedra, C., & Figueroa, C.	Perspectivas actitudinales de docentes en ejercicio y en formación hacia la educación inclusiva	Rodríguez, A., Gallego, J., Navarro, A., y Caurcel, M.		
Policy Brief:Education during COVID-19 and beyond	United Nations	Global Economic Prospects	World Bank		

Most of the variables identified in articles that made mention of the meaning, value, or effect of a specific variable fell under the academic determinant (57.14%), followed by the institutional (28.57%), socioeconomic (9.52%), and lastly, individual (4.76%) determinants.

Research on the academic determinant has identified "teachers" as the most important variable in explaining dropout. Findings have shown that "teachers" are viewed as individuals who engage and provide tools to students to support them in their learning process and

facilitate new relationships between students, teachers, and parents. It is teachers who are responsible for ensuring the right to education in a context of isolation and physical distancing, which combine with Colombia's socioeconomic inequalities, reflected in a Gini index of 0.57% and the country's ranking as the eighth most unequal, according to data from the Economic Commission for Latin America and the Caribbean (ECLAC) and the World Bank (Herrera, 2021).

At the same time, it was found that simply providing technology was not sufficient to yield better learning outcomes; rather, learning should be facilitated by teachers well versed in technology (Reimers & Schleicher, 2020; Sanabria et al., 2020). Another key aspect in this determinant is the lack of teacher readiness to cater to groups with special educational needs, a critical issue that deserves attention given the need for interaction between families, schools, and professionals working together toward equity (Díaz-Piñeres et al., 2020). It was also established that this variable includes limited teacher readiness in the technical and administrative aspects of ICT and LKTs to apply these tools to solve problems and support engagement and active teaching to improve teaching practice. This improvement motivates teachers and students in the teaching-learning process, compelling teachers to acquire the necessary technical and pedagogical skills to integrate them into this form of education (Avendaño et al., 2021; García, 2021; Sánchez et al., 2020).

The "curriculum matrix" variable encompasses various curricular, pedagogical, didactical, and attitudinal aspects of teachers, bringing together student autonomy resulting from the lack of teacher contact, the courses offered, ICT or LKT support, and the necessary accommodations to leave no student behind for socioeconomic reasons or due to special educational needs. The intention is to capture, through the structure of this "curriculum matrix," a proposal that allows for flexibility in resources, materials, deadlines, and assessments, with the goal of achieving pedagogical renewal and innovation. The objective is to respond to the crisis and equip educational stakeholders to migrate to new hybrid, in-person, and distance models, by prioritizing and defining what should be learned during physical distancing, but also to answer questions and verify learning (García, 2021; Díaz-Piñeres et al., 2020; Reimers & Schleicher, 2020; Serna et al., 2020).

Notable in the institutional determinant was "political environment." In previous years, the political environment referred to a context of armed conflict, violence, and the Peace Agreement, but in 2020-2021, this variable took on a new meaning in reference to the Colombian government's obligation to formulate and implement specific public policies to guarantee accessibility, opportunity, quality, and inclusion in education, taking into account specific regional characteristics and realities and helping to close the gap between urban and rural education in the pandemic and post-pandemic eras (García & Maldonado, 2020; Herrera, 2021; Maroscia & Ruiz, 2021). The "political environment" variable was associated with public policy in response to a need to prioritize support for students and schools most lacking in infrastructure and independent study skills, including wellbeing activities for both students and teachers (Findeter, 2021).

The "infrastructure" variable no longer referred to physical facilities and instead came to mean technological infrastructure, including the necessary adaptations for ICT to be accessed by students without the basic devices or connectivity necessary for academic progress, and for teachers to more easily fulfill their obligation to deliver education digitally, facilitating technical support for synchronous and asynchronous remote sessions that allow individual and group-based academic work and make it possible to deliver and assess distance learning. All of this also means overcoming obstacles like problems with connectivity and devices, and a rejection of or aversion to technology among teachers and students accustomed to learning in a physical space that has been transposed to a virtual room.

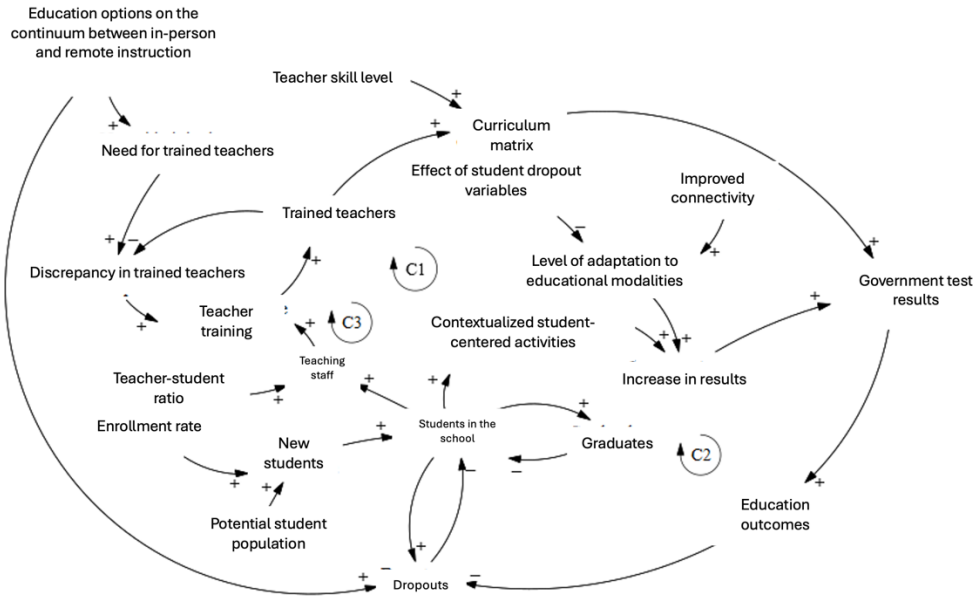
In the socioeconomic determinant, the variable "location of residence" was most cited, due to the differences in access between schools located in urban and rural areas. The switch from in-person to digital formats exposed even more clearly the historical education gap between towns and more rural settings. The lack of technological devices is more apparent in rural areas, where the ability to generate economies of scale in the education service is hampered by the geographical distances, which renders the provision of transportation, food, and accessibility costly and discourages students from continuing their studies due to the lack of physical and technological conditions or because a full range of courses is not offered (García & Maldonado, 2020), hindering the mitigation of school dropout (Díaz-Piñeres et al., 2020; Elacqua et al., 2020; Herrera, 2021; Osiobe, 2020).

In the individual determinant, the most frequently cited variable was "state of health," within a context of concern and uncertainty about the consequences of the pandemic. This compounded preexisting problems of malnutrition, domestic violence, and migration, which exacerbated student dropout and which, in any crisis, have a greater impact on more vulnerable groups (Maroscia & Ruiz, 2021).

3.2 Simulation model for options on the continuum from in-person to distance education

After identifying the variables, we proceeded to the second phase of the methodology and obtained the following causal loop diagram as an initial result (Figure 5).

Figure 5. Causal loop diagram – dynamic hypotheses



Note: Adapted from Serna and Flores (2015).

Figure 5 shows three loops that provide a qualitative representation of the following effects. First is the effect of teacher training on dropout: the greater the number of trained teachers, the better the curriculum matrix, which also improves results in government tests taken at the end of high school. This improvement has a positive effect on overall education outcomes and reduces the dropout rate. There are fewer dropouts, resulting in an increase in the active student population, which requires an increase in teaching staff. In turn, this

demands an increase in training time so that a greater number of trained teachers are available.

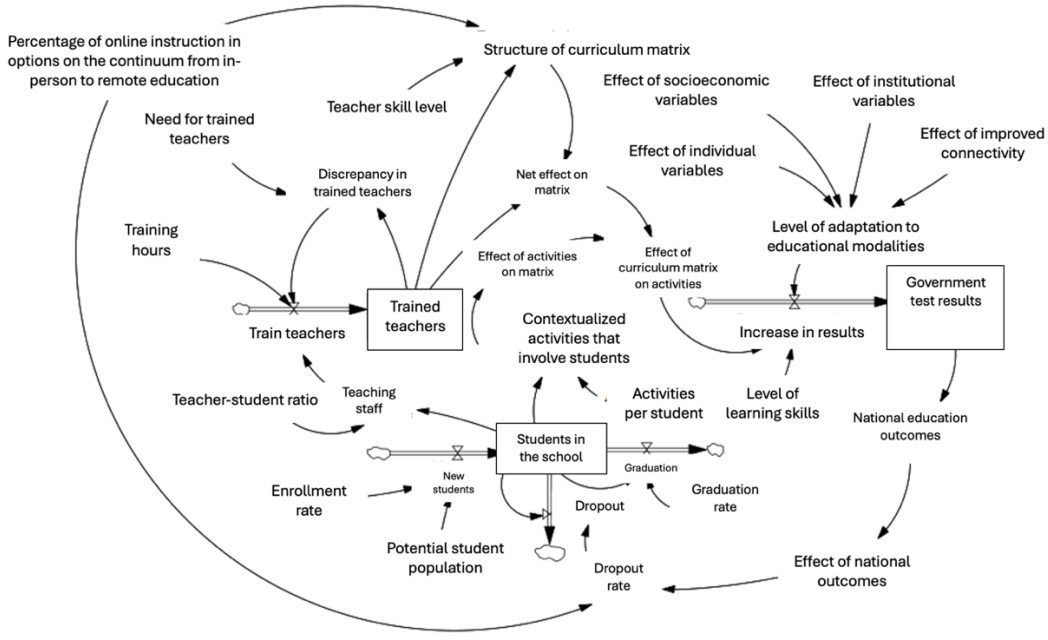
Second is the effect of contextualized student-centered activities on students in schools. The greater the number of activities that involve students, the better their results, including the results of standardized government testing. This improves education outcomes and reduces the dropout rate and the number of dropouts, allowing more students to remain in school, which in turn requires a greater number of contextualized activities.

Third is the effect of students in schools on student dropout. When a school has a high number of students, there is a need for more teaching staff and hence more training. When more teachers are trained, this improves the curriculum matrix and government test results, thus improving education outcomes, which reduces the number of dropouts and increases the active student population in schools.

Figure 6 shows the model developed using system dynamics to simulate three scenarios that demonstrate the impact on school dropout of the percentage of remote instruction in the different options on the continuum from in-person to remote instruction in preschool, basic, and upper secondary education.

The model includes an important assumption: at any percentage of virtual instruction, including the extremes of 0% (fully face-to-face) and 100% virtual learning, teachers receive curricular training in ICT and LKTs to develop their sensitivity toward the teaching profession and teaching practice. The teaching profession requires ongoing professional development in both teaching and subject-matter skills.

Figure 6. Model for options on the continuum from in-person to remote instruction

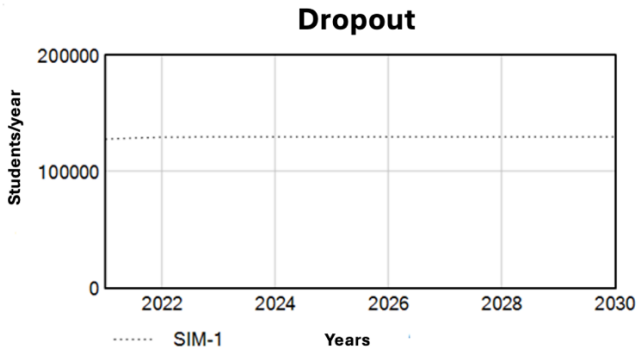


Note: Adapted from Serna and Flores (2015).

3.3 First scenario (SIM-1): assumptions and initial values

To begin the long-term trend analysis, we employed the variables and parameters listed in Appendix I. The parameters for the system's reference model (initial conditions) include, notably, 10% online instruction in planned activities and 40 hours of training per teacher per year for a potential student population of 8,613,646 and an annual dropout rate of 15.79%. SIM-1 showed that dropout displays horizontal asymptotic behavior at 129,281 students dropping out per year, nationwide (Figure 7).

Figure 7. SIM-1: 10% online activities as a reference model



Note: With information from Appendix I.

The simulations for the second and third scenarios were performed ceteris paribus; the second scenario only varied the parameter corresponding to the percentage of online instruction in academic activities (five simulations), and in the third simulation, only the number of hours of teacher training varied (two simulations).

3.4 Second scenario: progressive implementation of online instruction

For this analysis, five simulations were performed, in which we introduced incremental increases to the percentage of online instruction received by children and adolescents in the primary and lower secondary stages of basic education and in upper secondary education. The simulations were performed for the period from 2021 to 2030, in line with the horizon for achieving the Sustainable Development Goals (SDGs). As shown in Table 1, student dropout becomes more frequent as the percentage of online instruction increases. For example, when 20% of academic activities are online, student dropout stabilizes at 254,498 students, while moving all activities online results in over one million children and adolescents dropping out of school.

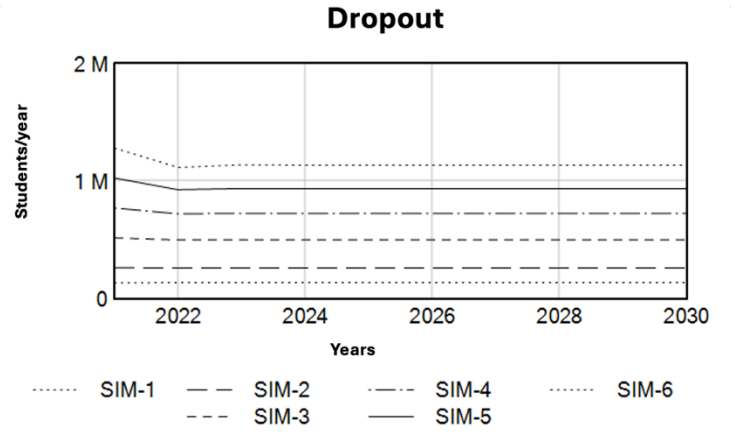
Table 1. Simulations of student dropout as online instruction increases

Computer simulation	Percentage*	Student dropout**
SIM-2	20	254,498
SIM-3	40	493,484
SIM-4	60	718,335
SIM-5	80	930,269
SIM-6	100	1,130,370

Notes: * Percentage of online instruction.
** Horizontal asymptote of dropout, as number of students.

Figure 8 shows the sensitivity of students who drop out of lower and upper secondary education to the percentages of online instruction, with the horizontal asymptotes (long-term trends) of student dropout behavior.

Figure 8. Student dropout behavior as online instruction increases



Note: With information from Appendix I.

3.5 Third scenario: teacher training

In this instance, two computer simulations were run for the parameter corresponding to teacher training hours as a tool to improve teaching practice and develop teacher sensitivity toward the profession. Importantly, all the other parameters were kept as in Appendix I – that is, as in the SIM-1 model. The initial parameter value of 40 hours of annual training per teacher is what is required in one week of institutional development each year (see Appendix I). Simulations SIM-7 and SIM-8 were performed with 80 and 120 hours of annual training per teacher, which is equivalent to two and three weeks of institutional development, respectively. In the long term, the student dropout trend is unchanged, at 129,281 students. In other words, dropout is not sensitive to teacher training under the conditions given. No simulations were run for longer durations – for example, for five weeks of institutional development in the academic year, as established by Decree No. 1075 of 2015 (Decreto No. 1075, 2015) – because that would be for large-scale specialization courses or graduate programs taken by teachers, and that is not feasible here.

IV. Discussion

The systematic review found that during the COVID-19 lockdown, 57.1% of studies on the determinants of student dropout in basic and upper secondary education in Colombia focused on the academic determinant, within which the most frequently cited variable was "teachers," who were identified firstly as being responsible for maintaining a link between students, teachers, and parents with the education service in a sudden, unexpected context of isolation and physical distancing, while also taking into account the conditions of social, economic, and technological inequality. Secondly, the studies note teachers' lack of personal and professional skills in the use of tools specific to remote education (ICT and LKTs). These are factors that make it difficult to provide education in the space between in-person and fully remote learning during pandemic and post-pandemic times.

The second most frequently cited variable in the academic determinant was "curriculum matrix," for which the aim is to provide an approach to teaching that allows flexibility in

resources, materials, deadlines, and assessments, thus enabling the various stakeholders in the education process to migrate to the hybrid models of education proposed in the continuum between in-person and remote instruction in this new normal.

At 28.75% of the documents retrieved, the institutional determinant became the second most widely studied determinant and included "political environment" as the most frequently cited variable. Previously, this referred to a context of armed conflict, violence, and the Peace Agreement, but in 2020-2021 it took on a new meaning in the context of the Colombian government's obligation to formulate and introduce public policies that guarantee accessibility, opportunity, quality, and inclusion in the education system, taking into consideration the specific characteristics of each local area, at all times endeavoring to close the gaps between urban and rural education. Lastly, within the institutional determinant, "infrastructure" was given a new meaning as it shifted from a physical to a technological connotation. This meant there was a need to introduce changes in order to provide education to students who did not all have access to electronic devices or an internet connection, which became indispensable to progress academically. As far as teachers were concerned, this meant further developing the compulsory digitalization of education, providing technical support for synchronous or asynchronous class sessions for individual or group work and making it possible to deliver and assess a new form of education remotely.

Finally, the socioeconomic determinant concerned 9.52% of studies and "location of residence" was the most frequently cited variable, in light of its implications for access and connectivity in the areas served by urban and rural schools.

By following the model progression approach and incorporating the variables into the baseline model proposed by Serna and Flores (2015), we found that student dropout was highly sensitive to the percentage of online instruction in the education received by children and adolescents in the Colombian system, and not sensitive to the duration of teacher training, which ranges from 40 to 200 hours a year. The difficulties of virtual learning are not offset by a focus on developing teachers' sensitivity to their profession and acquiring and improving teaching skills that promote pedagogical, didactical, and ICT and LKT competencies that build support for students in each school and in the system more broadly. This also fails to take into account that during training weeks, time must also be devoted to the institutional educational project, curriculum, pedagogical research and refesher training, institutional evaluation, and other activities for delivering education.

This poses a challenge for the system used by Colombia's Ministry of National Education (MEN) to train educators, which is designed to effectively provide the necessary pedagogical tools to deliver education, taking into account students' abilities and needs to enable them to learn better and learn more, and develop competencies for life (Ministerio de Educación Nacional, 2021).

The highest dropout rate was observed in the simulations with 100% online learning, potentially mirroring a situation in which students are under the academic supervision of parents or caregivers and carry out activities and instructions provided by teachers through photocopies, online platforms, or e-mails. Under this extreme scenario, children and adolescents have no in-person contact with their teacher or classmates, which combines with persistent regional inequalities in education in Colombia (Herrera, 2021) to trigger massive levels of school dropout, a phenomenon that was already severe given that "out of every 100 students that enter 5th grade, only 55 manage to reach 11th grade" (García & Maldonado, 2020, p. 6) and, similarly, out of every 100 students who begin 6th grade, 64 finish 11th grade (Forero & Saavedra, 2019), the last year of high school.

Lower levels of online instruction result in lower levels of dropout in the simulations. This could inform responses to adapt to any future lockdowns or peaks of infection, using alternatives or a combination of measures that ensure no child or adolescent is left behind (García, 2021). In any case, teacher attitudes make a difference in inclusive education (Rodríguez et al., 2021) and in understanding the contexts in which the teaching-learning process takes place (Herrera, 2021). Moreover, the social situation in Colombia in 2020 and 2021 due to the pandemic, which was further exacerbated by insecurity challenges in 2021, points to an increase in poverty rates and physical and mental health conditions, which should be tackled with proposals that acknowledge these deficiencies and work to strengthen education as a healthy life project – mentally, physically, economically, and socially.

V. Conclusions

The two phases of the research methodology successfully simulated the behavior of school dropout at preschool, basic, and upper secondary levels in Colombia in the aftermath of COVID-19. Using the system dynamics technique to simulate the behavior of the main variables in the proposed alternatives on the continuum between face-to-face and distance learning, we found that a higher level of online instruction (increased in 20% increments in each simulation) resulted in an increase in dropout, given the technological infrastructure and teacher and student ICT and LKT readiness. At the same time, an attempt to mitigate dropout by increasing teacher training hours, within the limits of teachers' annual minimum training program set by education policy, revealed the insensitivity of dropout in this respect. Training just one set of actors in the education process is therefore insufficient. Instead, joint efforts are needed on several fronts to facilitate access to minimum ICT tools and connectivity.

Sustained teacher training in technological appropriation, skills, and abilities improves teacher competencies recommended by UNESCO; this recommendation should be thoroughly adopted by Colombia throughout all stages of education to address the specific challenges of the reality of education that may be both face-to-face and remote. This continuum from face-to-face to distance learning demands immediate efforts to develop connectivity, as part of the right to education enjoyed by children and adolescents worldwide.

Educational research helps policymakers to formulate wide-ranging, impactful solutions and evaluate how they function, in order to implement, adjust, or undertake measures to benefit the commmunity. However, a study like this has limitations due to the delay in publishing research findings (given the time required for the editorial process, which means that data are already at least one year old when work is published). Another limitation is the lack of data to describe schools and students in terms of ICT availability and access. Highly accurate data make it possible to assess the real-world situation, offering a window of opportunity for formal research and knowledge generation that benefits all stakeholders in the education process.

Translation: Joshua Parker

Contribution of each author

Sandra Patricia Barragán-Moreno: conceptualization, investigation (60%), formal analysis, writing original draft (60%).

Oscar Leonardo Lozano Galindo: methodology, investigation (40%), data curation, writing original draft (40%).

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Appendix I. Description of model variables

Variable	Defining equation	Units	Interpretation	Source of information
Student activities	Students in the school * Activities per student	Activities	Assignments in class	Serna & Flores (2015)
Activities-student		Activities/Student	Minimum for year	Research parameter
Dropout	Students in the school*Dropout rate*Percentage of online instruction in educational modalities-Effect of national dropout derived from municipal rates	Students/Year	Students dropping out	http://bi.mineducacion.gov.co:8380/eportal/web/planeacion-basica/76
Discrepancies in trained teachers	Need for trained teachers-Trained teachers	Teachers	Teachers to be trained in ICT	https://www.dane.gov.co/files/investigaciones/boletines/educacion/bol_EDUC_19.pdf
Trained teachers	INTEG (Train teachers, 280.891)	Teachers	Trained teachers	https://colombiatic.mintic.gov.co/679/w3-propertyvalue-36665.html
National outcomes	IF THEN ELSE (National education outcomes<55. 0, 0.0001)		Impact	https://www.icfes.gov.co/documents/20143/193560/Guia%20de%20interpretacion%20y%20uso%20de%20resultados%20del%20examen%20saber%2011%202016%20-%20entidades%20territoriales.pdf
Improved connectivity	0.3		Impact	Research parameter
Individual variables	0.11		Impact	Research parameter
Institutional variables	0.25		Impact	Research parameter
Socioeconomic variables	0.22		Impact	Research parameter
Structure of curriculum matrix	Trained teachers*Teacher skill level*(1+ Percentage of online instruction in educational modalities)		Teacher skill level	https://repositorio.banrep.gov.co/bitstream/handle/20.500.12134/9560/DTSERU%20276.pdf
Students in the school	INTEG (New students-Graduation-Dropout 8.0777e+06)	Students	Enrollment for year	http://bi.mineducacion.gov.co:8380/eportal/web/planeacion-basica/sector

Variable	Defining equation	Units	Interpretation	Source of information
Graduation	Students in the school*Graduation rate	Students/Year	Graduating students	http://bi.mineducacion.gov.co:8380/eportal/web/planeacion-basica/tasa-de-repitencia
Training hours	260	Hours/Year	Per year	Research parameter
Increase in results	Level of adaptation to educational modalities *Contextualized activities that involve students *Level of learning skills	Points/Year	Point increase in ICFES exam	https://www.icfes.gov.co/documents/20143/193560/Guia%20interpretacion%20uso%20resultados%20saber%2011%20-%20establecimientos%20educativos-2017.pdf
Need for trained teachers	0.7+(0.1+Percentage of online instruction in educational modalities)	Teachers	Teachers to be trained	Defined variable
Adaptation to educational modalities	1-(Effect of institutional variables+Effect of improved connectivity+Effect of individual variables) +Effects of socioeconomic variables		Effect of no action	Defined variable
New students	Potential student population*Enrollment rate	Students/Year	New enrollment	Defined variable
Teaching staff	Teacher-student ratio*Students in the school	Teachers	Teachers in system	https://www.dane.gov.co/files/investigaciones/boletines/educacion/bol_EDUC_19.pdf
Potential population	8,613,646	Students		https://www.dane.gov.co/files/investigaciones/poblacion/proyepobla06_20/proyecciones-nivel-nacional-departamental-por-sexo-y-edades-simples-hasta-80-anos-y-mas.xls
Percentage of online instruction in educational modalities	0.1	[0.1]		Research parameter
Teacher-student ratio	$\frac{1}{32}$	Teachers/Students	Students/ Teacher	https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=6405
Government test results	INTEG (Increase in results *Structure of curriculum matrix,252)	Points	Saber test results	https://www.icfes.gov.co/documents/20143/2211695/Informe+nacional+de+resultados+Saber+11+2020.pdf
National outcomes	Government test results*$\frac{0.25}{3}$	Points	Points for initial capabilities	https://colaboracion.dnp.gov.co/CDT/Desarrollo%20Territorial/MDM/Resultados_MDM_2017.pdf

Variable	Defining equation	Units	Interpretation	Source of information
Level of learning skills	0.94	Dmnl (dimensionless)		Research parameter
Dropout rate	0.1579	1/Year	Annual	http://bi.mineducacion.gov.co:8380/eportal/web/planeacion-basica/76
Graduation rate	0.9731	1/Year		
Teacher skill level	0.3	Learning [0.1]		Research parameter
Enrollment rate	0.97	Students	Annual	http://bi.mineducacion.gov.co:8380/eportal/web/planeacion-basica/tasa-de-repitencia