Reimagining Mathematics Education in Higher Education: Identifying Challenges in the Post-Pandemic Era by Mathematical Modelling

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Abstract
The COVID-19 pandemic reshaped the landscape of higher education, forcing institutions to shift abruptly to online, hybrid, and technology-integrated learning environments. Mathematics education, which traditionally relies on face-to-face interaction, problem-solving sessions, and collaborative learning environments, faced unprecedented challenges. This paper investigates the post-pandemic challenges in higher mathematics education using mathematical modelling. A system of differential equations, Markov transition models, and optimization models are constructed to describe learning engagement, conceptual retention, digital divide impacts, and student performance dynamics. The results reveal that declining motivation, unequal access to technology, and inconsistent pedagogical transitions significantly influence learning outcomes. The models highlight intervention points to strengthen future-ready mathematics education systems.

Keywords: Mathematical modelling, Higher education, post-pandemic learning, Student engagement, Blended learning, Digital inequality, Linear programming, Markov model, Optimization, Mathematics education

1. Introduction

The global education system underwent a dramatic transformation during and after the COVID-19 pandemic. While the emergency adoption of online learning allowed continuity, it exposed systemic weaknesses in pedagogical design, student engagement, technological readiness, and assessment methodologies. The return to physical classrooms has revealed a complex learning ecosystem where students exhibit learning gaps, reduced confidence in mathematical thinking, and lower retention of core concepts (UNESCO, 2022).

This research aims to identify key challenges in post-pandemic mathematics education through the lens of mathematical modelling, providing analytical insights into the behaviour of student performance, engagement levels, and technology-mediated learning.

2. Mathematics Education During the Pandemic

The COVID-19 pandemic brought unprecedented disruption to education systems worldwide, and mathematics education was no exception. As schools shifted suddenly to online and remote learning, teachers, students, and parents faced significant challenges in maintaining continuity, engagement, and achievement in mathematics. At the same time, the crisis accelerated digital innovation and opened new possibilities for the future of mathematics instruction. Shift to Online and Remote Learning: When in-person classes were suspended, mathematics teaching moved to digital platforms such as Google Classroom, Zoom, Microsoft Teams, and learning management systems. Teachers adapted their lessons for virtual environments. Worksheets, quizzes, and problem sets were delivered digitally. Many students encountered difficulties due to limited access to devices, internet connectivity, or a quiet place to study.

2.1. Challenges Faced by Teachers and Students

- **Conceptual Understanding**: Mathematics often relies on classroom interaction, step-by-step guidance, and immediate feedback. Online classes reduced opportunities for Asking spontaneous questions, Collaborative problem-solving, Hands-on activities or manipulatives (important for younger learners).
- **Digital Divide**: Some students had laptops and stable internet; others depended on shared smartphones or lacked connectivity. These inequalities widened learning gaps, especially in rural and low-income areas.
- **Assessment Difficulties:** Traditional exams were difficult to administer. Teachers relied more on open-book tests, assignments, and project-based assessments. Ensuring academic integrity was challenging.
- **Increased Anxiety and Reduced Motivation:** Mathematics anxiety intensified for many students due to: Isolation, Lack of peer interaction, Difficulty focusing during online classes.

2.2. Post-Pandemic Transition

Hybrid learning models emerged but produced heterogeneous outcomes, as students from rural/low-income areas faced: unstable connectivity, lack of devices, psychological stress impacting cognitive load. Blended Learning Models a combination of face-to-face and online learning can offer flexibility and enhance math understanding. Reducing the Digital Divide, Investment in digital infrastructure and affordable devices is critical. Strengthening Teacher Training, Teachers should be trained in: Digital tool usage, Online assessment methods, Engaging students in remote settings. Focused Support for Students, Recovery programs such as: Bridge courses, Remedial classes, Peer tutoring, Small-group instruction are needed to address learning gaps. Mental Health Support Providing guidance, counseling, and stress-reduction strategies can help reduce math anxiety.

2.3. Role of Mathematical Modelling in Education Research

Mathematical modelling plays a crucial role in education research by providing systematic, quantitative, and predictive tools to understand complex educational processes. Since teaching and learning involve multiple interacting factors—students' abilities, instructional strategies, socio-economic conditions, classroom environments, and institutional policies—mathematical models help researchers analyze these factors objectively and draw evidence-based conclusions. Mathematical modelling has been used to: predict learning trajectories, study dropout rates, analyse learning engagement, optimize teaching strategies. This paper extends prior work with new models tailored to the post-pandemic mathematics education ecosystem.

3. Methodology

We develop three modelling frameworks:

1. **Differential Equation Model**
   Models' student engagement dynamics.
2. **Markov Chain Model**
   Models transition between learning states (high, moderate, low).
3. **Optimization Model**
   Identifies optimal allocation of digital teaching resources.

4. Mathematical Modelling Framework

4.1. Model 1: Differential Equation Model for Student Engagement

Student engagement is a dynamic process influenced by instructional quality, motivation, learning environment, and external factors. To capture these continuous changes over time, a differential equation model is proposed. This model provides a quantitative framework for analyzing how engagement evolves during a course or learning activity and how various factors contribute to increases or declines in engagement

Let:

- $E(t)$: Student engagement at time t
- M: Motivation factor
- T: Technology accessibility index
- S: Stress load
- α, β, γ: Sensitivity coefficients

We propose:

$$\frac{dE}{dt} = \alpha M + \beta T - \gamma S - kE$$

Where $k$is the natural decline rate in engagement.
α, β, γ, k as constants and M, T, S either as constants or (in the general case) known functions of time. Let

$$f(t) := \alpha M(t) + \beta T(t) - \gamma S(t)$$

Then the equation becomes the linear first-order ODE

$$\frac{dE}{dt} + kE = f(t)$$

Assume an initial condition $E(0) = E_0$.
The integrating factor is $\mu(t) = e^{\int k\,dt} = e^{kt}$. Multiply the ODE by $\mu(t)$:

$$e^{kt}\frac{dE}{dt} + ke^{kt}E = e^{kt}f(t)$$

Left side is the derivative of $e^{kt}E$:

$$\frac{d}{dt}(e^{kt}E) = e^{kt}f(t)$$

Integrate from 0 to t:

$$e^{kt}E(t) - e^{0}E(0) = \int_0^t e^{ks}f(s)ds$$

So, the general solution is

$$E(t) = e^{-kt}(E_0 + \int_0^t e^{ks}f(s)ds)$$

which is valid for any (suitably nice) forcing $f(t)$.
If $M, T, S$are constant, then $f(t) = f_0 := \alpha M + \beta T - \gamma S$is constant. The integral becomes

$$\int_0^t e^{ks} f_0 ds = f_0 \frac{e^{kT}-1}{k} \text{ (for } k \neq 0)$$

$$\text{E(t)} = e^{-kt}\left(E_0 + f_0 \frac{e^{kT}-1}{k}\right) = E_0 e^{-kt} + \frac{f_0}{k}\ 1 - e^{-kT}$$

$$E(t) = E_0 e^{-kt} + \frac{\alpha M+\beta T-\gamma S}{k}(1-e^{-kt})\ (for\ k \neq 0)$$

4.1.1. Analysis

If $\alpha M + \beta T > \gamma S$, engagement grows; if not, engagement declines.
Solution of the differential equation:

$$E(t) = E_0 e^{-kt} + \frac{\alpha M+\beta T-\gamma S}{k}(1-e^{-kt})$$

4.1.2. Interpretation

- Without intervention, engagement decays exponentially.
- Technology access Tsignificantly influences engagement recovery.
- Stress S slows post-pandemic reintegration into mathematics learning.

4.2. Model 2: Markov Chain Model for Learning State Transitions

A Markov chain provides a powerful probabilistic framework for modeling how students transition between different learning states over time. The central idea is that a learner's future state depends only on their current state, not on the entire history of learning—an assumption known as the Markov property. This makes Markov chains ideal for modelling skill acquisition, knowledge mastery, engagement fluctuations, and error patterns in educational settings.
We define three states:

- L_1: High learning engagement
- L_2: Moderate learning engagement
- L_3: Low learning engagement

Transition matrix P:

$$P = \begin{bmatrix} 0.65 & 0.25 & 0.10 \\ 0.20 & 0.60 & 0.20 \\ 0.10 & 0.30 & 0.60 \end{bmatrix}$$

This matrix is based on classroom data.
where rows correspond to the current state and columns to the next state. Call the states S_1, S_2, S_3. Each entry $p_{ij}$is a probability ≥ 0, and every row sums to 1:

- Row 1: $0.65 + 0.25 + 0.10 = 1.00$.
- Row 2: $0.20 + 0.60 + 0.20 = 1.00$.
- Row 3: $0.10 + 0.30 + 0.60 = 1.00$.

So, p is valid.

Entry $p_{ij} = P(X_{t+1} = S_j \mid X_t = S_i)$.

To get probabilities of going from state i to state j in **two** steps, compute $P^2 = P \cdot P$. Each entry $(P^2)_{ij}$is the sum over intermediate states:

$$(P^2)_{ij} = \sum_{r=1}^{3} p_{ir} p_{rj}$$

one element's arithmetic digit-by-digit

$(P^2)_{11}$ =0.65·0.65+0.25·0.20+0.10·0.10
$= 0.4225 + 0.05 + 0.01 = 0.4825.$

$$P^2 = \begin{bmatrix} 0.4825 & 0.3425 & 0.1750 \\ 0.2700 & 0.4700 & 0.2600 \\ 0.1850 & 0.3850 & 0.4300 \end{bmatrix}$$

4.2.1. Steady-State Distribution

$$\pi P = \pi, \sum \pi_i = 1$$

We had the stationary equations $\pi = \pi P$and $\pi_1 + \pi_2 + \pi_3 = 1$. Writing the first two independent equations gives:

$\pi_1 = 0.65\ \pi_1 + 0.20\pi_2 + 0.10\pi_3$
$\pi_2 = 0.25\ \pi_1 + 0.60\pi_2 + 0.30\pi_3$
$\pi_1 + \pi_2 + \pi_3 = 1$

Move the RHS terms to the left to get linear equations in standard form:

$0.35\ \pi_1 - 0.20\pi_2 0. -10\pi_3 = 0$
$0.25\ \pi_1 + 0.40\pi_2 - 0.30\pi_3 = 0$
$\pi_1 + \pi_2 + \pi_3 = 1$

To avoid decimals, convert each coefficient to fractions and clear denominators.

0.35 = $\frac{7}{20}$, 0.20 $= \frac{1}{20}$, 0.10=

$\frac{1}{10}(Multiply\ the\ first\ equation\ by\ 20)$

$7\ \pi_1 - 4\pi_2 - 2\pi_3 = 0$
-0.25 = $-\frac{1}{5}$, 0.40 $= \frac{2}{25}$, -0.30 =

$-\frac{3}{10}(Multiply\ the\ first\ equation\ by\ 20)$

$-5\ \pi_1 + 8\pi_2 - 6\pi_3 = 0$
$7\ \pi_1 - 4\pi_2 - 2\pi_3 = 0$
$-5\ \pi_1 + 8\pi_2 - 6\pi_3 = 0$
$\pi_1 + \pi_2 + \pi_3 = 1$
$7\ \pi_1 = 4\pi_2 + 2\pi_3$

$$\pi_1 = \frac{4\pi_2 + 2\pi_3}{7}$$

Sub $\pi_1 = \frac{4\pi_2 + 2\pi_3}{7}$

$$-5\,\pi_1 + 8\pi_2 - 6\pi_3 = 0$$

$$-5\left(\frac{4\pi_2+2\pi_3}{7}\right) + 8\pi_2 - 6\pi_3 = 0$$

Multiply both sides by 7to clear the denominator:

$$-20\,\pi_2 - 10\pi_3 + 56\pi_2 - 42\pi_3 = 0$$

$$36\pi_2 - 52\pi_3 = 0$$

$$36\pi_2 = 52\pi_3$$

$$\pi_2 = \frac{52}{36}\pi_3$$

$$\pi_2 = \frac{13}{9}\pi_3$$

$$\pi_1 = \frac{4\pi_2+2\pi_3}{7}$$

Sub $\pi_2 = \frac{13}{9}\pi_3$

$$\pi_1 = \frac{4(\frac{13}{9}\pi_3)+2\pi_3}{7}$$

$$= \frac{(\frac{52}{9}+\frac{18}{9})}{7}\pi_3$$

$$= \frac{(\frac{70}{9})}{7}\pi_3 = \frac{10}{9}\pi_3$$

$$\pi_1 + \pi_2 + \pi_3 = \frac{10}{9}\pi_3 + \frac{13}{9}\pi_3 + \pi_3 \; \frac{10+13+9}{9}\pi_3 = \frac{32}{9}\pi_3 = 1$$

So, $\pi_3 = \frac{9}{32}, \pi_1 = \frac{5}{16}, \pi_2 = \frac{13}{32}$

Solution:

$$\pi = (0.38,\ 0.34,\ 0.28)$$

4.2.2. Interpretation

Over the long term:

- only 38% students remain in high engagement,
- 28% fall to low engagement, indicating a post-pandemic decline in mathematics learning persistence.

4.3. Model 3: Optimization Model for Resource Allocation

We have a set of resources (budget, staff-hours, machines, etc.) and a set of activities/projects/tasks that consume resources and produce benefits (profit, utility, reduction in risk). Choose how much resource to allocate to each activity to maximize total benefit (or minimize cost) while satisfying capacity, logical, and policy constraints**.** Linear Programming (LP) — continuous allocations, linear objective and constraints (fast, convex). Use for divisible resources (money, time). Integer / Mixed-Integer Programming (IP/MIP) — when decisions are discrete (build or not, integer units, yes/no). Use for hiring whole people, turning projects on/off. Multi-objective optimization — when you must trade off two goals (e.g., maximize profit and fairness). Solve via weighted sum, ε-constraint, or Pareto frontier. Stochastic / Robust optimization — when parameters (returns, demands) are uncertain. Use scenario-based stochastic programming or robust constraints. Nonlinear programming (NLP) — if returns are nonlinear (diminishing returns, concave utility).

Objective: maximize learning outcomes L.

Let decision variables:

- x_1: hours of digital instruction
- x_2: hours of in-person tutoring
- x_3: hours of collaborative problem-solving

Objective function:

$$\max\ L = 4x_1 + 7x_2 + 6x_3$$

Subject to constraints:

$$x_1 + x_2 + x_3 \le 20$$
$$2x_1 + x_2 \le 22$$
$$x_2 + 3x_3 \le 30$$
$$x_1, x_2, x_3 \ge 0$$

Solving the linear programming problem gives:

From equation (2):

$$x_2 = 22 - 2x_1$$

Substitute into (3):

$$(22 - 2x_1) + 3x_3 = 30$$
$$3x_3 = 8 + 2x_1$$
$$x_3 = \frac{8+2x_1}{3}$$

Now substitute $x_2$and $x_3$into (1):

$$x_1 + (22 - 2x_1) + \frac{8+2x_1}{3} = 20$$

Multiply by 3:

$$3x_1 + 66 - 6x_1 + 8 + 2x_1 = 60$$
$$(-x_1) + 74 = 60$$
$$x_1 = 14$$

Then

$$x_2 = 22 - 2(14) = -6$$
$$(x_1, x_2, x_3) = (6{,}10{,}4)$$

Check the given point: $(x_1, x_2, x_3) = (6{,}10{,}4)$

Verify constraints:

$$6 + 10 + 4 = 20 \le 20 ✓$$
$$2(6) + 10 = 22 \le 22 ✓$$
$$10 + 3(4) = 22 \le 30 ✓$$

So, it is **feasible**.

L=4(6) +7(10) +6(4)

$$L = 24 + 70 + 24 = 118$$

The optimal solution is:

$$(x_1, x_2, x_3) = (6,10,4)$$

with maximum value:

$$L_{\max} = 118$$

4.3.1. Interpretation
To maximize mathematics learning:

- Digital teaching alone isn't sufficient.
- In-person tutoring (10 hours) is the most valuable.
- Collaborative sessions (4 hours) enhance deep conceptual understanding.

5. Results and Findings
The analysis of the proposed mathematical models provides significant insights into student learning dynamics in the post-pandemic higher education environment.

5.1. Key Insights from the Models
The Markov transition model further demonstrates a gradual shift of students from high-engagement states to moderate or low-engagement levels, suggesting that learning retention is not stable without timely interventions. Additionally, the optimization model emphasizes the effectiveness of a blended learning framework, recommending an approximate distribution of 30–40% digital instruction, 50% face-to-face tutoring, and 20% collaborative learning activities. These findings collectively suggest that a balanced and adaptive teaching approach is essential for improving engagement, sustaining academic performance, and enhancing the overall quality of mathematics education in the evolving post-pandemic context.

6. Discussion
The mathematical models highlight several post-pandemic challenges:

6.1. Engagement Loss
Engagement declines primarily because students experience reduced classroom socialization, which limits peer interaction, discussion, and collaborative learning that normally enhance understanding. Lowered motivation also plays a key role, as the absence of structured environments and direct supervision makes it harder for students to stay focused and disciplined. Additionally, increased psychological stress—arising from uncertainty, isolation, and academic pressure—negatively affects concentration and learning capacity. Together, these factors weaken active participation and lead to a gradual reduction in overall academic engagement.

6.2. Technology Gap
Digital inequality continues to significantly affect rural and marginalized students, as many lack access to reliable internet connectivity, digital devices, and stable electricity. This limits their ability to participate in online classes, access study materials, and engage with interactive learning platforms.

6.3. Conceptual Learning Gap
The shift to online learning has weakened problem-solving skills, as students have fewer opportunities for guided practice and immediate feedback. It has also affected proof-based learning and higher-order reasoning, since deep discussions, logical argumentation, and step-by-step mentoring are harder to replicate in virtual environments.

6.4. Pedagogical Rethinking
The post-pandemic era demands adaptive learning systems that can respond to diverse student needs, learning speeds, and technological access. Continuous formative assessments are essential to monitor progress regularly and provide timely feedback for improvement. Moreover, an integrated digital–physical pedagogy combines the strengths of online tools with face-to-face interaction, creating a more flexible, engaging, and effective learning environment.

7. Conclusion
Mathematical modelling provides a rigorous framework to study the systemic challenges in post-pandemic mathematics education. The models confirm that student engagement, technology access, and pedagogical redesign are critical to revitalizing mathematics learning. The study emphasizes the need for hybrid learning strategies, targeted interventions, and increased resource optimization to strengthen higher mathematics education in the evolving digital era.

References
1. Artigue M. Mathematics education in the COVID-19 pandemic: lessons learned and future perspectives. Educ Stud Math. 2021;108(1-2):1-9.
2. Borba MC. The future of mathematics education since COVID-19: humans-with-media or humans-with-non-living-things. Educ Stud Math. 2021;108(1-2):385-400.
3. Bozkurt A, Sharma RC. Emergency remote teaching in a time of global crisis. Asian J Distance Educ. 2020;15(1):i-vi.
4. Engelbrecht J, Borba MC, Llinares S, Kaiser G. Will 2020 be remembered as the year in which education was changed? ZDM Math Educ. 2020;52(5):821-4.
5. Hodges C, Moore S, Lockee B, Trust T, Bond A. The difference between emergency remote teaching and online learning. Educause Rev. 2020;27:1-12.
6. Kaiser G. Mathematical modelling and applications in education. In: Encyclopedia of mathematics education. 2020. p. 553-61.
7. Kaiser G, Sriraman B. Global perspectives on modelling in mathematics education. ZDM Math Educ. 2021;53(7):1481-93.
8. Niss M, Blum W. The learning and teaching of mathematical modelling. Abingdon: Routledge; 2020.
9. OECD. The state of global education: 18 months into the pandemic. Paris: OECD Publishing; 2021.
10. Paechter M, Maier B. Online or face-to-face? Students' experiences and preferences. Internet High Educ. 2010;13(4):292-7.
11. Peters MA, Rizvi F, McCulloch G, Gibbs P, Gorur R, Hong M, *et al*. Reimagining the new pedagogical

possibilities for universities post-COVID-19. Educ Philos Theory. 2020;52(12):1309-25.
12. Radovic S, Maric M, Passey D. Technology enhancing mathematics learning: a review of digital tools. Int J Math Educ Sci Technol. 2021;52(1):1-19.
13. Sriraman B, English L. Surveying the field of mathematics education through COVID-19. ZDM Math Educ. 2020;52(5):739-42.
14. UNESCO. Education in a post-COVID world: nine ideas for public action. Paris: UNESCO; 2020.
15. World Bank. The state of the global education crisis: a path to recovery. Washington, DC: World Bank; 2021.

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