سلسلة أوراق عمل
معهد التخطيط القومي

A System Dynamics Model to Study the Primary Education System in Egypt

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ورقة عمل رقم (4 - 2024)
يوليو 2024

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ورقة عمل رقم 4-2024

تم النشر لأول مرة في عام 2024 بواسطة معهد التخطيط القومي.

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سلسلة أوراق عمل - معهد التخطيط القومي

نموذج ديناميكي لدراسة نظام التعليم الإبتدائى في مصر

A System Dynamics Model to Study the Primary Education System in Egypt

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ملخص:

تطور هذه الدراسة نموذجًا ديناميكيا لتحليل نظام التعليم الابتدائي في مصر واقتراح مجموعة من السياسات التي تهدف إلى تحسينه، وذلك لتعزيز جودة التعليم الابتدائي. حيث تسلط الضوء على التحديات التي تواجه التعليم الابتدائي، بما في ذلك زيادة كثافة الفصول الدراسية، وارتفاع مؤشر تلميذ لكل مدرس، وتراجع مهارات التفكير لدى الطلاب. اقترحت الدراسة تصميم نموذج ديناميكي لفهم تأثير مجموعة من السياسيات المقترحة على أداء بعض تلك المؤشرات.

من خلال تطوير نموذج شامل لديناميكيات النظام، تم تحليل سيناريوهات متعددة لتقييم التأثير المحتمل للتدخلات المختلفة.

أشار سيناريو الأعمال كالمعتاد (BAU) إلى أنه بدون تدخل، سيستمر نظام التعليم الابتدائي في التدهور، مع تفاقم كثافة الفصول ونسب الطلاب إلى المعلمين. في المقابل، أظهرت السيناريوهات التي تضمنت تحسينات في البنية التحتية وتدريب المعلمين إمكانات كبيرة للتغيير الإيجابي.

على وجه التحديد، أدى السيناريو الأول، الذي دمج تحسينات البنية التحتية وتوظيف معلمين جدد، إلى انخفاض كثافة الفصول وتحسين نسب الطلاب إلى المعلمين. أظهر السيناريو الثاني، الذي ركز على تدريب المعلمين على مهارات التفكير (HOTS)، تحسينات متواضعة في مهارات التفكير النقدي ولكنه أشار إلى الحاجة إلى تدخلات إضافية للنجاح على المدى الطويل. أظهر السيناريو الثالث، الذي جمع بين تحسينات البنية التحتية وتدريب المعلمين، التحسينات الأكثر جوهرية عبر جميع المؤشرات الرئيسية.

تؤكد النتائج على ضرورة اتباع نهج سياسي شامل يجمع بين تحسين البنية التحتية للمدارس وبرامج التدريب المهني للمعلمين. تعد مثل هذه الاستراتيجية المتكاملة والشاملة أمرًا حاسمًا لمعالجة المشكلات في قطاع التعليم الابتدائي في مصر وخلق بيئة تعليمية أكثر ملاءمة للطلاب. ينبغي على صانعي

السياسات وأصحاب المصلحة النظر في هذه الرؤى لتنفيذ تدخلات فعالة تعزز جودة التعليم ومهارات التفكير النقدي بين طلاب المدارس الابتدائية.

تم اختبار النموذج مقابل البيانات التاريخية من 2016 إلى 2023، من خلال تطبيق سيناريو العمل كالمعتاد (BAU) ، بينما تقيم السيناريوهات البديلة التدخلات السياسية. يعتمد السيناريو الأول على توسيع البنية التحتية وتوظيف المعلمين. بيمنا، يقدم السيناريو الثاني تدريب المعلمين على مهارات التفكير (HOTS) . ويدمج السيناريو الثالث كلا من السيناريوهين. أوضحت النتائج أن السيناريو الثالث يحقق أفضل النتائج من حيث تحسن مؤشرات كثافة الفصول، ونسب التلاميذ إلى المعلمين، وكذلك مؤشر التفكير النقدي. وهذا يؤكد الحاجة إلى حلول شاملة قائمة على الأدلة تعالج القيود المادية والبشرية والتعليمية لتعزيز وتحسين جودة التعليم.

الكلمات الدالة: نموذج ديناميكي – التعليم الابتدائي- كثافة الفصول – مؤشر تلميذ لكل مدرس – التفكير النقدي

Abstract:

This study develops a system dynamics model to analyze the primary education system in Egypt and explore policies for improvements. The goal of this research is to enhance the quality of primary education in Egypt by developing and utilizing a system dynamics model. The model is designed to understand and predict the impacts of various policy interventions on critical indicators such as class density, pupil-teacher ratios, and the development of critical thinking skills, therefore, the key factors: student enrollment, classrooms, teachers, and critical thinking indicators are studied. The central question guiding the investigation is how the system dynamics model can specifically improve class density, pupil-teacher ratio, and critical thinking skills in Egypt's primary education. The model is tested against historical data from 2016-2023. A business-as-usual (BAU) scenario projects trends, while alternative scenarios evaluate policy interventions. Scenario 1 combines infrastructure expansion and teacher hiring. Scenario 2 introduces teacher training in higher order thinking skills (HOTS). Scenario 3 integrates both scenarios. Results show that Scenario 3 achieves the greatest improvements in class density, pupil-teacher ratios, and critical thinking index. This underscores the need for comprehensive, evidence-based solutions addressing physical, human, and instructional constraints to enhance and improve the quality of education. The model provides a tool for decision-makers and stakeholders to anticipate impacts, optimize resource allocation, and progress towards quality primary education for all.

Keywords: **System dynamics - Primary education - Class density - Pupil-teacher ratio - Critical thinking -HOTS**

1. Introduction

Over the past twenty years, the United Nations (UN) has led efforts to enhance global living conditions across various sectors through two sequential phases of its flagship development initiative. Initiated in 2001, the Millennium Development Goals (MDGs) were operational until 2015, then they were succeeded by the Sustainable Development Goals (SDGs), with a projected timeline extending to 2030. Each of the projects includes a goal focused on education, Goal 2 within the MDGs (MDG 2 'Achieve universal primary education') and Goal 4 within the SDGs (SDG 4 'Quality Education'). Therefore, the primary education is crucial for achieving the sustainable development because it lays the groundwork for individual and societal improvements across various dimensions, including economic, health, social, and environmental aspects, (Kushnir and Nunes 2022).

The Egyptian Constitution of 2014, in Article 19, mandates that "Education is compulsory until the end of the secondary stage or its equivalent. The State shall provide free education in the various stages in the State's educational institutions according to the Law.1" The Constitution also commits the State shall allocate a percentage of government spending to education equivalent to at least 4% of the Gross National Product (GNP), which shall gradually increase to comply with international standards. Article 25 of the Constitution mandates the state to devise a plan to eradicate literacy and digital illiteracy

[1] https://sschr.gov.eg/en/the-egyptian-constitution/#:~:text=We%20are%20drafting%20a%20Constitution%20that%20holds%20all%20of%20us,the%20Constitution%20of%20our%20revolution.

among citizens of all ages, with a defined timetable and the involvement of civil society institutions.

The Seventh pillar, "Education and Training, " of the strategic vision for Egypt until 2030 aims to provide high-quality education and training for all without discrimination within an institutional system that is efficient, fair, sustainable, and adaptable. It seeks to be learner-centered, empowering individuals to think critically and possess technical, technological, and vocational skills. The strategic objectives for basic (primary) education until 2030 encompass a set of goals:

The first objective is to enhance the overall quality of the educational system by applying accreditation and global quality standards through the National Authority for Quality Assurance and Accreditation.

The second objective is to provide high-quality education for all students by ensuring there are enough classrooms for everyone.

The third objective aims to improve competitiveness by enhancing education quality and availability in Egypt, thereby improving its rankings in global reports like the Global Competitiveness Report (GCR) and the Human Development Report.

The quality of primary education in Egypt is a key concern for stakeholders. System Dynamics models are valuable tools for integrating and evaluating various policies, offering a comprehensive understanding of the challenges affecting educational quality. These models identify the factors influencing education quality and help improve educational indicators, highlighting crucial areas for focused improvement efforts. System Dynamics is a type of causal modeling used to understand complex systems over time by representing interdependencies and feedback loops among system components. This approach uses causal loop diagrams or stock-and-flow diagrams to graphically depict causal relationships between variables, showing how changes in one variable affect others. By simulating these models, we can explore the propagation of changes through feedback loops, gaining deeper insights into system behavior and the impacts of interventions or policy changes. Thus, System Dynamics effectively uncovers causal relationships driving complex system dynamics (Kurniasih et al. 2023).

System dynamics models differ from statistical models in that they focus on understanding the underlying structure of complex systems rather than merely predicting outcomes based on past data. They provide insights into the interactions of system components over time, including feedback loops, delays, and non-linearities. By incorporating both exogenous and endogenous variables, system dynamics models reveal how changes in one part of the system can affect the entire system. This holistic approach not only aids in prediction and control but also uncovers causal relationships and mechanisms driving system behavior. As a result, these models are particularly useful for designing policies and interventions that address the root causes of complex issues rather than just responding to symptoms (Al Hallak et al. 2019).

This study aims to explore how a system dynamics model can be applied to analyze and enhance the primary education system in Egypt. It addresses key issues such as high-class density, unfavorable pupil-teacher ratios, and the insufficient development of critical thinking skills among students. By constructing and utilizing the model, the research simulates various scenarios and policy interventions to understand their potential impacts on these issues. This method provides a comprehensive analysis of current educational challenges and offers data-driven insights and recommendations for policymakers. The central question guiding the investigation is how the system dynamics model can specifically improve class density, pupil-teacher ratio, and critical thinking skills in Egypt's primary education.

2. Overview of the Primary Education System in Egypt

The education system in Egypt relies on centralization in making decisions related to education policies, study systems, curricula, time frame for teaching and preparing curricula, student evaluation systems, teacher recruitment, training, and promotion2. The education system also depends on decentralization in the implementation of teaching processes, technical supervision and follow-up of teachers, procedures for monitoring and evaluating students in their transition to higher classes, and other factors. Hence, education decisions at the national level are made by the Minister of

[2] https://timssandpirls.bc.edu/timss2019/encyclopedia/pdf/Egypt.pdf

Education, and executive decisions are issued at the governorate level by the Undersecretary of the Ministry of Education in the governorate3.

The primary education facilities to ensure places for all children of school age, which was fixed at 6 years, for a course of six years. therefore, children aged 6-12 were expected in the primary schools. Primary school education is under the direct control and supervision of the Ministry of Education which through its appropriate departments decides curriculum issues. Primary education is free except in the private schools which charge fees.

Egypt's primary education system confronts a multitude of challenges, ranging from issues of quality to overcrowded classrooms, teacher shortages, inadequate teacher training, and a deficiency in teaching critical thinking skills4. These challenges collectively contribute to the declining ranking of Egypt in education quality indices. In response to these pressing issues, a system dynamic model is proposed, leveraging a new model tailored specifically to the complexities of Egypt's primary education landscape. Therefore, the key components and elements of the suggested model are:

Student enrollment through grades are fundamental variables representing the progress of students into the education system and their advancement from one grade to another. These variables are regulated by inflows, such as passing fractions indicating students moving to higher grades, and outflows, such as dropout fractions reflecting students leaving the system prematurely.

[3] https://timssandpirls.bc.edu/timss2019/encyclopedia/pdf/Egypt.pdf
[4] https://www.capmas.gov.eg/Pages/Researchs.aspx?page_id=5031

The management of classrooms are represented by the variable "classes." Classes, considered as physical spaces for teaching and learning, are increased by adding new classrooms and decreased by depreciation or inadequate maintenance. The dynamics of classroom availability and utilization are influenced by feedback loops, such as class density:

Class Density represents the number of students per classroom, can significantly impact the quality of teaching and learning within Egypt's primary education system. Research suggests that high class density can have a detrimental effect on student performance (Kalemba 2022). However, it's important to note that the impact of class density can vary depending on other factors such as the teaching methods used, the subject being taught, and the resources available (Kalemba 2022). This highlights the complex interplay between class density and various educational factors, underscoring the need for comprehensive strategies to optimize classroom environments and enhance learning outcomes.

Teachers represent another key component in the model; they are replenished by new hires and diminished by retirements. In this model, we assumed that teachers could either be trained in modern methods such as Higher-Order Thinking Skills (HOTS) or not yet trained:

HOTS refers to students' abilities to think at a higher level. HOTS are vital for students in the 21st century due to technological advancements like the 4th Industrial Revolution. HOTS has become a global educational objective, shifting focus from mere memorization to fostering skills in analyzing, evaluating, and creating. Without the appropriate skill set and training, it is challenging to expect students to excel in higher-level thinking and reasoning (Sidiq et al. 2021, Kosasih et al. 2022). Many studies have demonstrated HOTS programs can significantly improve students' critical thinking abilities. Research indicates that teachers focused explicitly on developing skills like analysis, evaluation, synthesis and problem-solving leads to meaningful gains (Darling-Hammond 2017, Lombardi et al. 2021, Sidiq et al. 2021, Azid et al. 2022, Kosasih et al. 2022, Khaeruddin et al. 2023, Pradana et al. 2023) Consequently, teachers must equip students with high-level thinking skills, including the ability to analyze, evaluate, and create. In today's educational landscape, curricula and objectives worldwide emphasize the development of students' thinking skills. Therefore, ministries of education might consider designing teaching and learning methods that integrate Higher Order Thinking Skills (HOTS) across all subjects.

HOTS can be applied in elementary schools through various methods and approaches (Pradana et al. 2023), however, the availability of technology and multimedia capable of enhancing HOTs learning is also required, the most prominent of which is the use of fun thinker media based on HOTs questions. Teachers incorporate technology tools and multimedia resources to engage students in interactive and thought-provoking activities. These resources can stimulate critical thinking, encourage exploration, and provide opportunities for problem-solving and creativity (Pradana et al. 2023).

Pupil-to-Teacher Ratio: Furthermore, the quality of primary education is also influenced by factors such as the Pupil-to-Teacher Ratio in primary education. The pupil-to-teacher ratio can play a significant role in the effectiveness of teaching critical thinking (Kalemba 2022). A high pupil-to-teacher ratio can make it more challenging for teachers to give individual attention to each student, potentially hindering the development of critical thinking skills. The Global Competitiveness Report (GCR) includes the pupil-to-teacher ratio in primary education as an indicator under the “Skills” pillar, recognizing its importance in assessing the quality of education across different economies. A lower pupil-to-teacher ratio often indicates that teachers can give more individual attention to students, potentially leading to better learning outcomes. In the 2019 the GCR, Egypt was ranked 89th out of 141 countries.

Critical Thinking Index: critical thinking involves asking questions, collecting information, creatively sorting through it, connecting ideas with what has been learned, checking assumptions, and making logical conclusions and decisions. Critical thinking abilities of students must be enhanced in order to fulfill the demands of 21st century learning. One of these is through the use of HOTS-based learning (Pradana et al. 2023). Teachers can assist students by encouraging them to ask questions and reflect on their thought processes, extending beyond the classroom to real-life situations, not only within school but also in their daily lives. Research shows that primary education plays an important role in the development of critical thinking (Facione 2011, Lai 2011, Gelerstein et al. 2016, Lombardi et al. 2021). Critical Thinking in Teaching is considered a key skill to develop and foster among students across the school syllabi (Lombardi et al. 2021). The teaching of critical thinking is considered crucial for improving competitiveness as it equips citizens with the ability to analyze information objectively and make reasoned judgments. Teachers' perceptions of critical thinking among students influence their behaviors in the classroom (Choy and Cheah 2009). Teachers believe they are imparting critical thinking skills to their students and are confident that fostering critical thinking will stimulate intellectual growth (Choy and Cheah 2009). Regarding the ranking of Egypt according to this index, in 2019 Global Competitiveness Report, Egypt was ranked 123rd out of 141 countries, with a score of 2.7 out of 7, where 7 represents the highest level of competitiveness.

To enhance the quality the primary education in Egypt, a system dynamic model has been developed allowing decision-makers to intervene in studying a set of alternatives to improve some quantitative indicators of education, such as class density and pupil-to-teacher ratio. This is aimed at enhancing Egypt's position in the Critical Thinking Index as the final goal of this model.

3. Literature Review

System dynamics modeling has emerged as an effective tool for analyzing complex educational systems and providing insights for decision-makers. The studies presented here demonstrate varied applications of system dynamics across different educational contexts and levels.

(Altamirano and Van Daalen 2004) developed a system dynamics model for the Nicaraguan Ministry of Education, predicting that without intervention, there would be minimal improvements in school coverage and a notable increase in illiteracy. Their study suggests combining literacy programs and subsidies for impoverished families to effectively address educational issues in Nicaragua, emphasizing the necessity of multifaceted policy solutions. (Pedamallu et al. 2010) developed a system dynamics model to enhance primary education enrollment via infrastructure in Gujarat, India. It finds that better infrastructure significantly increases enrollment, offering insights for policymakers tackling educational challenges in developing countries through infrastructure upgrades. (Pedamallu et al. 2010) introduces a system dynamics model assessing infrastructure's influence on primary education quality. Employing Cross Impact Analysis, it underscores infrastructure's importance in enhancing education access and quality, offering policymakers a tool to simulate infrastructure improvements' effects on primary education systems.

(Qiu et al. 2017) examines higher education development coordination in Beijing, Tianjin, and Hebei regions via system dynamics modeling. It pinpoints challenges like resource distribution disparities, weak academia-industry cooperation, and talent-market mismatch. The study suggests strategic interventions in education investment, teacher enhancement, and regional collaboration to improve higher education quality and effectiveness.

(Al Hallak et al. 2019) studies Syrian private higher education enrollment dynamics through a system dynamics approach. It constructs simulation models to analyze interactions among student flows, staff ratios, and investments. The research, including interviews and surveys in private universities, aims to support decision-making in enrollment management. Results indicate the simulation model's utility in forecasting and improving enrollment strategies, with implications for educational sectors beyond Syria.

(Tomljenović et al. 2022) utilizes system dynamics modeling to analyze and predict teacher education enrollment policies in Croatia. It underscores challenges in aligning teacher supply with market demand, advocating for dynamic policy planning. The study validates the model with historical data, showcasing its effectiveness in guiding strategic decisions in educational policy to address potential teacher shortages or surpluses.

(Lin and Yu 2023) use a modified dynamic network data envelopment analysis model to evaluate Taiwan's compulsory education system efficiency from 2011 to 2020. It identifies inefficiencies, particularly in primary and middle school subsystems managed by local governments, emphasizing the importance of teacher and staff allocation based on student numbers for improvement. This research offers a methodological framework for evaluating and enhancing compulsory education system performance, contributing to educational policy.

(Bozkurt and Bozkurt 2024) emphasize the rising significance of systems thinking (ST) for sustainable development, noting increased research integration into education, particularly in science and engineering fields. They identify four main research clusters: theoretical ST studies, science and technology education, education for sustainable development, and green chemistry. However, while ST is prevalent in scientific disciplines, its application in social sciences and general education remains limited. The paper highlights the necessity for expanding ST applications in education, especially in social sciences, to address complex educational issues comprehensively.

The literature review reveals a research gap in developing a system dynamics model to model, analyze and improve the primary education system in Egypt in a holistic manner. While some studies examine aspects like enrollment and infrastructure, there is a lack of an integrated model mapping the key dynamics and interrelationships over time.

More specifically, an opportunity exists to explore how developing critical thinking skills can be incorporated into such a model. Given issues facing Egypt's primary schools like quality concerns, overcrowding and teacher shortages, cultivating critical thinking presents a promising approach. By including critical thinking, as a variable, the potential impacts of factors such as class density, pupil-to-teacher ratio and HOTS training could be assessed. Understanding the connections between critical thinking and these factors will aid decision-makers, therefore, this study provides a modeling tool to simulate scenarios and strategize reforms.

4. Methodology

System dynamics is a holistic methodology for analyzing and designing systems, diverging from traditional approaches that isolate individual factors. This method integrates various system components into a unified framework, exploring their interconnectedness and interdependencies over time. It's adept at tackling complex dynamic issues across social sciences, economics, environmental studies, and management, which involve feedback loops, delays, and nonlinear relationships. System dynamics enables profound insights into complex system structures and behaviors, allowing for scenario simulations, policy testing, and long-term consequence exploration. As a result, it supports informed decision-making, policy formulation, and strategy development in diverse fields, addressing the challenges posed by dynamic systems effectively. The system dynamics methodology was developed in the 1950s by (Forrester 1997). System dynamics is a robust method for comprehending the dynamics of complex systems over time. It focuses on system component interaction, highlighting feedback loops and time delays as key drivers of system behavior. This approach offers a thorough understanding and management of complex systems by examining the interplay between structure and behavior. Leveraging feedback loops, stocks and flows, and simulation modeling, system dynamics provides insights to inform decision-making in dynamic environments. The basic features of system dynamics are (Sterman 2010):

Feedback loops are essential for understanding how actions influence system behavior. Positive feedback loops amplify changes, potentially causing exponential growth or collapse, while negative feedback loops stabilize the system by counteracting deviations. Analyzing these loops is crucial for predicting behavior and identifying intervention points. Systems are dynamic entities shaped by internal processes and feedback loops, not merely extensions of past trends (Kennedy 1998).

Stock and Flow Diagrams: Stock and flow diagrams are tools used in system dynamics to illustrate the accumulation (stocks) and movement (flows) of quantities or resources within a system. Stocks represent accumulations of entities or resources over time, like population sizes or inventory levels. Flows depict the rates of change in these stocks due to inflows and outflows. These visualizations allow stakeholders to understand system behavior and identify crucial variables influencing change.

Simulation Modeling: System dynamics utilizes simulation modeling to replicate the behavior of complex systems across time. By incorporating feedback loops, stocks, flows, and other system dynamics principles into computational models, analysts can assess the outcomes of various policies, interventions, or scenarios. Simulation modeling allows stakeholders to experiment with hypotheses, evaluate strategies, and forecast the long-term effects of decisions prior to implementation. It serves as a valuable decision-making tool in dynamic and uncertain environments.

Relationship between Structure and Behavior: System dynamics emphasizes the relationship between structure and behavior. Changes in system structure, like adding or removing feedback loops, profoundly affect behavior. Examining these relationships helps identify leverage points where small interventions can lead to significant changes, enabling a deeper understanding and more effective management of complex systems.

5. System Dynamics model of the primary educational system of Egypt

The suggested Primary Education System Dynamic Model for Egypt includes interconnected subsystems: Enrollment, Primary Students, Classes, Teachers, and Critical Thinking. The Enrollment Subsystem captures demographic demand, while the Primary Students Subsystem manages student flow through grades. The Classes Subsystem oversees classroom dynamics, and the Teachers Subsystem manages teacher supply. The Critical Thinking Subsystem assesses Class Density, Pupil-to-Teacher Ratio, and Critical Thinking in Teaching. Together, these subsystems aim to analyze and improve educational quality in Egypt.

This section explains the subsystems of the suggested Primary Education system dynamic model, while detailed equations, variables, and parameters can be found in Appendix A. Generally speaking, the initial values of the parameters have been obtained from historical data, while the values of parameters in the model have been determined during the calibration process.

5.1. Enrollment Subsystem

The Enrollment Subsystem serves as the cornerstone for stimulating demand within primary education by capturing demographic dynamics related to children aged six. At its core lies the stock of "Children at the Entrance Age," which increases over time in accordance with the "Children Growth Rate," indicating the rate of child population expansion. This increment is further influenced by the "Children Growth Fraction," directly impacting the total of "Children at the Entrance Age." The output of this subsystem is the "Gross Enrollment Rate," calculated by multiplying the number of "Children at the Entrance Age" by the "Enrollment Fraction," representing the proportion of enrolled children relative to the eligible population. Figure 1 shows "Enrollment Subsystem," of the student enrollment in the primary education system. The elements of the "Enrollment Subsystem" are:

1. **Stocks**
    - "Children at the entrance Age": This accumulates the total number of students reaching school age and potentially enrolling.
2. **Flows**
    - "Children growth rate": This represents the rate at which the number of students reaching school age increases over time.
3. **Auxiliary Variables and Parameters**
    - "Enrollment Fraction": This parameter represents the portion of children reaching school age that actually enrolls.
    - "Gross Enrollment Rate": This reflects the total number of children enrolling in school, in each year.
    - "Children Growth Fraction": This parameter represents the fractional growth rate of Children[5].
    - "time": This parameter represents the progression of time in the model.

[5] https://worldpopulationreview.com/countries/egypt-population

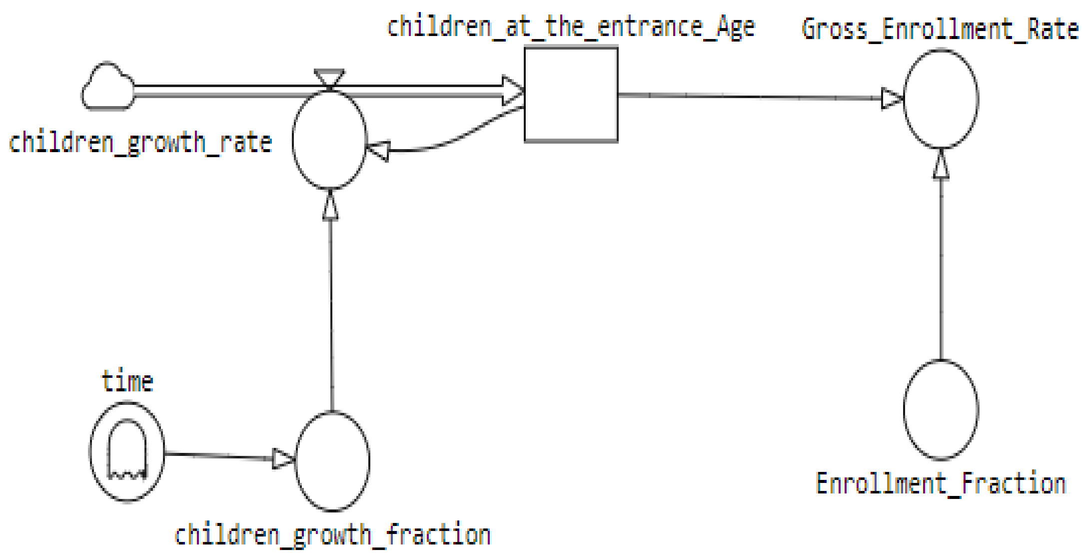

Figure 1
Enrollment Subsystem

5.2. Primary Students Subsystem

The Primary Students Subsystem comprises six stocks, with each stock representing the number of students progressing from stage one to stage six. Each stock is associated with one inflow and one outflow. The inflow represents the rate at which students passing rate to the next stage, while the outflow represents the dropout rate. We assume that all students enrolled in grade one is from the Enrollment Subsystem.

Figure 2 shows the "Primary Students Subsystem" of the suggested model of student enrollment in primary schools. It tracks student progression through different grades and considers factors that influence the number of students in each grade level. The subsystems elements are:

1. **Stocks**
   - Y1, Y2, Y3, Y4, Y5, and Y6: These six stocks represent the number of students in each grade level of the primary education system.
2. **Flows**
   - pass_1, pass_2, pass_3, pass_4, pass_5 and pass_6: These inflows represent the rate at which students successfully progress from one level to the next, e.g., pass_1 is the rate at which students move from Y1 to Y2.
   - Dropout_1, Dropout_2, Dropout_3, Dropout_4, Dropout_5, and Dropout_6: These outflows represent the rate at which students drop out of the respective grade level.
3. **Auxiliary Variables and Parameters**
   - Passing Fractions (1 to 6): These parameters represent the portion of students passing each grade level.
   - Dropout Fractions (1 to 6): These parameters represent the portion of students dropping out from each grade level.

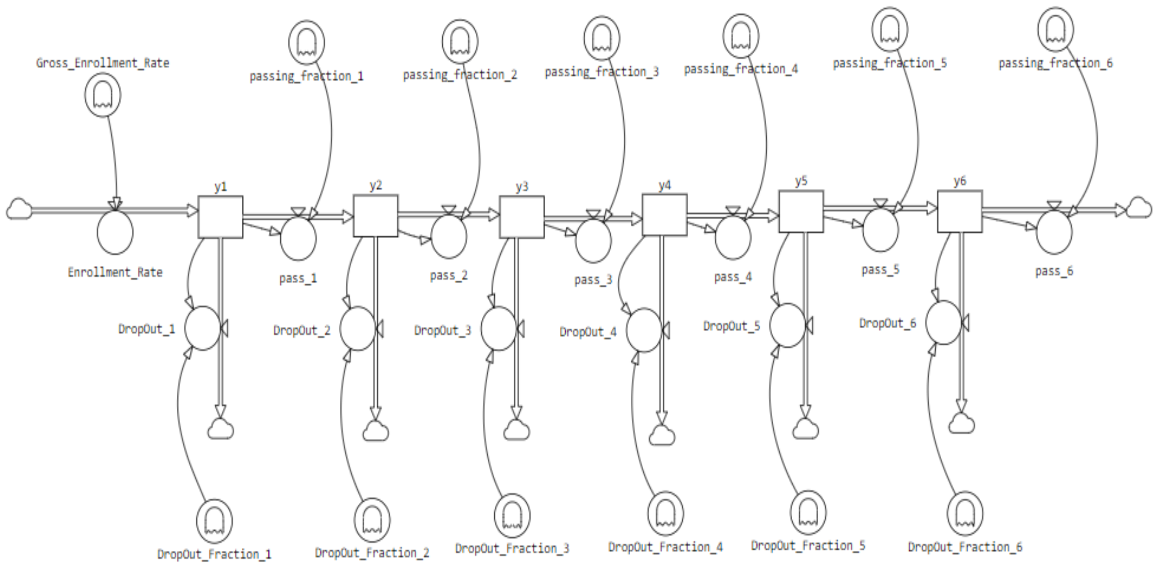

Figure 2
Primary Students Subsystem

5.3. Classes Subsystem

- The Classes Subsystem consists of only one stock, denoted as "classes," which represents the total number of classes. This stock grows over time through the inflow "Classes Growth Rate," representing the expansion of classroom numbers. Additionally, this growth is influenced by the "Classes Growth Fraction," which is controlled by two parameters: "Hist Classes Growth Fraction" and "Target Classes Growth Fraction." The former represents the historical growth rate of classes, while the latter can be utilized as a policy parameter, reflecting interventions made by decision-makers. The "classes" stock has one outflow, which is the "depreciation rate" affected by the "depreciation time." Figure 3 shows Classes Subsystem. The subsystems elements are:

1. **Stocks**

- "Total number of classes": This represents the total number of classes in the system.

5.4.Flows

- "Classes Growth Rate": This represents the rate at which new classes are added to the system.
- "Depreciation Rate": This represents the rate at which classes are removed from the system (due to depreciation).

5.5.Auxiliary Variables and Parameters

- "Classes Growth Fraction": This represents the fractional growth rate of total number of classes.
- "Depreciation Time": This time parameter determines how long (on average) it takes for a class to depreciate.
- "Hist Classes Growth Fraction": This parameter represents the historical fractional growth rate of classes.
- "Target Classes Growth Fraction": This parameter represents the desired fractional growth rate of classes.

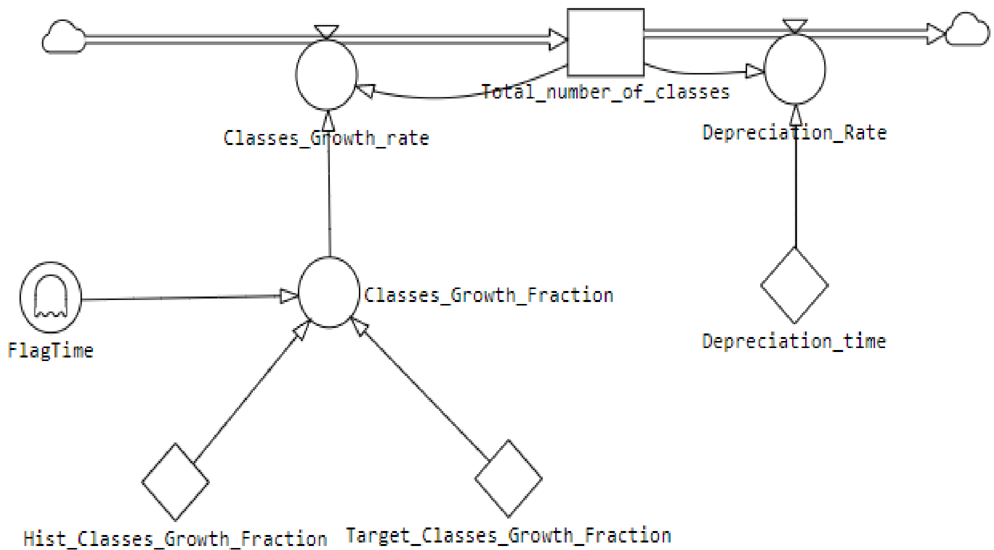

Figure 3
Classes Subsystem

5.6. Teachers Subsystem

The Teachers Subsystem manages the stock of teachers, comprising two categories: "ordinary teachers," representing untrained teachers, and "HOTS teachers," representing those trained in Higher Order Thinking Skills (HOTS). The total number of teachers equals the sum of these two stocks, increasing through hiring and decreasing through retirement. We assume that the Ministry of Education will design and implement a HOTS training program to increase teachers' efficiency by 50% throughout their academic careers, with 20% of teachers receiving HOTS training annually. Figure 4, shows the "Teachers Subsystem." The subsystems elements are:

1. **Stocks**
   - "Ordinary Teachers": This represents the total number of untrained teachers.

- "HOTS teachers": This represents the total number of HOTS trained teachers.

2. **Flows**
   - "Teachers Hiring Rate": This represents the rate at which new teachers are hired.
   - "Training Rate": This represents the annual training rate of ordinary teachers to become highly qualified trained teachers (HOTS).
   - "Teachers Retirement Rate": This represents the rate at which ordinary teachers retire. It is influenced by the average number of service years for a teacher.
   - "Trained Teachers Retirement Rate": This represents the rate at which trained teachers retire.

3. **Auxiliary Variables and Parameters**
   - "Teachers Hiring fraction": This represents the ratio of annual hiring of new teachers relative to the total number of teachers.
   - "Hist Teachers Hiring Fraction": This parameter represents the historical ratio of annual hiring of teachers relative to the total number of teachers.
   - "Target Teachers Hiring Fraction ": This parameter represents the desired ratio of annual hiring of new teachers relative to the total number of teachers.

- "Target annual training fraction": This parameter represents the desired fraction of ordinary teachers who should be annually trained to become highly qualified teachers (HOTS) each year.
- "Ind training rate": This auxiliary represents the indicated training rate of ordinary teachers to become highly qualified trained teachers (HOTS).

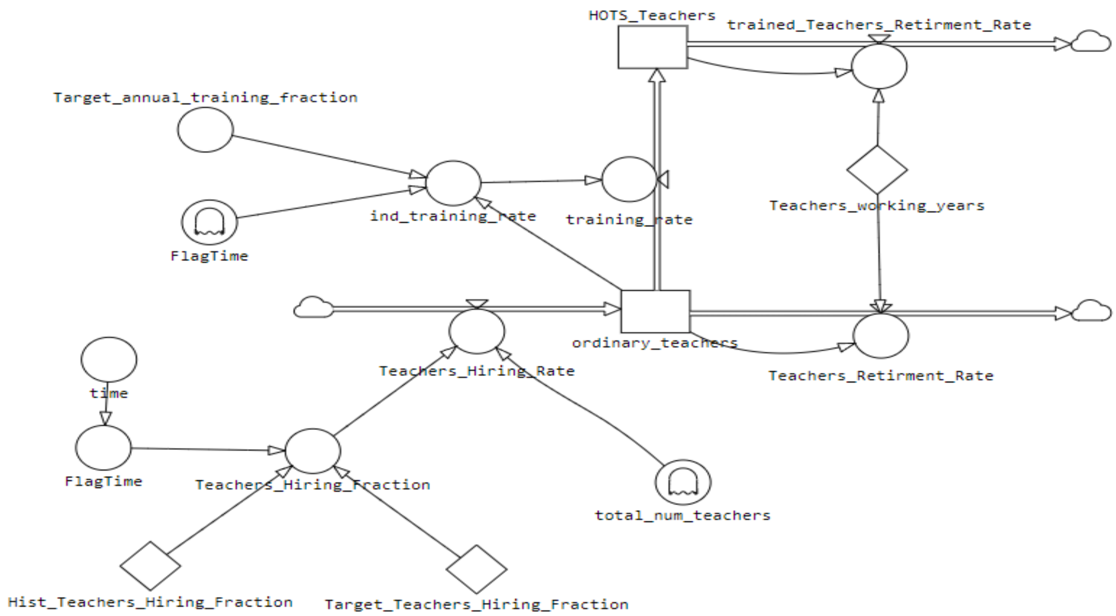

Figure 4
Teachers Subsystem

Our main assumption for this subsystem is that the Egyptian Ministry of Education will implement a HOTS training program that enhances the teacher's effectiveness by 50%. Therefore, the total effectiveness of the teachers will increase, and the total number of effective teachers can be calculated as follows: ("HOTS Teachers" by 1.5) plus "Ordinary Teachers", as Figure 5 shows.

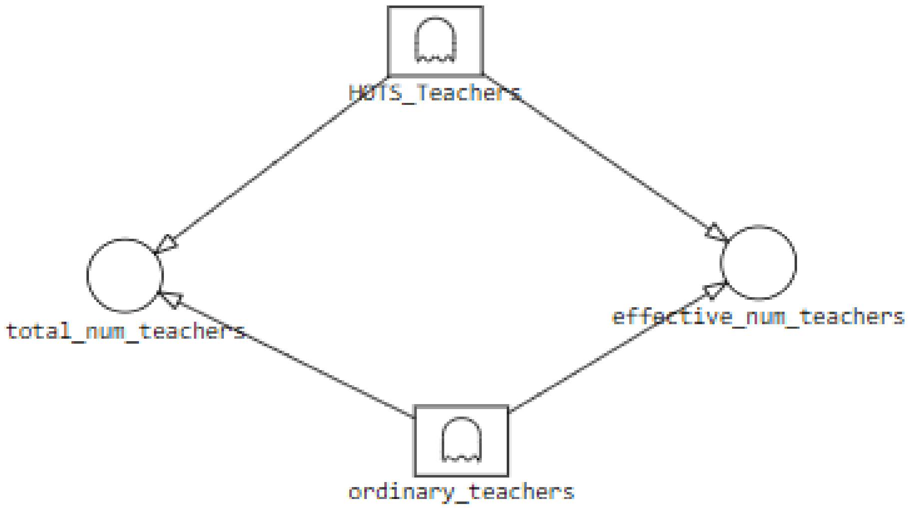

Figure 5
Total number of Teachers.

5.7. Critical Thinking Subsystem

While the preceding subsystems model the dynamics of primary education in Egypt, the critical thinking subsystem introduces the key indicators for measuring, assessing, and enhancing educational quality in Egypt. This subsystem calculates three main indicators: Class Density, Pupil-to-Teacher Ratio in primary education, and Critical Thinking. These indicators are vital for improving educational competitiveness and quality. The subsystem employs system dynamics to analyze the interplay among all the other subsystems and their influence on critical thinking.

We assumed that the Critical Thinking Index is calculated as a combination of factors: class density and pupil-to-teacher ratio. Our main assumption in this study is that the increasing rate of pupil-to-teacher ratio and class density indicators have negative influence on the critical thinking, the relationship among them could be complex, however, system dynamics can be used effectively.

Figure 6 illustrates the Critical Thinking Subsystem. Initially, class density is determined by dividing the total number of primary students on the total number of classes. Subsequently, the normalized class density is obtained by dividing the class density by the initial class density value. The next step involves the subsystem assessing the impact of class density on the critical thinking index by raising the normalized class density to the power of -1, representing the elasticity of the thinking index to class density. Also, the teacher-to-pupil ratio is determined by dividing the total number of primary students on the total number of teachers. Subsequently, the normalized teacher-pupil value is obtained by dividing the teacher-pupil ratio by the initial teacher-pupil value. Following this, the subsystem assesses the impact of teacher-pupil ratio on critical thinking by raising the normalized class density to the power of -1, representing the elasticity of the thinking index to class density. This implies that an increase in the teacher-pupil ratio has a negative effect on the critical thinking index. Finally, The Critical Thinking Index is derived by multiplying the Initial Thinking Index with the Effective Class Density on Thinking Index and the Effective Teachers on Thinking Index.

1. Auxiliary Variables and Parameters

1. "Class Density": This represents the average number of students per class and is calculated by: "Total number of primary students"/"Total number of classes."
2. "Initial Class Density": This parameter represents the initial value of number of students per class at the starting year 2016.
3. "Normalized Class density": This represents the normalized value of class density and is calculated by: "Class Density"/"Initial Class Density."
4. "Elasticity Thinking Idx to Class Density": This depicts how sensitive (on average) a student thinking ability to changes in class density. A high absolute value for this elasticity suggests that student thinking ability is highly affected by class size.
5. "Eff Class Density on Thinking Ux: This represents the impact of class density on students thinking ability (via the associated elasticity measure)
6. "Teacher pupil": This represents the pupil-teacher ratio (number of students per teacher).
7. "Initial Teacher pupil": This parameter represents the initial value of Pupil-Teacher at the starting year 2016.
8. "Normalized teacher pupil": This represents the normalized value of the pupil-teacher ratio.
9. "Elasticity Thinking Idx to Teacher": This depicts how sensitive (on average) a student thinking ability to changes in the pupil-teacher ratio. A

high absolute value for this elasticity suggests that student thinking ability is highly affected by this ratio.

10. "Eff Teachers on Thinking Idx": This represents the impact of pupil to teacher's ratio on student thinking ability (via the associated elasticity measure).
11. "Initial Thinking Idx": This represents the initial value of critical thinking index.
12. "Thinking Idx": This represents the current overall index of student thinking ability.

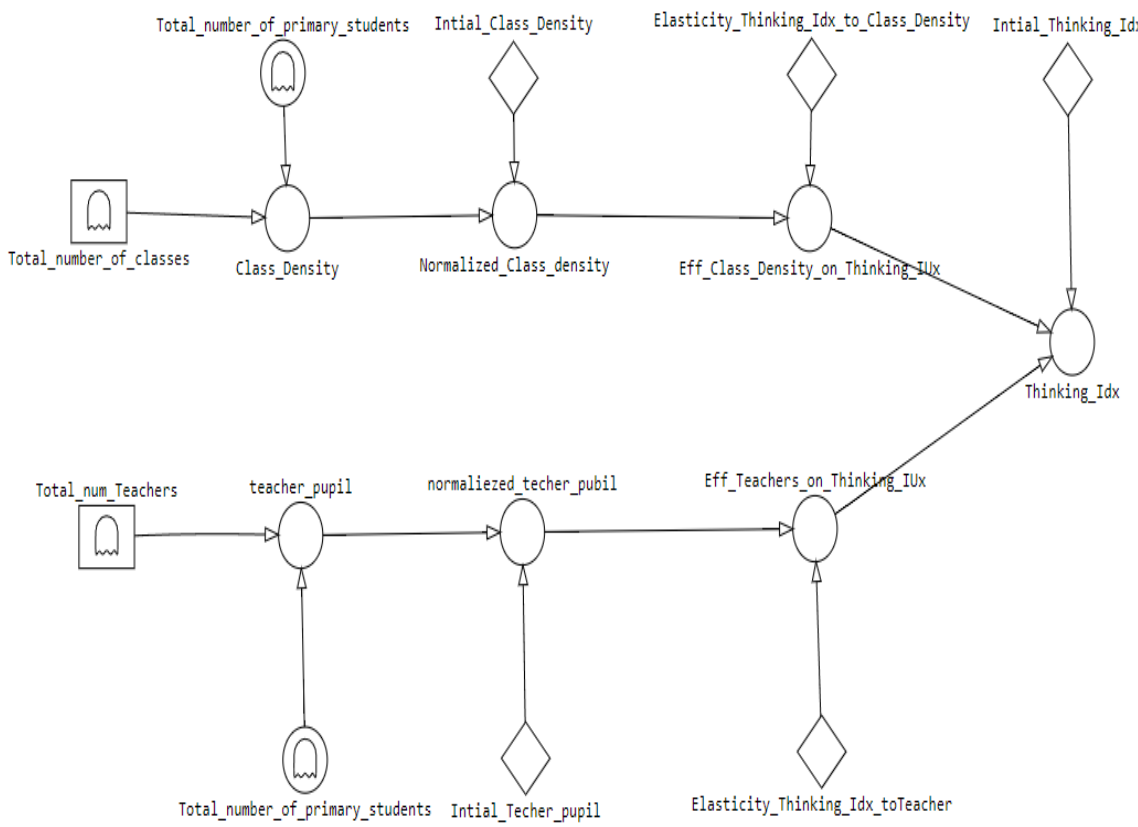

Figure 6
Critical Thinking Subsystem

6. Model Calibration and Validation

After completing the model development phase, the next step was to start the data collection process. The data has been gathered from authoritative sources, notably the Ministry of Education and Technical Education's Yearly Statistical Book and the Education section of CAPMAS Statistical Yearbook. Data has been gathered from the academic years 2016/2017 to 2023/2024. This data covers various issues related to the model. The model will be built and tested from 2016 to 2023 and then used to predict behavior and performance until 2035.

After completing the initial data collection phase, we transitioned to the crucial stage of data calibration. This iterative process is fundamental for fine-tuning and optimizing model parameters, variables, and equations to ensure a proper alignment with real-world dynamics. By comparing the model outputs with the collected data, we identified differences and variances, which enabled us to distinguish areas requiring refinement. Subsequent adjustments were then implemented to enhance the model's predictive accuracy and reliability. This calibration process facilitated a more robust and effective model that can better capture the complexities and nuances of the system under study. Figure 7 show the results of the calibration process.

Subsequent to the calibration process, a comprehensive quantitative behavioral validation was conducted across all subsystems, coupled with the comparison of key indicators as shown in Figure 7. Our findings reveal a notable convergence between the actual historical values of key indicators in the primary education system and the corresponding simulated values generated by the model. Particularly noteworthy, is that for each key indicator the simulated behavior has the same pattern as the corresponding historical behavior. Moreover, the variances (between simulated and historical behavior) fall within a narrow range of 1% to 4%. These validation testes corroborates that the proposed system dynamic model accurately capture the complex dynamics within Egypt's primary education system.

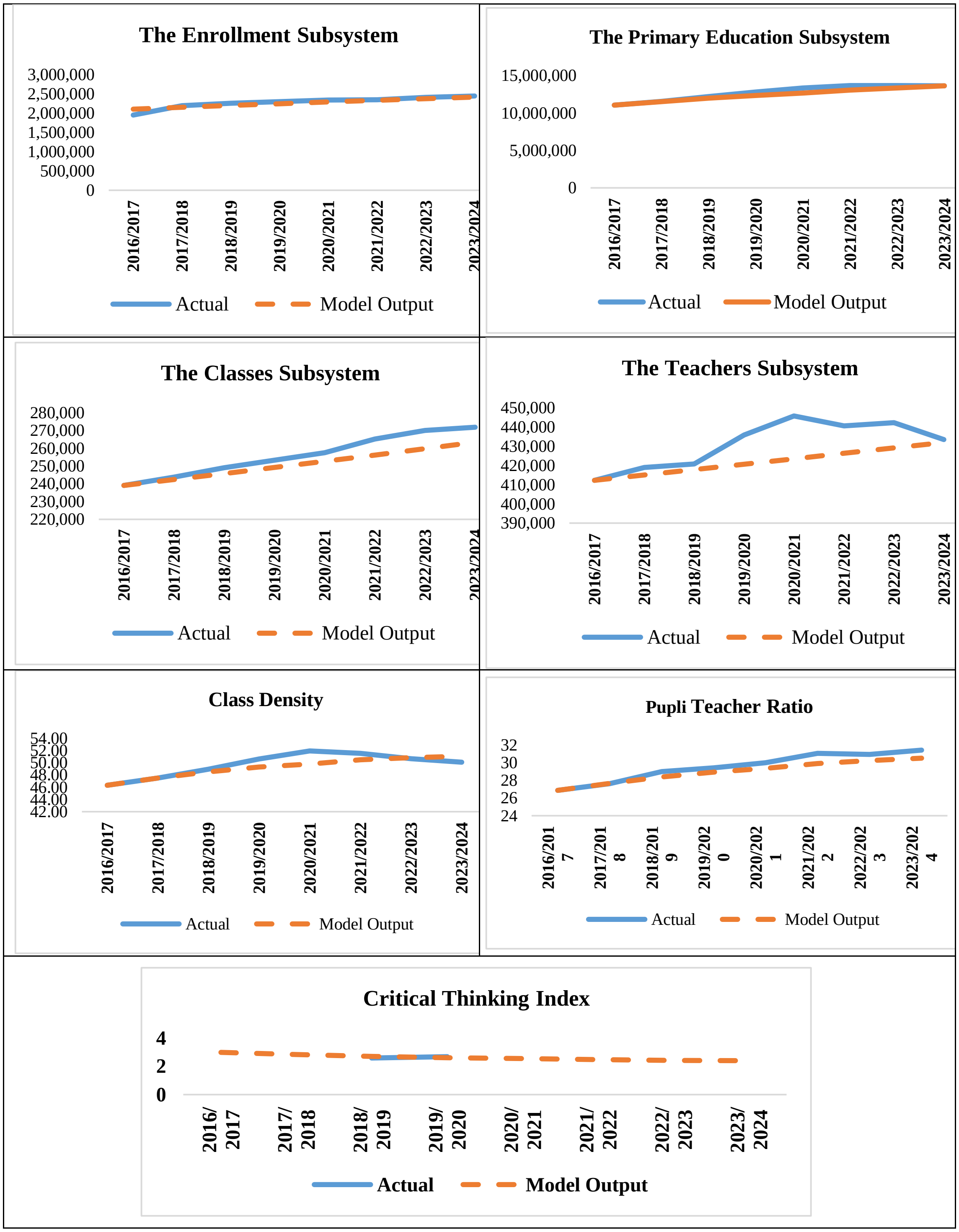

Figure 7
Model Calabrian Results

7. Model Behavior & Business-as-Usual Scenario

The purpose of this section is to examine the performance of Egypt's primary education system from the academic years 2016/2017 to 2023/2024, as well as to gain insights, trends, and patterns in performance indicators from 2024/2025 to 2034/2035.

This section introduces the Business-as-usual (BAU) scenario, which serves as the foundational framework for evaluating the educational system's performance. The BAU scenario is based on the idea that things will keep going as they have been, following current policies and plans. It looks at recent trends in important factors that affect the primary education. It is important because it sets a starting point to see how well the system is doing under normal and current conditions over the study period. This helps us to understand how the system works in the future. The reason for considering the BAU scenario are:

- The BAU scenario acts as a benchmark for assessing the primary education system's current performance under consistent practices. Decision-makers use it to evaluate effectiveness, strengths, and weaknesses, providing a reference point for analysis. Contrasting it with other scenarios enables robust comparative analyses, helping policymakers understand the impact of proposed interventions. This framework initiates discussions on implementing changes to improve education quality.
- The BAU scenario is vital for pinpointing areas needing improvement in the education system, offering insights into current challenges and future

possibilities. It equips decision-makers to make informed choices for ongoing educational enhancements, serving as a cornerstone for evidence-based policymaking. This scenario empowers stakeholders to navigate complexities with clarity and foresight, guiding the development of targeted strategies to propel the education system towards improved performance.

Table 1 displays the output of the suggested model's performance under the BAU scenario, offering insights into its trends and implications. The results indicate that:

- Both the class density and pupil-teacher ratio have experienced upward trends over the years, indicating potential challenges in maintaining optimal learning environments. From 2023/2024 to 2030/2031, class density increased by approximately 1.1 students per class, and the pupil-teacher ratio rose by approximately 2.3 students per teacher. Similarly, from 2023/2024 to 2035/2036, class density increased by approximately 1.4 students per class, and the pupil-teacher ratio rose by approximately 3.8 students per teacher. These trends suggest a need for careful resource allocation and potentially smaller class sizes to ensure effective teaching and learning experiences.
- The critical thinking index has shown a declining unfavorable trend over the modeled period, indicating a potential decrease in critical thinking skills. From the basic year 2023/2024 to 2030/2031, the index decreased by approximately 0.3, and from 2023/2024 to 2035/2036, the decrease was approximately 0.4. This trend emphasizes the significance of integrating

strategies that foster critical thinking skills into the educational curriculum, ensuring students are well-prepared for the challenges of the 21st century.

Table 1
Business-as-Usual Scenario outcomes

Academic Year	2023 / 2024	2030 / 2031	2035 / 2036
Class Density	51.0	52.1	52.4
Pupil Teacher	31.1	33.4	34.9
Critical Thinking	2.4	2.1	2.0

8. Scenario Planning for Primary Education in Egypt

The system's performance discussed earlier will serve as the standard baseline for comparing alternative policies in the following section. To continually improve the education sector, it's crucial to examine various scenarios aimed at boosting teaching and learning quality. These scenarios involve a range of interventions, all aiming to envision a future where education is accessible to everyone and fosters critical thinking, creativity, and lifelong learning. By exploring diverse strategies, we can pave the way towards a more equitable, inclusive, and effective educational system, preparing students for the challenges and opportunities of the 21st century. These scenarios explore different approaches to enhancing the education system, each targeting specific challenges and improving overall outcomes.

Scenario 1: Integrating Infrastructure and Teacher Hiring Scenario, which proposes a holistic strategy combining school infrastructure enhancement and hiring new teachers to accommodate a growing student population while maintaining teaching standards. The scenario assumes improved Infrastructure and hire teachers to create a suitable learning environment.

Scenario 2: Enhancing Teaching Quality through HOTS Training Program, which focuses on elevating teaching standards by implementing a HOTS training program for teachers. This scenario emphasizes professional development to enhance instructional techniques and improve the quality of education.

Scenario 3: Comprehensive Approach to Educational Enhancement, which combines infrastructure improvement, teacher hiring, and teacher training through the HOTS program. By addressing both physical and human resource constraints, this scenario aims to create an optimal learning environment and drive tangible improvements in student outcomes.

Scenario 1: Integrating Infrastructure and Teacher Hiring

This scenario proposes an integrated approach to educational enhancement by combining two key interventions: School Infrastructure Enhancement and Hiring New Teachers at a rate of 5% annually. This integrated strategy aims to address both infrastructure and human resource constraints within the educational system, providing a holistic solution to the challenges of accommodating a growing student population while maintaining high-quality teaching and learning standards.

The School Infrastructure Enhancement intervention involves constructing new classrooms to alleviate overcrowding, while Hiring New Teachers aims to expand the teaching workforce for adequate student support and favorable pupil-teacher ratios. This integrated scenario addresses challenges posed by increasing student enrollment. Scenario 1 explores synergies between infrastructure improvements and staffing enhancements, envisioning schools equipped with physical and human resources for academic excellence and student success. Table 2 displays the scenario results.

- Class density shows a consistent decrease over the modeled period. From 51.0 in 2023/2024, class density decreases to 37.6 in 2035/2036, indicating a significant improvement in the distribution of students across classrooms.
- Pupil-teacher ratio demonstrates a favorable trend, decreasing from 31.1 in 2023/2024 to 29.0 in 2035/2036. This decrease indicates a more balanced distribution of teaching resources, resulting from the increase in total teachers through the Hiring New Teachers intervention.
- Critical Thinking Index exhibits notable improvement, reflecting enhanced critical thinking skills development within the educational system. Starting at 2.4 in 2023/2024, the critical thinking index rises to 3.4 in 2035/2036, indicating the positive impact of comprehensive educational enhancement strategies on student learning outcomes.

Table 2
Integrating Infrastructure and Teacher Hiring Scenario outcomes.

Academic Year	2023 / 2024	2030 / 2031	2035 / 2036
Class Density	51.0	43.5	37.6
Pupil Teacher	31.1	30.2	29.0
Critical Thinking	2.4	2.8	3.4

Scenario 2: Enhancing Teaching Quality through HOTS Training Program

This scenario suggests the implementation of the HOTS training program for teachers to improve instructional methodologies and teaching strategies. This intervention aims to elevate teaching standards, improve teaching quality, and create a more conducive learning environment for students. Through this scenario, we aspire to create a learning environment where students thrive, teachers excel, and educational excellence becomes the norm.

We assumed that the HOTS training program, facilitated by the Ministry of Education, focuses on enhancing the effectiveness and building the capacity of teachers. Additionally, we assumed that HOTS training will be conducted for 20% of the total teachers annually and will be designed to increase teacher efficiency by 50% over the course of their tenure as educators. The main assumption of this scenario is that HOTS training will enhance teachers' efficiency and build their capacity, enabling them to utilize modern, technology-supported methods. This will assist in better classroom management and the fostering of critical thinking skills.

Table 3 shows that the Pupil Teacher Ratio has improved from 31.1 in 2023/2024 to 24.9 in 2030/2031 and remains relatively stable at 24.8 in 2035/2036. However, this improvement is a result of the increased efficiency of the teacher as a direct result of HOTS training. Therefore, the critical thinking index improved, with an increase from 2.4 in 2023/2024 to 2.9 by 2035/2036.

This suggests that interventions or changes in educational practices have positively impacted students' critical thinking skills, contributing to overall educational quality. The results also indicate that in the short term, Scenario 2 may succeed in empowering teachers to enhance students' critical thinking abilities. However, in the long term, intervention through other scenarios may be necessary.

Table 3
Enhancing Teaching Quality through HOTS Training Program scenario outcomes.

Academic Year	2023 / 2024	2030 / 2031	2035 / 2036
Class Density	51.0	52.1	52.4
Pupil Teacher	31.1	24.9	24.8
Critical Thinking	2.4	2.9	2.9

Scenario 3: Comprehensive Approach to Educational Enhancement

In this comprehensive scenario, we propose a comprehensive approach to educational enhancement by combining two key interventions: School Infrastructure Enhancement and Hiring New Teachers at a rate of 5% annually, alongside the implementation of a HOTS training program for teachers. This multifaceted strategy aims to address both physical and human resource constraints within the educational system, providing a holistic solution to the challenges of accommodating a growing student population while maintaining high-quality teaching and learning standards.

Table 4 shows that, Class Density shows a significant decrease over the years. It drops from 51.0 in the academic year 2023/2024 to 43.5 in 2030/2031 and further decreases to 37.6 in 2035/2036. The pupil-teacher ratio decreases substantially. It drops from 31.1 in 2023/2024 to 22.8 in 2030/2031 and further decreases to 21.0 in 2035/2036. The Critical Thinking Index shows a remarkable increase over the years. It rises from 2.4 in 2023/2024 to 3.8 in 2030/2031 and further increases to 4.7 in 2035/2036.

The substantial improvement in the Critical Thinking Index is attributed to the decreasing class density and pupil-teacher ratio, which may have a positive impact on the quality of education and the development of critical thinking skills among students.

Table 4
Comprehensive Approach Outcomes

Academic Year	2023 / 2024	2030 / 2031	2035 / 2036
Class Density	51.0	43.5	37.6
Pupil Teacher	31.1	22.8	21.0
Critical Thinking Index	2.4	3.8	4.7

9. Results and Discussion

Egypt's primary education system is confronting substantial challenges that pose a threat to both educational quality and the fostering of critical thinking skills among students. Consequently, the examination and discussion of both the BAU scenario and alternative scenarios becomes essential, highlighting the necessity of adopting a multifaceted approach to address these pressing challenges. Therefore, this section outlines the implications of implementing BAU and the suggested three scenarios, each representing potential interventions for decision-makers aimed at improving key educational indicators:

- Class Density: Under the BAU scenario, the class density ratio consistently increases over the years, indicating a trend of overcrowding in classrooms. This highlights the challenge of maintaining optimal learning environments within the existing educational framework. As Figure 8 shows, in Scenario 1, which focuses on enhancing infrastructure and hiring new teachers, there is a noticeable improvement in class density ratios compared to the BAU scenario. Similarly, Scenario 3 demonstrates a significant improvement in class density ratios compared to the BAU scenario.

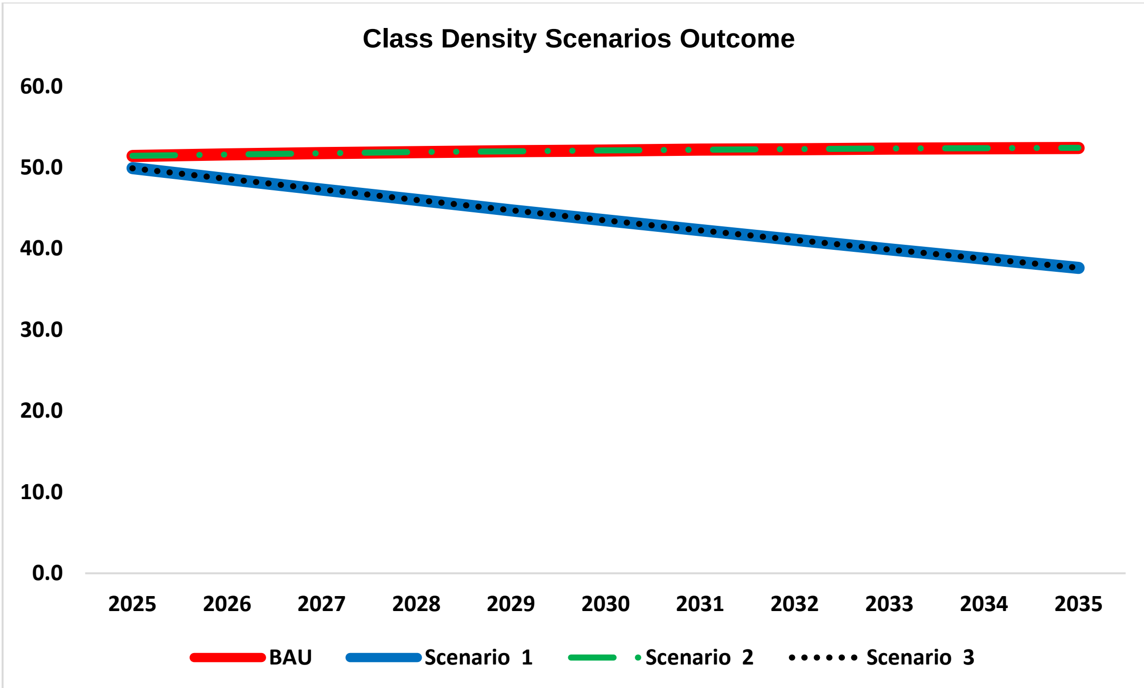

Figure 8
Class Density Scenarios Outcome

- **Pupil-Teacher Ratio**: In the BAU scenario, the pupil-teacher ratio consistently increases, indicating a growing imbalance between student numbers and the total number of teachers. Figure 9 illustrates that all scenarios exhibit enhancements in the index, underscoring the effectiveness of the interventions. Scenario 1 exhibits a decreasing trend attributed to infrastructure enhancements and increased teacher hiring. Scenario 2 highlights significant improvement due to HOTS teacher training, indicating the positive impact of investing in professional development. Lastly, Scenario 3 demonstrates the most substantial improvement, resulting from a combined approach of infrastructure enhancement, teacher hiring, and training.

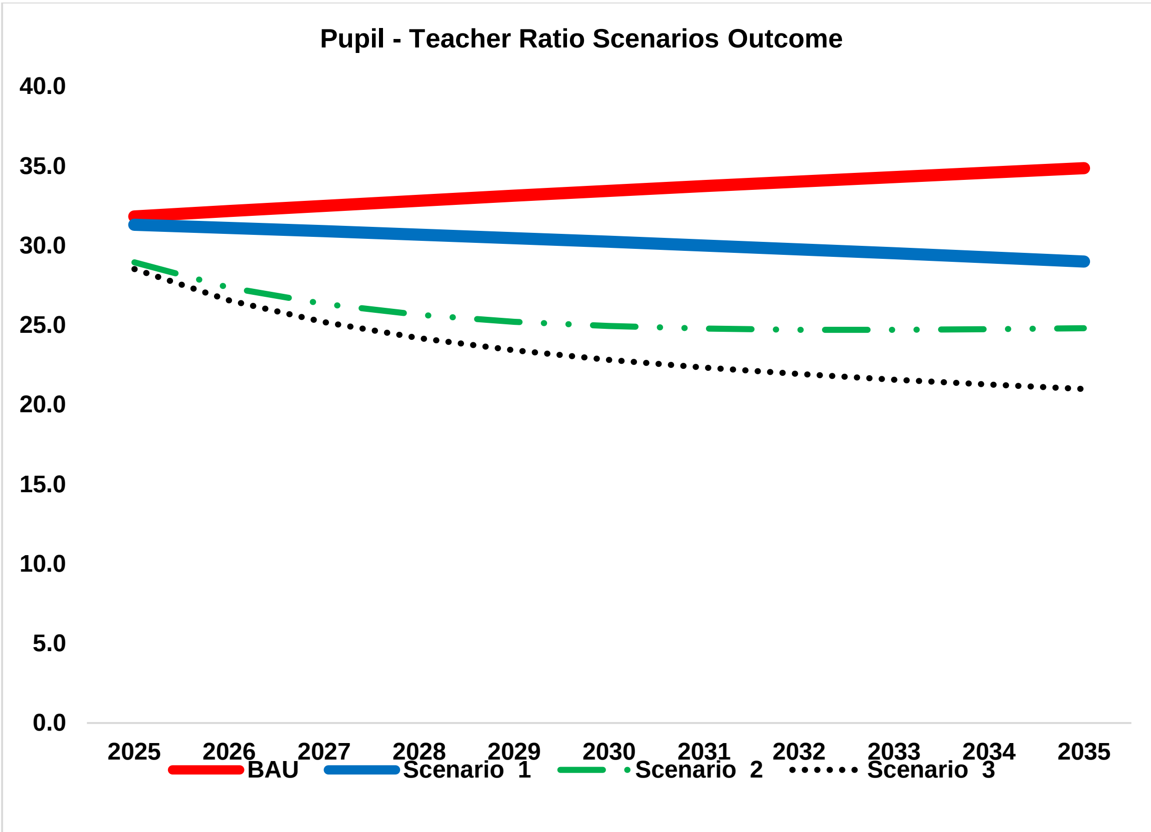

Figure 9
Pupil - Teacher Ratio Scenarios Outcome

- **Critical Thinking:** In the BAU scenario, the critical thinking index consistently declines, signaling a concerning trend in critical thinking skill development without interventions. This suggests current educational practices may not effectively foster critical thinking abilities. Scenario 1 exhibits a gradual increase in the critical thinking index, attributed to infrastructure enhancements and teacher hiring. Scenario 2 shows modest improvement due to the HOTS training program, emphasizing the need for additional interventions. Scenario 3 demonstrates the most significant improvement, resulting from a comprehensive approach.

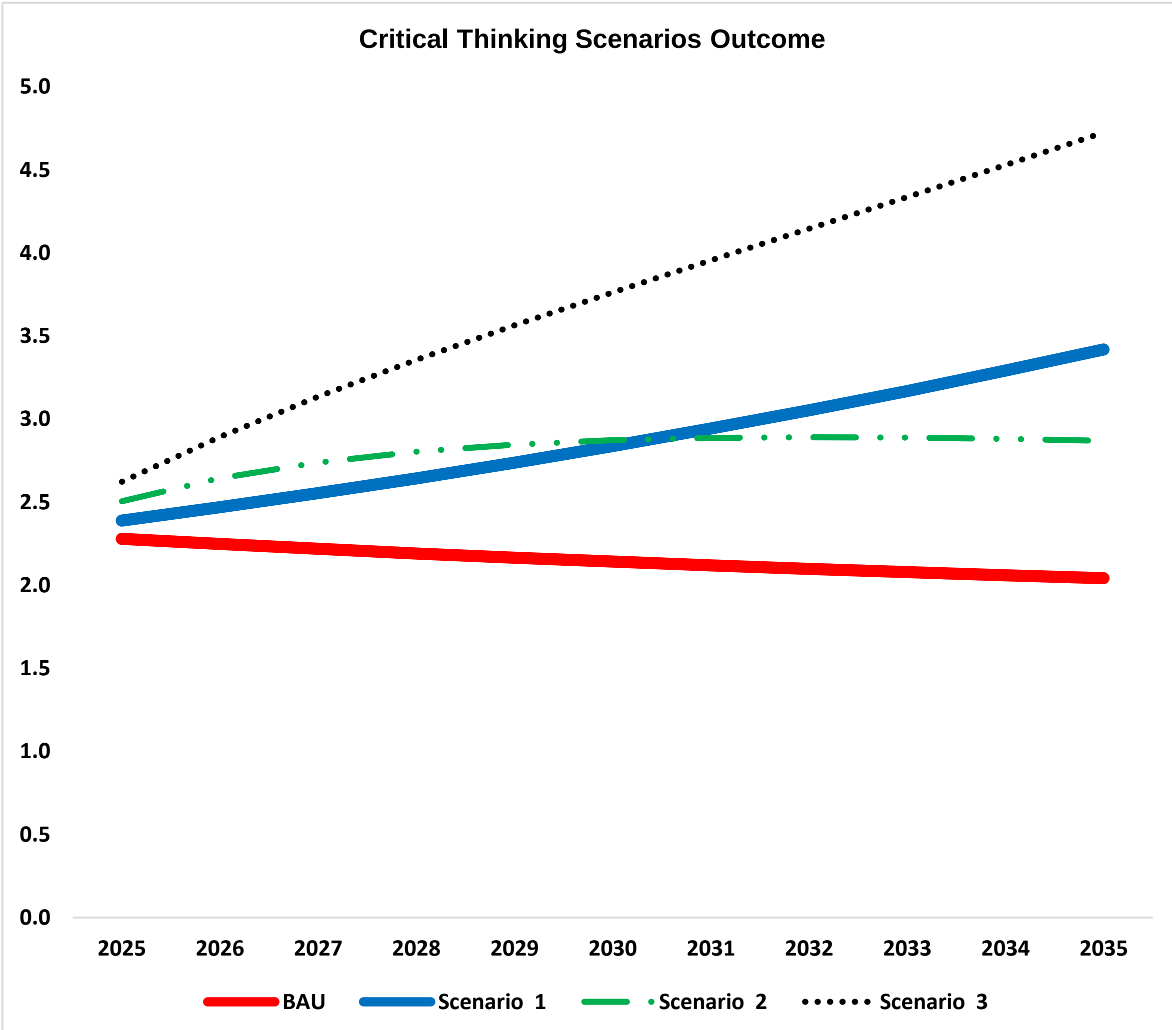

Figure 10
Critical Thinking Scenarios Outcome

This study suggests a new system dynamics model to model, analyze and improve Egypt's primary education system, identifying challenges and proposing interventions to improve educational quality and critical thinking skills among students. It considers a Business-as-Usual scenario, projecting negative trends like increased class density, Pupil-teacher ratio, and declining critical thinking abilities. The findings emphasize the necessity of strategic interventions, particularly focusing on infrastructure, human resources, and professional development for teachers. Ultimately, the study offers valuable insights for policymakers and stakeholders, advocating for a holistic approach to address Egypt's primary education challenges.

10. Conclusion

This study highlights the critical challenges within Egypt's primary education system, including increasing class density, unfavorable pupil-teacher ratios, and declining critical thinking skills. Through the development of a comprehensive system dynamics model, various scenarios were analyzed to assess the potential impact of different interventions.

The Business-as-Usual (BAU) scenario indicated that without intervention, the primary education system will continue to decline, with worsening class density and pupil-teacher ratios. In contrast, scenarios that included infrastructure improvements and teacher training showed significant potential for positive change.

Specifically, Scenario 1, which integrated infrastructure enhancements and new teacher hiring, resulted in decreased class density and improved pupil-teacher ratios. Scenario 2, focusing on HOTS (Higher Order Thinking Skills) training for teachers, showed modest improvements in critical thinking skills but suggested the need for additional interventions for long-term success. Scenario 3, combining both infrastructure improvements and teacher training, demonstrated the most substantial improvements across all key indicators.

The findings emphasize the necessity of a comprehensive policy approach that combines school infrastructure enhancement with professional training programs for teachers. Such an integrated and comprehensive strategy is crucial for tackling problems in Egypt's primary education sector and creating a more conducive learning environment for students. Policymakers and stakeholders should consider these insights to implement effective interventions that enhance educational quality and critical thinking skills among primary school students.

Acknowledgment

I would like to acknowledge Prophet Muhammad (Peace Be Upon Him), who has guided all of humanity from darkness into light.

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