THE EFFECT OF SOLVING ENVIRONMENTAL PROBLEMS WITH SYSTEMS DYNAMICS ON EIGHTH-GRADE STUDENTS' COMPREHENSION OF LINEAR EQUATIONS AND SYSTEM DYNAMICS

INTRODUCTION

1.1 Statement of the Problem

Mathematics has always been one of the main tools individuals utilize to address difficulties in their daily lives (Krantz, 2010). It gives one the capacity to take a multifaceted approach to problems, cultivate an analytical mindset, and make predictions (Korkmaz, Dündar & Yaman, 2016). However, mathematics in school often appears as a disconnected, abstract entity from students' everyday problems, making it challenging for them to understand (Bishop, 1991). This is why it's essential to make mathematical concepts concrete from an early age, bring problems from daily life into the classroom, and present them in their context (Lopes, Grando, & D'Ambrosio, 2017). When looking at the mathematics curriculum in Turkey, it primarily focuses on improving students' procedural skills while not allocating enough time to the application of higher-order thinking skills (Altıner, 2021).

Since 2018, the mathematics curriculum has included "contextual problems" which are questions that are contextualized in real-world settings. Additionally, contextual problems make up the majority of the content of central high school entrance tests (Ministry of National Education (MoNE), 2023). When examining the curriculum as a whole, it is evident that the lesson material falls short of providing students with the necessary skills to address these complex issue types (Arı, 2022).

Examining the issue from all aspects is necessary when defining complex problems. It takes interdisciplinary thinking to approach problems from all angles. Real-world issues are, in fact, intrinsically multidisciplinary (Yanitsky, 2020). Students need to learn an interdisciplinary approach and the ability to look at things holistically to acquire these thinking practices (Lyneis, 1995).

The systems thinking approach encourages examining and evaluating the problems created by the complexity of a problem, paves the way for holistic thinking, and enhances the ability to reach better solutions (Maani & Maharaj, 2001). It develops students' thinking patterns

in terms of how to address a problem, how to approach it, and which tools are appropriate (Ehrlinger & Eibach, 2011).

System dynamics tools enable systems thinking approach to be concretely applied in education. These tools are adaptable to different subjects, suitable for all age levels, and useful. Students can better delineate real-life problems they encounter by designing numerical models using system dynamics tools within a simulation program. They can observe the movements of dynamic problems with behavioral graphs over time. In this way, they have the opportunity to find more sustainable solutions to problems (Göktepe, 2022).

The Turkish education system should also be supported with approaches to self-directed learning and holistic thinking (Bulut, 2022). In Turkey, the Ministry of National Education (2006) aims to address this issue by incorporating constructive learning methods in new curriculum designs, but the educational programs and practices have not yet reached an adequate level (Arslan, 2007). The system dynamics approach, based on the philosophy of constructive learning, supports this framework as an interdisciplinary learning approach. Extending the examples and incorporating the systems dynamics method into the mathematics and other disciplines' curricula will help students investigate, define, and come up with comprehensive answers to the issues in their environment (Nuhoğlu, 2008).

1.2 Purpose of the Study

The aim of this study is to explore the effect of using system dynamics tools on understanding and comprehension of linear equations among 8th-grade middle school students. When we look at examples in the literature, we can see that the systems thinking in education contributes to the skills of the 21st century that are evolving in the light of technological advancements, and when integrated into lessons in a way that enhances learning, it increases student achievement in various skill areas (Richmond, 2010; Thornton, Peltier & Perreault, 2004). In light of these studies, the purpose of the study has been shaped as follows:

1. Enhancing students' skills in drawing linear graphs using numerical data in the digital simulation environment of STELLA Online, interpreting real-life situations as linear or nonlinear through graphs, predicting the behavior of events over time, and drawing conclusions,
2. Developing comprehension skills, including the interpretation of cause-and-effect relationships between variables established through models, with the use of feedback loop approach (Kim, 1999),

3. Increasing students' success in solving skill-based questions related to linear equations,
4. It will enable students to understand the systems thinking approach; To enable stock-flow and factors, which are basic tools of system dynamics, to establish their relationships with behavior graphs over time,
5. Lesson plans to be implemented with the systems thinking approach are inherently interdisciplinary (Yanitsky, 2020). Increasing students' motivation in mathematics classes through interdisciplinary lesson plans centered around real-life environmental problems adapted from real life,
6. Raising awareness and a sense of responsibility toward their environment among students through the integration of real environmental issues into the applications,
7. Observing potential issues during the implementation of the study and collecting data to minimize these issues in future similar applications,
8. The aim is to present examples of mathematics lesson plans created using the system dynamics approach in a way that serves as a model for mathematics teachers and teacher candidates, with the goal of promoting the wider use of the system dynamics approach in education.

METHODOLOGY

2.1 Research Questions

This study aims to investigate the impact of system dynamics tools on the comprehension of linear equations in the 8th grade secondary school mathematics course. The research questions for this study are:

1. Is there a significant difference in the mathematical achievement scores related to linear equations, which are part of the algebra unit, between the experimental group and the control group students after the experimental process?
2. Is there a correlation between the scientific achievement test results of the experimental group students and their system dynamics comprehension test results?
3. How does teaching mathematics using the System Dynamics approach affect eighth-grade students' attitudes towards linear equations?

2.2 Research Design

The study employed a two-group posttest design, with one group serving as the control and the other as the experimental group. Statistical analyses were conducted on the scores obtained from the post-test instruments. To support the findings, the researcher conducted interviews with students from both groups whose solutions were not understood or interpreted due to low processing in the scientific achievement post-test and the dynamics of the cognitive system post-test. Ericsson and Simon (1993) argue that the Think Aloud Protocol they developed enables students to articulate their thoughts out loud while solving problems, allowing researchers to gain insights into students' cognitive processes. In this study, students were asked to explain the methods they used to solve the questions and their purposes using the think-aloud method after the tests. The aim was to obtain information about the cognitive processes of students whose solutions were not clearly understood or did not show the procedural steps.

2.3 Study Group

This study examines 8th-grade students at a foundation school in Sarıyer, Istanbul. The school was chosen because the researcher was a teacher at the school. The research school is a boarding school that admits students through an exam. The students come from various provinces of Turkey.

Additionally, the study utilizes the Stella Online application as a simulation program, which requires students to use a tablet or computer during each session. The school where the research was conducted teaches with tablets, and each student has a personal tablet. The study involved a control group and an experimental group, each comprising 22 participants. The school has three classes with similar math grade point averages (GPAs) and one class with students who have higher math GPAs. For this study, classes 8C and 8D with similar GPAs were chosen. The math GPA of the control group, class 8D, was 79.0, while that of class 8C was 79.0. The researcher selected class 8C as the experimental group because it had a more suitable mathematics syllabus. A total of 44 students, consisting of 26 boys and 18 girls aged 13-14 years, participated in the study. There were 13 boys and 9 girls in both groups.

2.4 Data Collection

The objective of this study is to examine the impact of system dynamics tools on the understanding and comprehension skills of 8th grade students regarding linear equations. The control and experimental groups were administered scientific achievement tests on linear equations as a data collection tool, while the experimental group was given system dynamics comprehension tests. Post-test questions and data analysis were selected using SOLO Taxonomy. This section provides a detailed account of the data collection and analysis methods employed in the study.

2.4.1 The Scientific Achievement Test

The researcher created the Scientific Achievement Test (SAT) to assess the post-test of the experimental and control group students on linear equations, taking into account the learning outcomes in the mathematics curriculum (MoNE, 2022). The test questions were selected from the multiple-choice questions under the title of 'Contextual Problems' shared on the website of the Ministry of National Education and were applied as open-ended questions by deleting the choices (MoNe, 2022). Additionally, the lesson plan included similar linear equation questions that assessed the same skills and were solved during the lesson. The researcher added two higher-level questions, based on the SOLO taxonomy, by including two extra options in two of the four selected questions. During the test, the questions required the students to provide process steps. The scientific achievement test consisted of four questions and was completed within 20 minutes.

2.4.2 The System Dynamics Comprehension Test

The System Dynamics Comprehension Test (SDT) was administered as a post-test to measure the experimental group students' understanding of the basic concepts of system dynamics. SDT was originally designed by Hasret Nuhoğlu for her doctoral dissertation (2008) and was restructured and applied by the researcher in accordance with her own study. The test consists of six questions. The first five questions include various question types, such as multiple choice, fill-in-the-blank, model and graph construction, and model completion. Question 6 is an open-ended inquiry that solicits feedback from students regarding the most

significant aspect of mathematics lessons that incorporate system dynamics tools. The purpose of this question is to collect data that can be utilized to enhance future implementations.

2.4.3 SOLO Taxonomy

The aim of the research is to measure students' comprehension of linear equations using system dynamics tools and scales. System dynamics is a methodology that enables us to identify the components of a system and the connections between them, and to approach events from a holistic perspective (Richmond & Peterson, 2001). Upon analyzing the SOLO Taxonomy steps, it becomes apparent that the steps are based on either existing or non-existing relationships. For instance, the unistructural and multistructural steps do not have any relationship, but the relational step mentions the relationship of information. Thus, the SOLO Taxonomy steps can aid in evaluating applications created with the systems thinking approach. Additionally, according to Biggs and Collis (1982), cognitive response progresses from simple to abstract, and the SOLO Taxonomy was developed based on this theory. The SOLO Taxonomy's hierarchical structure enables more effective measurement of students' cognitive levels.The model supports the relationship between system dynamics and the SOLO taxonomy (Figure 2.1).

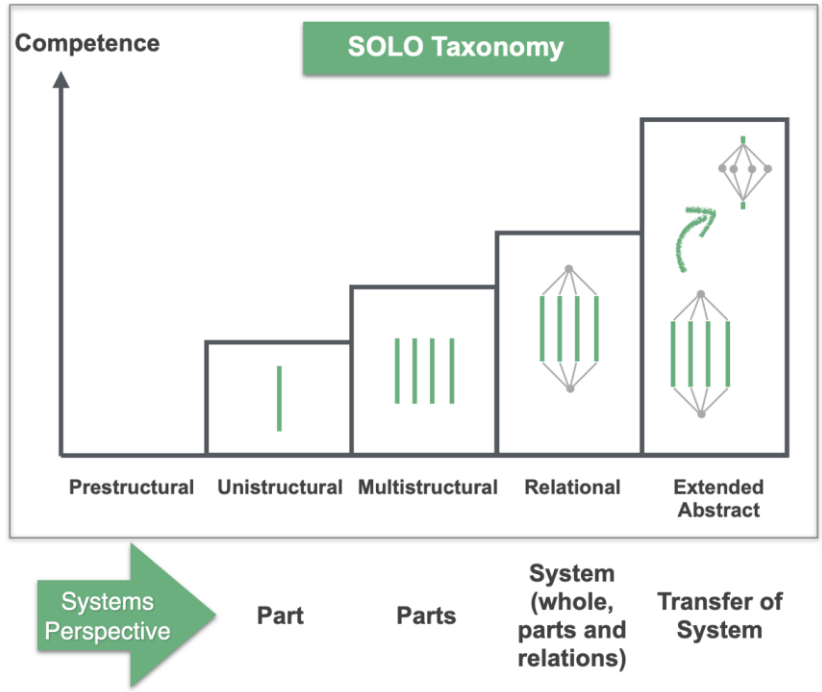

Figure 2.1 Alignment of SOLO Taxonomy with Systems Thinking (Systems Thinking Association, 2024)

2.5 Data Analysis

Below is a mention of the scales used to answer the research questions.

2.5.1 Analysis of the Scientific Achievement Test

Prior to the application, the mathematics exam averages of the experimental and control groups for the fall semester of 2023-2024 were accepted as pretests and analyzed. The independent sample t-test was applied in the SPSS program, revealing no significant difference between the two groups. Therefore, it was concluded that the two groups had equal achievement levels.

The scientific achievement test includes four open-ended questions, two of which require higher thinking skills based on the SOLO Taxonomy. The questions were evaluated using the four steps of the SOLO Taxonomy: Unistructural, Multistructural, Relational, and Extended Abstract. The researcher used a rubric to examine the relationship between each step taken by the students and the steps in the SOLO Taxonomy. The language used is clear, concise, and objective, adhering to formal register and avoiding biased or ornamental language. The text is grammatically correct and follows conventional academic structure and formatting. Each question was scored on a scale of 0 to 4. If the students' solutions were unclear, interviews were conducted to better understand their thought process before scoring.

The scientific achievement test scores of the experimental and control groups were analyzed using an independent t-test in the SPSS program to determine if there was a significant difference between the averages.

An independent samples t-test was conducted to compare the average scores of the experimental group (M = 13.41, SD = 4.25) and the control group (M = 9.27, SD = 3.61). The t-test revealed a statistically significant difference between the groups ($t(42) = 3.48$, $p = 0.69$). The study found that the effect sizes (Cohen's (1988) d = 0.21) indicated that there was a significant difference between the two groups.

2.5.2 Data Analysis of the System Dynamics Comprehension Test

The experimental group students underwent a post-test on their comprehension of system dynamics. The test consisted of six questions, five of which assessed their logic and use of system dynamics tools. The final question asked for their evaluation of the mathematics

lessons taught with system dynamics.The evaluation of the system dynamics comprehension test was based on the SOLO Taxonomy, as used in scientific achievement tests. The researcher used a rubric to associate student answers with the steps of the SOLO Taxonomy and score each question between 0 and 4.

A correlation test analysis was performed in the SPSS program to determine if there is a relationship between the scientific achievement test results and the system dynamics comprehension test results.

The System Dynamics Comprehension Test consists of 5 items (M = 13.27, SD = 0.70). The Scientific Achievement Test has 6 items with question choices (M = 13.41, SD = 4.25). A moderate correlation (r = 0.57) between the Total Score SDT and Total Score SAT of the experimental group. This suggests that participants in the experimental group with high Total Score SDT also tend to have high Total Score SAT, indicating a statistically significant relationship between the two measures.

2.5.3 Analysis of the Students' Attitudes Towards Linear Equations

This question was answered by only the students in the experimental group, which consisted of 22 individuals. To answer the research question, "How does teaching mathematics using the System Dynamics approach affect eighth-grade students' attitudes towards linear equations?". The following are the students' responses to the 6th question of the System Dynamics Comprehension Test.

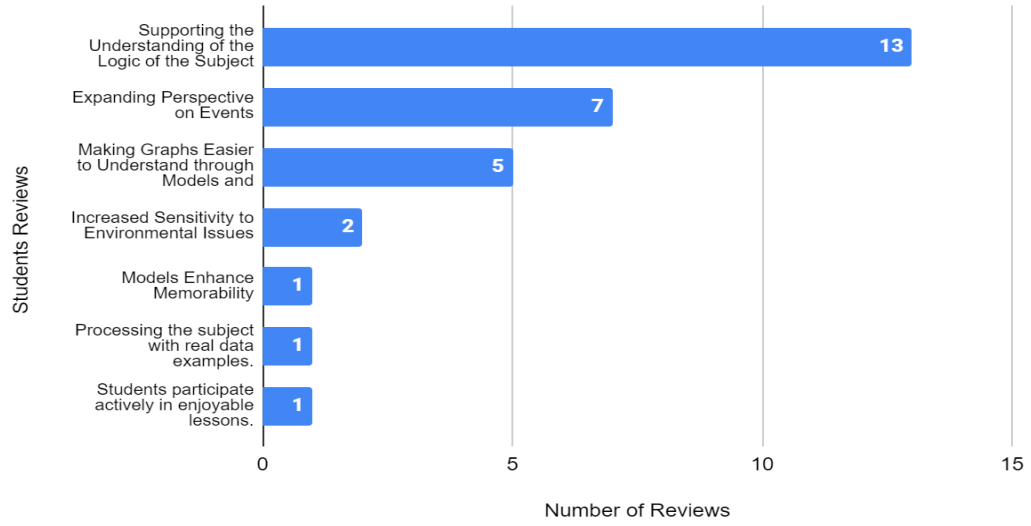

Figure 2.1 Students Reviews for SDT

Upon examination of the figure, it is evident that over 50% of the students noted that the most significant aspect of the mathematics lesson process utilizing system dynamics was its ability to aid in their comprehension of the subject's logic. Seven students expressed that the systems thinking approach expanded their perspectives, while five students stated that the modeling of linear graphs in the STELLA Online application helped them to better understand the graphs and solidify their understanding of the subject. In addition, 2 students stated that their environmental sensitivity increased when the topic of linear equations was taught around environmental problems. Drawing graphs with real data, models increasing memorability and student-centered lessons are also comments made by one student.

CONCLUSION AND DISCUSSION

1.1 Conclusion and Discussion

A significant difference was observed between the scientific achievement post-tests of the experimental and control group students. This suggests that integrating system dynamics tools into the mathematics course, specifically in the subject of linear equations, can enhance student achievement. Four out of the six items in the scientific achievement test were sourced from the sample questions published by the Ministry of National Education on its website for the high school transition system exam (Talim Terbiye Kurulu, 2023). The remaining two items were included by the researcher as additional options to two of these questions. The two added items correspond to multiple relations and generalization of abstract thinking steps, which are at the highest levels of the SOLO Taxonomy. These items measure the 21st century skills that students should acquire and are included in the educational objectives of the Ministry of National Education (MoNE, 2023). Students gave the least correct answers to these items. Upon examination of the results of the scientific achievement test, it was found that students had less difficulty applying basic concepts and rules. However, they encountered more challenges when interpreting situations that involved multiple relationships, as well as with equations, graphs, and predictions that required generalization of these situations.

A moderate relationship was found between the results of the system dynamics comprehension test administered to the experimental group and the results of the scientific achievement tests. Additionally, the experimental group was asked to evaluate the contribution of teaching mathematics with system dynamics tools in the final question of the System

Dynamics Comprehension Test. In response to this question, over 50% of the students reported that system dynamics tools were effective in aiding their understanding of the subject, while over 25% stated that the systems thinking approach broadened their perspectives. These findings suggest that system dynamics tools can be effective in helping students comprehend linear equations and contribute positively to their scientific achievement test results.

1.2 Recommendations

This study implemented lesson plans that focused on the acquisition of linear equations using system dynamics tools. Regular exposure to system dynamics and time spent with these tools are necessary to become a systems thinker. The lesson plan was effective in understanding the subject matter and increasing students' achievement. However, to be more effective in the long run, it is recommended that system dynamics tools be implemented simultaneously in all disciplines. Careful selection of subjects for the application of system dynamics tools, along with longer lesson hours, can further enhance their effectiveness. Additionally, if the Ministry of National Education increases the content aimed at developing high-level thinking skills, the impact of these tools will be even more pronounced in such courses.

To integrate system dynamics tools into various disciplines, teachers require support through in-service training on the systems thinking approach and system dynamics tools. The Ministry of National Education and school administrations have a significant role to play in this regard.

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