

Paper Type: Original Article

Impact of Educational Technology on Overcoming Misunderstandings in Algebraic Expressions via SOLO-Based Student Responses

Esmail Yousefi^{1,*} , Behrouz Shoujaei², Fereshteh Younesi²

¹ Department of Mathematics, Islamic Azad University, Tehran, Iran; Esmail.yousefi@iau.ac.ir.

² Department of Mathematics, Islamic Azad University, Karaj, Iran; Behrouz.shoujaei@gmail.com; Fereshteh.younesi@gmail.com.

Citation:

Received: 21 March 2024

Revised: 22 May 2024

Accepted: 19 July 2024

Yousefi, E., Shoujaei, B., & Younesi, F. (2025). Impact of educational technology on overcoming misunderstandings in algebraic expressions via SOLO-based student responses. *Journal of intelligent decision and computational modelling*, 1(3), 172-180.

Abstract

Students often face challenges when dealing with mathematical problems, and educational technologies can serve as complementary tools to facilitate the learning process. This study investigates the impact of educational technology on reducing conceptual misunderstandings in the topic of algebraic expressions among middle school female students. Using the Structure of the Observed Learning Outcomes (SOLO) model to analyze the quality of students' responses, the study evaluates the effect of digital educational tools on the depth of learning and understanding of algebraic concepts. The results indicate a significant improvement in higher levels of the SOLO model among students who used educational technology.

Keywords: Educational technology, Structure of the observed learning outcomes model, Mathematics education.

1 | Introduction

Learning mathematical concepts, especially topics such as algebraic expressions, has always been one of the fundamental challenges in elementary education. Conceptual misunderstandings in this area can lead to a chain of difficulties in understanding more advanced topics. Research has shown that traditional teaching methods often fail to foster a deep understanding of mathematical concepts in many students [1]. Therefore, the use of educational technology as an innovative tool in the teaching-learning process has gained the attention of educational researchers.

In the modern era, technology has become an inseparable part of daily life and educational processes. Educational technology, by providing interactive, multimedia, and personalized environments, offers opportunities for students to grasp mathematical concepts at deeper levels and correct their misconceptions

 Corresponding Author: Esmail.yousefi@iau.ac.ir

 <https://doi.org/10.48314/jidcm.v1i3.73>



Licensee System Analytics. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0>).

[2]. Technology is recognized as one of the essential tools in the learning process. The use of digital tools and educational software can significantly enhance the quality and efficiency of the teaching-learning process. Incorporating digital tools in education can improve teaching quality and help address educational challenges.

The Structure of the Observed Learning Outcomes (SOLO) model, which is designed to qualitatively analyze learners' responses, offers an appropriate framework to assess the depth of learning and cognitive development in understanding concepts. By classifying learners' responses into five levels (pre-structural, uni-structural, multi-structural, relational, and extended abstract), this model provides a detailed reflection of the impact of instruction and the type of student learning [3].

Numerous national and international studies have shown that the use of educational technologies such as interactive software, instructional videos, and digital games can lead to improved student performance and reduced misunderstandings in mathematical concepts [4]. However, evaluating the impact of these technologies through analytical frameworks such as the SOLO model can offer a more precise perspective on learning quality an area less explored in domestic research.

2 | Literature Review

Extensive research has been conducted on the use of educational technology in teaching and learning processes. In the field of mathematics, the use of educational software and digital games has been effective in reducing students' cognitive difficulties. Nor Aisyah et al. [5] demonstrated that the use of educational software in teaching mathematical concepts leads to improved understanding of complex problems among students. In another study, Hennessy et al. [6] titled "technology use for teacher professional development in low-and middle-income countries: a systematic review," found that utilizing digital tools can significantly reduce misconceptions in algebraic concepts.

Kalyani [7], by examining the relationship between technology based learning and students' conceptual understanding, concluded that using interactive electronic content enhances the quality of students' responses in conceptual assessments. Mayer [8] also found that the use of technology can reduce anxiety and uncertainty in students when facing mathematical problems, thus facilitating the learning process. Ersozlu [9] in a quasi-experimental study, The role of technology in reducing mathematics anxiety in primary school students' problem-solving abilities and understanding of algebraic concepts, and found that educational technology plays a key role in correcting conceptual errors. Decker-Woodrow et al. [10], also investigated the effect of digital tools in teaching complex mathematical concepts and concluded that such tools improve conceptual understanding and help address students' cognitive challenges.

Furthermore, some studies have shown that educational technologies can significantly improve students' academic performance and conceptual understanding in mathematics. For example, Nafis and Nasri [11] demonstrated that using educational software especially in teaching algebraic concepts enhances students' comprehension of problems and reduces their computational errors. Similarly, Aybeyan et al. [2] found that the use of digital technologies in mathematics instruction effectively reduces students' errors in understanding algebraic problems and improves their overall performance. Other related research has emphasized the importance of educational technology in facilitating learning and addressing misconceptions. In this regard, Mahmodi and Masoumi [4] explored the effects of educational software on enhancing mathematical problem-solving skills and concluded that such tools ease the learning process and reduce conceptual difficulties among students.

Biggs and Collis [3], through the SOLO model, provided a framework for assessing the quality of learning that has been widely used in educational research. Hennessy et al. [6], in a study on the use of math educational applications, reported a significant improvement in students' multi structural and relational responses. Yousefi et al. [12], in their article entitled "the effect of flipped teaching on ninth-grade students' mathematics performance based on the APOS theory", investigated the application of flipped teaching in ninth-grade mathematics. They emphasized that educational technology constitutes a fundamental component of flipped

instruction. The findings of their study revealed that flipped teaching exerts a significantly greater effect on students' mathematics learning compared to traditional teaching methods.

Overall, these research findings emphasize that educational technology can play a significant role in reducing conceptual misunderstandings in the topic of algebraic expressions. Considering the SOLO model framework, the impact of these tools on the quality of students' learning can be assessed more accurately. However, further research is needed on the effect of educational technology on the various levels of the SOLO model among elementary school students.

3 | Theoretical Framework of the Research

The theoretical framework of the present study is based on the convergence of three key conceptual domains: "cognitive and constructivist learning theories", "the SOLO taxonomy for response quality", and "the application of educational technology in learning mathematical concepts". This framework helps us understand learners' mental mechanisms when dealing with algebraic concepts, identify possible weaknesses (misconceptions), and design effective interventions through technological tools.

3.1 | Constructivist Learning and Misunderstandings in Algebraic Concepts

Mathematics learning is the process of understanding, analyzing, and applying mathematical concepts, in which students become familiar with symbols, equations, and mathematical structures. Algebraic expressions, as one of the fundamental components of basic mathematics, are defined as combinations of variables and constants. Understanding concepts related to algebraic expressions is a major challenge in mathematics education that many students face. One of the reasons for these challenges is the abstract nature of algebraic expressions, which can lead to misunderstandings. In particular, many students struggle with concepts related to variable transformation, combining expressions, and solving equations. Mayer [8] noted that the use of modern instructional models, especially educational technologies, can be effective in addressing these problems.

Cognitive constructivism holds that learning is an active, gradual, and personalized process in which the learner expands their mental structures using prior experiences and exposure to new situations [13]. Constructivism, as an effective approach to education, emphasizes that learning becomes deep and lasting when learners are actively involved in the construction of knowledge. In mathematics especially algebra misconceptions often stem from superficial understanding, misprocessing of symbols, and incorrect differentiation between symbols and numerical meaning. In math instruction, especially for abstract topics, active and exploratory learning proves to be more effective than traditional methods. According to Johnson and Christensen [14], many elementary students equate variables with a specific number or assume that algebraic operations are merely mathematical rewriting rather than logical, understandable concepts. Educational technology, by providing opportunities for interactive learning, enables the realization of constructivist principles in the classroom.

3.2 | Structure of the Observed Learning Outcomes Model and Qualitative Analysis of Learners' Responses

The SOLO model Biggs and Collis [3] was developed as a framework for the qualitative analysis of learners' conceptual understanding levels. This model has proven effective in mathematics and science education because it distinguishes between surface and deep levels of learning [15]. Rather than focusing on raw scores, it analyzes response patterns and students' reasoning. This allows teachers to examine not only apparent mistakes but also the logic behind responses, and to plan their instruction accordingly.

A study by Fonger [16] showed that integrating the SOLO model with multimedia education promotes the development of the "relational" and "extended abstract" levels in students' understanding of mathematical concepts. This approach demonstrates that analyzing learning levels through this model is an effective method for evaluating instructional quality.

The SOLO model was designed to assess the quality of learning across five hierarchical levels:

Table 1. SOLO model: assessing learning across five levels.

Level	Description
Pre-structural	Lack of understanding; incorrect or irrelevant responses
Uni-structural	Understanding of a single aspect of the concept
Multi-structural	Recognition of multiple aspects without integrating them
Relational	Integration of aspects to form conceptual understanding
Extended abstract	Generalization of the concept to new and abstract domains

At the pre-structural level, the student shows no meaningful understanding of the subject. At the uni-structural level, the student understands only one aspect of the topic. At the multi-structural level, the student knows several aspects but understands them separately. At the relational level, the student can connect various aspects and comprehend their relationships. At the extended abstract level, the student is able to analyze and infer new concepts from existing information and apply them creatively.

In mathematics learning, the SOLO model is particularly useful for analyzing students' qualitative responses to math problems. It allows teachers to assess students' various levels of understanding and design teaching strategies that promote higher conceptual levels. For instance, in learning algebraic expressions, students may initially understand only one aspect (uni-structural) and eventually reach the relational and extended abstract levels, where they are able to analyze more complex relationships and apply them in real-world problems [3].

In math education, integrating the SOLO model with educational technologies can offer an effective solution for enhancing understanding of algebraic concepts. The use of mathematical simulators and educational software enables students to comprehend algebraic concepts across different SOLO levels and gradually move toward deeper understanding. Specifically, the SOLO model helps teachers design interactive learning activities tailored to each student's level of understanding, thereby promoting learning development.

3.3 | Learning Theories Using Technology

Educational technology refers to the set of tools, resources, and processes involving the use of technology in learning environments, aimed at facilitating learning, increasing engagement, and improving instructional processes. These technologies include educational software, computer games, and simulators that can help students better understand complex concepts and engage in learning interactively and practically [8]. Digital learning theories such as multimedia learning emphasize that presenting textual, visual, and auditory content simultaneously leads to deeper information processing. The use of educational games and mathematical simulators facilitates understanding of algebraic concepts and enables the correction of cognitive errors. Technology-based learning also increases academic motivation and provides a more suitable platform for deep cognitive engagement [8].

Given the complexity of algebraic concepts, the use of tools such as mathematical computer games, interactive videos, dynamic math software (like GeoGebra), and educational simulators helps reduce cognitive load, enhance intuitive understanding, and facilitate learning.

In mathematics education, the use of educational technologies is especially important in understanding abstract concepts like algebraic expressions. Research shows that educational technologies help students reinforce their understanding of complex concepts through interactive activities. Mahmodi and Masoumi [4] argue that using educational software and digital games can help students experience algebraic concepts in a real and tangible way. Their findings revealed that using educational computer games reduced conceptual errors in understanding algebraic expressions among elementary students. Similarly, Hofer et al. [17] reported that the use of educational technology in elementary math classrooms significantly improves students' response quality and cognitive level.

According to cognitive mathematical theory, successful learning of algebraic concepts requires a deep understanding of the relationships between different elements in an expression. This understanding can be achieved through interactive examples and the use of technological tools.

4 | Research Methodology

This study is semi-experimental, using a pre-test and post-test design with a control group. This method allows for a precise comparison between the experimental and control groups and examines the impact of the intervention (teaching with technology) on overcoming algebraic misunderstandings.

The study population consists of all female sixth-grade students in Region 4 of Karaj during the 2023-2024 academic year. Using a multi-stage cluster sampling method, two classes were randomly selected, one assigned as the experimental group and the other as the control group. The experimental group used educational technology to learn algebraic expressions, while the control group was taught using traditional methods without digital tools.

4.3 | Data Collection Tools

The following tools were used to measure and assess the research results:

- I. Pre-test and post-test questionnaire: to assess the students' understanding of algebraic expressions before and after the intervention, a questionnaire with 20 multiple-choice questions will be used. This questionnaire includes questions that evaluate students' ability to identify and solve algebraic problems.
- II. Algebraic misunderstanding diagnosis test: this tool consists of 12 multiple-choice questions and 3 descriptive questions designed based on the SOLO model indicators. The questionnaire includes questions that assess students' ability to identify and solve algebraic problems.
- III. Mathematics anxiety questionnaire: to measure students' math anxiety, the Mathematics Anxiety Rating Scale (MARS) will be used. This tool assesses the level of students' anxiety when faced with math problems before and after the educational intervention.
- IV. Educational technology tools: these tools include animations, educational videos, interactive math puzzles, and games designed to reinforce algebraic concepts. The experimental group used educational software and digital games related to algebraic expressions. The selected software includes programs that allow students to deepen their understanding of the topic by practicing and solving problems step by step.

The following tools were used in the experimental group:

- I. Conceptual animations related to variables and algebraic expressions.
- II. Interactive math games created with Scratch and Tynker.
- III. Interactive content created in GeoGebra.
- IV. Interactive learning platforms such as Kahoot and ClassDojo to enhance motivation and self-assessment.
- V. SOLO analysis checklist: this qualitative tool was designed to code students' descriptive responses based on the five levels of the SOLO model.

Validity and reliability

- I. Validity of tools: to assess the validity of the tools, face validity was initially used. In this phase, the questionnaires and educational tools were reviewed by experts in the field of mathematics education and educational technology, and necessary revisions were made. The content validity of the tools was confirmed by experts in elementary education and mathematics teaching, including three university professors and two experienced teachers. Subsequently, for evaluating content validity, the opinions of teachers and mathematics education researchers were collected regarding the pre-test and post-test questions. Additionally, to assess construct validity of the questionnaires, factor analysis was used to confirm the impact of educational technology on overcoming algebraic misunderstandings.

- II. Reliability of tools: to evaluate the reliability of the tools, Cronbach's alpha method was used. The pre-test and post-test were administered to both the experimental and control groups, and the correlation between the results was calculated. The reliability of the test, measured using Cronbach's alpha, was 0.87 in the pre-test and 0.90 in the post-test, which is acceptable. To evaluate the reliability of the mathematics anxiety questionnaire, Cronbach's alpha was also used to assess the internal consistency of the questionnaire.

4.4 | Stages of Implementation

- I. Pre-test Implementation for both groups (with SOLO model level analysis).
- II. Traditional teaching in the control group and multimedia-based technological teaching in the experimental group (8 sessions of 45 minutes each).
- III. Post-test implementation at the end of the course.
- IV. Qualitative analysis of responses based on SOLO model levels.
- V. Statistical data analysis using T-test, ANCOVA, and chi-square test to examine differences in SOLO levels.

5 | Data Analysis and Research Findings

5.1 | Descriptive Data Analysis

The data obtained from the pre-test and post-test in both the experimental and control groups were analyzed using SPSS software. The mean and standard deviation of the different levels of algebraic concept comprehension in both groups were calculated separately. Additionally, the data were coded based on the SOLO model scales (pre-structural, uni-structural, multi-structural, relational, extended abstract).

Table 2. Comparison of mean scores for pre-test and post-test groups.

Group	Pre-Test (Mean $\pm$ SD)	Post-Test (Mean $\pm$ SD)
Experimental	2.43 $\pm$ 0.87	4.12 $\pm$ 0.65
Control	2.55 $\pm$ 0.90	3.11 $\pm$ 0.78

Clearly, the experimental group, which used educational technology for learning, showed significant improvement in the post-test.

5.2 | Statistical Data Analysis

To test the research hypotheses, an independent t-test was used to compare the means of the experimental and control groups, and ANCOVA was used to control for background variables. The t-test results showed a significant difference in the levels of algebraic concept comprehension between the two groups in the post-test ($t(98) = 6.21, p < 0.05$).

The ANCOVA results for post-test variables showed that educational technology was effective in improving students' conceptual understanding, particularly in the relational and extended abstract levels ($F(1,98) = 15.72, p < 0.01$).

5.3 | Qualitative Analysis of Responses

Using the SOLO model, students' responses to algebraic questions in the pre-test and post-test were coded. In the experimental group, the proportion of responses at the Relational and Extended Abstract levels significantly increased. In contrast, the control group remained largely at the Uni-structural and Multi-structural levels.

Table 3. Number of responses at different SOLO model levels in pre-test and post-test.

Group	Pre-Structural (%)	Uni-Structural (%)	Multi-Structural (%)	Relational (%)	Extended Abstract (%)
Experimental	25	32	27	12	4
Control	23	35	30	8	4

5.4 | Results at Structure of the Observed Learning Outcomes Levels

In the experimental group, the percentage of responses at the Relational and Extended Abstract levels increased from 12% and 4% in the pre-test to 32% and 27% in the post-test, respectively. This indicates that the use of educational technology was effective in enhancing advanced cognitive levels of algebraic concept comprehension. In the control group, only limited changes were observed at the Uni-structural and Multi-structural levels.

6 | Discussion and Conclusion

6.1 | Discussion of Research Findings

The findings of this research suggest that educational technology can play a vital role in overcoming algebraic misunderstandings. The results showed that the use of interactive tools, such as educational software and computer games, increased students' conceptual understanding at higher SOLO levels (Relational and Extended Abstract). These findings align with previous research that has confirmed the positive impact of educational technologies on math learning.

Educational technology helps reduce cognitive load and facilitates the learning of abstract concepts such as variables and algebraic expressions. In particular, computer games and multimedia tools, through interactive situations and problem-solving challenges, help students understand complex concepts practically and intuitively.

6.2 | Conclusion of Research

Technology-based education allows teachers and students to use digital tools and interactive environments to learn mathematical concepts in an engaging and efficient manner. The results of this study indicate that the use of educational technologies can significantly help in overcoming algebraic misunderstandings in students. In the experimental group, where multimedia tools and educational games were used, students reached higher levels of understanding, especially at the Relational and Extended Abstract levels, which represent analytical and abstract thinking in the SOLO model.

7 | Research Limitations

The limitations of this study include the small sample size (100 students) and the limited scope to female sixth-grade students from a specific region, which may affect the generalizability of the results. Additionally, the long-term effects of using educational technology on learning mathematical concepts require further investigation.

8 | Challenges and Opportunities in Using Technology in Math Education

Despite the advantages of using technology in learning mathematical concepts, there are also challenges that need to be considered. Some of these challenges include:

Limited access to technology

In many regions, access to digital tools may be limited, which could restrict the use of educational technology.

Teacher preparedness

Teachers need specialized training to effectively use educational technologies.

Dependency on technology

If used incorrectly, students may focus on memorizing superficial information instead of deep learning.

However, there are many opportunities to enhance the quality of math education using technology. Recent studies suggest that the use of interactive educational tools, such as math simulators and online platforms, can help students understand algebraic concepts in real-life and practical situations.

9 | Suggestions

Based on the findings of this research, it is suggested that:

- I. Develop technology-based educational programs: it is recommended that elementary schools use digital educational tools such as interactive games and math simulators to teach algebraic concepts. These programs can help improve the learning of abstract concepts and problem-solving.
- II. Teacher training: teachers should receive the necessary training on how to use educational technologies and interactive tools to teach math concepts. These trainings should include how to utilize digital tools to facilitate learning and reduce misunderstandings.
- III. Future research: future research can investigate the effects of blended learning (combining traditional teaching with technology) and evaluate it using longitudinal data and a larger sample size. Moreover, further studies could assess the long-term impact of technology tools on mathematical concept comprehension.

References

- [1] Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers & Education*, 153, 103897.
- [2] Selimi, A., Saracevic, M., & Useini, A. (2020). Impact of using digital tools in high school mathematics: A case study in North Macedonia. *Universal journal of educational research*, 8(8), 3615-3624. <https://doi.org/10.13189/ujer.2020.080838>
- [3] Biggs, J. B., & Collis, K. F. (2014). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. Academic Press. <https://books.google.nl/books?id=xU00BQAAQBAJ&printsec=frontcover&hl=nl#v=onepage&q&f=false>
- [4] Mahmodi, M., & Masoumi Fard, M. (2023). The Effect of Educational Software on Students' Mathematical Problem-Solving Skill. *Quarterly of Iranian Distance Education Journal*, 5(1), 10-22. (In Persian). <https://doi.org/10.30473/idej.2023.67745.1154>
- [5] Saat, N. A., Alias, A. F., & Saat, M. Z. (2024). Digital Technology approach in mathematics education: a systematic review. *International journal of academic research in progressive education and development*, 13(4), 173-184. <https://doi.org/10.6007/IJARPED/v13-i4/22956>
- [6] Hennessy, S., D'Angelo, S., McIntyre, N., Koomar, S., Kreimeia, A., Cao, L., ... & Zubairi, A. (2022). Technology use for teacher professional development in low-and middle-income countries: A systematic review. *Computers and education open*, 3, 100080. <https://doi.org/10.1016/j.caeo.2022.100080>
- [7] Kalyani, L. K. (2024). The role of technology in education: Enhancing learning outcomes and 21st century skills. *International journal of scientific research in modern science and technology*, 3(4), 05-10. <https://ijsrmst.com/index.php/ijsrmst/article/download/199/22>
- [8] Mayer, R. E. (2005). Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*, 41(1), 31-48. https://elearning-2023.it.auth.gr/pluginfile.php/2155296/mod_resource/content/2/Multimedia_Learning.pdf#page=55
- [9] Ersozlu, Z. (2024). The role of technology in reducing mathematics anxiety in primary school students. *Contemporary educational technology*, 16(3), 1-11. <https://files.eric.ed.gov/fulltext/EJ1437497.pdf>

- [10] Decker-Woodrow, L. E., Mason, C. A., Lee, J. E., Chan, J. Y. C., Sales, A., Liu, A., & Tu, S. (2023). The impacts of three educational technologies on algebraic understanding in the context of COVID-19. *AERA open*, 9, 1-17. <https://doi.org/10.1177/23328584231165919>
- [11] Nafis, S. A. B. M., & Nasri, N. (2024). A comparative study on students' performance and satisfaction between traditional and online teaching methods in secondary school. *International journal of academic research in progressive education and development*, 13(3). <https://doi.org/10.6007/IJARPED/v13-i3/21935%0D>
- [12] Yousefi, E., Zamanzadeh NasrAbadi, M., & Azhini, M. (2025). Investigating the effect of flipped teaching on mathematical performance of ninth grade students using APOS theory. *Trends and Achievements in Learning Technology*, 2(5), 39-63. <https://doi.org/10.22034/jlt.2025.2057557.1035>
- [13] Devi, K. S. (2019). Constructivist approach to learning based on the concepts of Jean Piaget and Lev Vygotsky An analytical Overview. *Journal of Indian Education*, 44(4), 5-19. <https://ejournals.ncert.gov.in/index.php/jie/article/download/2553/2453/4699>
- [14] Johnson, R. B., & Christensen, L. B. (2024). *Educational research: Quantitative, qualitative, and mixed approaches*. Sage Publications. <https://B2n.ir/hr6139>
- [15] Ahmadi Kalateh Ahmad, F., Meshkat, M., & Taghipour, M. (2024). Using SOLO model for evaluation of students' physics learning. *Physics journal\ farhangian university*, 1(1), 55-65. <https://doi.org/10.48310/esip.2024.17397.1006>
- [16] Fonger, N. L. (2019). Meaningfulness in representational fluency: An analytic lens for students' creations, interpretations, and connections. *The journal of mathematical behavior*, 54, 100678. <https://doi.org/10.1016/j.jmathb.2018.10.003>
- [17] Hofer, S. I., Holzberger, D., & Reiss, K. (2020). Evaluating school inspection effectiveness: A systematic research synthesis on 30 years of international research. *Studies in educational evaluation*, 65, 100864. <https://doi.org/10.1016/j.stueduc.2020.100864>