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# THE EFFECT OF STEAM-BASED EDUCATIONAL GAMES ON ELEMENTARY SCHOOL STUDENTS' SCIENTIFIC LITERACY

# PENGARUH GAME EDUKASI BERBASIS STEAM TERHADAP LITERASI SAINS SISWA SD

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**Abstract**

This study aimed to investigate the effect of STEAM-based educational games on elementary school students' scientific literacy. The research employed a quasi-experimental design with a nonequivalent control group, including an experimental group and a control group. The STEAM-based educational game integrated science, technology, engineering, arts, and mathematics through contextual problem-solving activities that encouraged students to actively explore scientific concepts and collaborate with their peers. The research instrument consisted of a scientific literacy test covering knowledge, competencies, and context. The findings revealed that students who learned through STEAM-based educational games demonstrated greater improvement in scientific literacy than those who participated in conventional learning. The results indicated that STEAM-based educational games have a significant positive effect on elementary school students' scientific literacy. Therefore, STEAM-based educational games can serve as an innovative learning medium to support the development of scientific literacy in elementary education.

***Keywords:*** *Scientific Literacy, Educational Games, STEAM, Elementary School, Contextual Learning*

***Abstrak***

*Penelitian ini bertujuan untuk mengetahui pengaruh penggunaan game edukasi berbasis STEAM terhadap literasi sains siswa sekolah dasar. Metode yang digunakan adalah eksperimen semu dengan desain nonequivalent control group yang melibatkan kelas eksperimen dan kelas kontrol. Game edukasi berbasis STEAM yang digunakan mengintegrasikan unsur sains, teknologi, rekayasa, seni, dan matematika melalui aktivitas pemecahan masalah kontekstual yang mendorong siswa untuk mengeksplorasi konsep sains secara aktif dan kolaboratif. Instrumen penelitian berupa tes literasi sains yang mencakup aspek pengetahuan, kompetensi, dan konteks. Hasil penelitian menunjukkan bahwa siswa yang belajar menggunakan game edukasi berbasis STEAM memiliki peningkatan literasi sains yang lebih baik dibandingkan siswa yang mengikuti pembelajaran konvensional. Temuan penelitian ini menunjukkan bahwa penggunaan game edukasi berbasis STEAM berpengaruh signifikan terhadap peningkatan literasi sains siswa sekolah dasar. Oleh karena itu, game edukasi berbasis STEAM dapat menjadi alternatif media pembelajaran yang inovatif untuk mendukung pengembangan literasi sains pada jenjang sekolah dasar.*

***Kata Kunci:*** *Literasi Sains, Game Edukasi, STEAM, Sekolah Dasar, Pembelajaran Kontekstual*

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## 1. Introduction

Scientific literacy is recognized as an essential competency that students must develop to address the challenges of the twenty-first century, as it serves as a fundamental foundation for navigating the rapid advancement of science and technology (Widiyanto, Fauzan, Latip, Rizqa, Suryaningsih, & Uswatun, 2025). Scientific literacy encompasses not only understanding scientific concepts but also the ability to apply scientific knowledge to solve problems, make informed decisions, and use science in everyday life (Yuliati, 2017). Despite its importance, the level of scientific literacy among Indonesian students remains relatively low.

According to the Program for International Student Assessment (PISA) 2022, Indonesia scored 383 in science literacy, which remains substantially below the OECD average of 485. Furthermore, only approximately 1% of Indonesian students reached proficiency levels 5 and 6, while the majority performed below the minimum proficiency required to utilize scientific knowledge in everyday contexts effectively. Indonesia was also positioned in the lower tier among participating countries, indicating persistent challenges in developing students' scientific literacy competencies (OECD, 2023). Within the PISA 2025 science framework, the OECD emphasizes that science education should foster students' competencies in scientific reasoning, problem-solving, information evaluation, and evidence-based decision-making in real-life contexts (Putri, Rachmadiarti, Purnomo, & Satriawan, 2025). Furthermore, PISA 2025 highlights the importance of preparing students to address twenty-first-century global challenges, including technological advancement, environmental issues, health concerns, and the effective use of digital information (OECD, 2024). These competencies involve explaining phenomena scientifically, evaluating scientific investigations, interpreting data critically, and applying scientific evidence to support informed actions and decisions.

Several studies have reported that science learning in elementary schools remains predominantly teacher-centered and relies heavily on lecture-based instruction. Such learning practices tend to emphasize memorization rather than scientific inquiry, thereby limiting students' opportunities to investigate problems, interpret evidence, and apply scientific concepts in authentic situations. Consequently, students often struggle to develop higher-order scientific literacy competencies. The low level of scientific literacy can be attributed, in part, to instructional practices that remain predominantly teacher-centered and provide limited opportunities for students to engage directly in meaningful learning experiences (Valio, Safira, Aulliyah, & Suwarna, 2025). Learning activities that lack contextual relevance often hinder students' ability to connect scientific concepts to real-life situations (Sari, Rambitan, Masitah, Purwati, & Makkadafi, 2025; Wulan, Iskandar, Nurbayan, Fajrussalam, Hikmatunisa, Yogiarni, Ravy, & Nurdiansyah, 2025). Therefore, teachers need to provide contextual problems that encourage students to apply their knowledge and reasoning skills in authentic situations (Putri, Prasetyo, Purwastuti, & Purnama, 2025). Consequently, innovative instructional approaches that integrate meaningful and contextual learning experiences are urgently needed. One promising approach is Science, Technology, Engineering, Arts, and Mathematics (STEAM), which emphasizes integrating multiple disciplines within a unified learning experience.

Scientific literacy is not solely developed through science content but can also be fostered through interdisciplinary learning experiences (Roy, Sikder, & Danaia, 2025). Safitri (2022) argues that STEAM integrates science, technology, engineering, arts, and mathematics while actively engaging students in exploring and understanding the underlying meaning of learning content. Such an approach enables students to develop

critical thinking, creativity, problem-solving abilities, and scientific inquiry skills (Wahyuningsih, Nurjanah, Rasmani, Hafidah, Pudyaningtyas, & Syamsuddin, 2020). The dimensions of scientific literacy assessed in this study include scientific knowledge, scientific competencies, and contextual application, as defined by the PISA 2025 framework. STEAM learning is considered relevant for developing these dimensions because it encourages students to understand scientific concepts (scientific knowledge), engage in problem-solving and inquiry processes (scientific competencies), and apply scientific understanding to real-world situations (contextual application). Therefore, STEAM provides a theoretical foundation for improving scientific literacy through interdisciplinary learning experiences.

At the same time, the rapid development of digital technology has created new opportunities for implementing game-based learning as an interactive and engaging instructional medium. In addition to adopting learning approaches that address students' needs in the digital era, educators must also use technology-enhanced learning media (Aprillionita, Nuraeni, & Alindra, 2025). Digital educational games serve as learning tools that can create a more engaging learning environment, thereby increasing students' interest and motivation to learn (Afidah & Subekti, 2024). This situation reflects a fundamental challenge in elementary science education, instruction often remains teacher-centered and fails to provide contextual, meaningful learning experiences. Previous studies have examined both STEAM approaches and educational games in educational settings. Firdianika, Joharmwan, & Yulistiadi (2023) reported that STEAM-based game-based learning can stimulate students' interest and improve academic achievement. Similarly, Darmawan, Novita, & Hakim (2024) found that STEAM-oriented digital game-based learning enhances students' collaboration, problem-solving skills, and creativity.

Although previous studies have integrated STEAM and game-based learning, most research has focused on learning achievement, motivation, creativity, and collaboration. Limited studies have specifically examined scientific literacy as the primary outcome variable using comprehensive indicators aligned with the PISA 2025 framework. Furthermore, previous studies rarely provide empirical evidence regarding how STEAM elements embedded within educational games contribute to the dimensions of scientific knowledge, scientific competencies, and contextual application. Therefore, the novelty of this study lies in: (1) the development of a STEAM-based educational game specifically designed to foster scientific literacy, (2) the measurement of scientific literacy using comprehensive indicators derived from the PISA 2025 science framework, and (3) the examination of the effectiveness of the game among elementary school students through a quasi-experimental design. Theoretically, this study contributes to the growing body of literature on integrating STEAM and game-based learning to develop scientific literacy. In practice, the findings provide empirical evidence for teachers and schools on the use of STEAM-based educational games as an innovative instructional medium to improve elementary students' scientific literacy.

## 2. Research Method

This study employed a quantitative approach using a quasi-experimental design. The research design adopted was a nonequivalent control group design, comprising two groups: an experimental group and a control group. This design was selected because full randomization was not feasible under the existing classroom conditions, while still

allowing the researcher to examine the treatment effect. The research design is presented in table 1.

Table 1. Research Design

| Group | Pretest | Treatment | Posttest |
|---|---|---|---|
| Experimental | $O_1$ | STEAM-based educational game | $O_2$ |
| Control | $O_3$ | Conventional learning | $O_4$ |

The study population consisted of all fifth-grade students at SDIT Daarul Azka during the current academic year. The sample was selected using a purposive sampling technique, based on students' academic equivalence and similar characteristics. A total of 60 students participated in the study, comprising 30 students in the experimental group and 30 students in the control group. Academic equivalence between the groups was determined based on students' previous science achievement scores obtained from school records. Two intact classes with comparable average science achievement scores were selected. One class was assigned to the experimental group, and the other to the control group, in consultation with the school administration to ensure similar academic characteristics.

The study was conducted in three stages: planning, implementation, and evaluation. During the planning stage, the researchers developed instructional materials, including lesson modules, scientific literacy assessment instruments, observation sheets, and a STEAM-based educational game as the learning medium. The observation sheet was used to assess students' engagement during learning activities, including participation in discussions, collaboration, problem-solving involvement, and responsiveness to instructional activities. Before implementation, the scientific literacy test was pilot-tested with 30 fifth-grade students from another school with characteristics similar to those of the research participants. The pilot test aimed to evaluate item validity, reliability, readability, and the appropriateness of the assessment instrument before its use in the main study.

During the implementation stage, both the experimental and control groups were administered a pretest to determine students' initial scientific literacy levels. Subsequently, the experimental group received instruction using a STEAM-based educational game for four instructional sessions, each lasting 2 × 35 minutes. The educational game integrated STEAM elements through interactive activities aligned with elementary science learning objectives. Students were organized into small groups to complete challenges, answer questions, engage in discussions, and solve problems embedded within the game. Throughout the learning process, the teacher served as a facilitator, guiding students in their exploration and problem-solving.

The implementation of STEAM-based educational game learning followed several stages: (1) introducing the lesson and activating students' prior knowledge, (2) explaining the rules and procedures of the educational game, (3) engaging students in collaborative gameplay to complete the assigned challenges, (4) facilitating group discussions and presentations of solutions, and (5) conducting reflection and drawing conclusions together with the students. Following the intervention, both groups completed a posttest to assess improvements in scientific literacy.

The scientific literacy test consisted of essay-type items developed based on three dimensions of scientific literacy: content knowledge, scientific competencies, and contextual understanding. Before administration, all research instruments underwent

validity and reliability testing. Construct validity was examined using Pearson's Product-Moment correlation analysis. The results showed that all items achieved correlation coefficients ranging from 0.43 to 0.82, exceeding the critical value ($r_{table}$ = 0.36), indicating that all items were valid. Reliability analysis using Cronbach's Alpha yielded a coefficient of 0.87, demonstrating high instrument reliability, while reliability was assessed using Cronbach's Alpha coefficient. The research instruments included pretest and posttest questions and observation sheets. Data were analyzed quantitatively through several stages. Preliminary assumption tests were conducted, including a Kolmogorov–Smirnov normality test and a Levene's Test of Homogeneity of Variance. Hypothesis testing was performed using an independent-samples t-test to determine whether there were significant differences between the experimental and control groups. Furthermore, the normalized gain (n-gain) score was calculated to evaluate the extent of improvement in students' scientific literacy following the intervention. To determine the level of improvement in students' scientific literacy following the intervention, the normalized gain (n-gain) scores were calculated and interpreted according to the criteria presented in table 2.

Table 2. Interpretation Criteria of N-Gain Scores

| N-Gain | Category |
|---|---|
| $g < 0.30$ | Low |
| $0.30 \leq g < 0.70$ | Moderate |
| $g \geq 0.70$ | High |

## 3. Results and Discussion

### 3.1 Results

In this study, the STEAM-based educational game was utilized as an interactive digital learning medium that integrated the elements of science, technology, engineering, arts, and mathematics into elementary science instruction. The game was designed through problem-solving activities, interactive quizzes, simple simulations, and contextual challenges related to students' daily lives. The educational game was implemented in three stages: planning, implementation, and evaluation.

The first stage is the planning stage. During the planning stage, the researchers prepared instructional materials, including lesson modules, learning scenarios, student activity observation sheets, and scientific literacy assessment instruments. The learning content was aligned with the science learning outcomes for fifth-grade elementary students. The STEAM-based educational game was selected and adapted to align with scientific literacy indicators covering scientific knowledge, competencies, and contextual application.

The second stage is the implementation stage. During the implementation stage, students in the experimental group participated in STEAM-based educational game learning activities over four instructional sessions, each lasting 2 × 35 minutes. The teacher acted as a facilitator, guiding students through challenges and contextual problems presented in the game. Throughout the game, students engaged in scientific observations, answered science-related questions, performed simple simulations, and solved real-life problems. Learning activities were conducted both individually and collaboratively, encouraging students to actively participate in discussions, exploration, and decision-making. In contrast, students in the control group received conventional

instruction consisting of lectures, question-and-answer sessions, and written exercises without the use of educational games.


Figure 1. Student Identification Interface in the Educational Game

Figure 1 displays the student identification interface used at the beginning of the learning activity. This feature enables students to enter their personal information before accessing the learning content and game activities. In addition to facilitating user identification, the interface serves as the entry point to the learning environment, enabling students to navigate the educational game systematically. The simple, user-friendly design supports students' readiness to engage with STEAM-based learning activities.


Figure 2. Main Homepage of the Educational Game

Figure 2 presents the main homepage of the educational game, which provides access to several learning features, including learning objectives, instructional materials, educational games, quizzes, and case study activities. These features are designed to support the integration of STEAM elements through a combination of conceptual learning, interactive exploration, and problem-solving tasks. The homepage functions as the central navigation menu, enabling students to access various learning resources independently and systematically throughout the instructional process.


Figure 3. STEAM-Based Educational Game Interface

Figure 3 illustrates one of the main challenge activities embedded in the STEAM-based educational game. In this activity, students must identify respiratory organs, analyze scientific information, and solve contextual problems related to the human respiratory system. The science component is reflected in students' understanding of biological concepts, while technology is represented through the digital learning platform. Engineering skills are fostered through problem-solving tasks, the arts are incorporated through visual and interactive design elements, and mathematics is integrated through logical reasoning and analytical thinking. These activities facilitate the development of scientific literacy by supporting students' scientific knowledge, scientific competencies, and contextual application of science in everyday situations.

The educational game was intentionally designed to integrate all STEAM components within meaningful learning activities. Through interactive challenges, quizzes, and contextual case studies, students were encouraged to explore scientific concepts, analyze evidence, communicate ideas, and apply scientific reasoning to solve real-world problems. These learning experiences closely align with the dimensions of scientific literacy assessed in this study: scientific knowledge, scientific competencies, and contextual application.

The third stage is the evaluation stage. The evaluation stage used a posttest to assess students' scientific literacy across three dimensions: scientific knowledge, scientific competencies, and contextual application. In addition, classroom observations were carried out to examine students' engagement during the implementation of the STEAM-based educational game.

The research findings were derived from the analysis of scientific literacy test scores, student activity observations, and student response questionnaires regarding the use of the STEAM-based educational game. All research instruments were confirmed to be valid and reliable, and the collected data met the assumptions required for statistical analysis.

Table 3. Descriptive Statistics of Students' Scientific Literacy Scores

| Data | Experimental Group (A) | | Control Group (B) | |
|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttest |
| Mean | 65.30 | 82.46 | 64.80 | 74.20 |

| Data | Experimental Group (A) | | Control Group (B) | |
|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttest |
| Median | 65.00 | 82.00 | 65.00 | 77.00 |
| Standard Deviation | 5.20 | 6.05 | 8.70 | 7.17 |
| Minimum Score | 52.00 | 68.00 | 50.00 | 60.00 |
| Maximum Score | 78.00 | 95.00 | 77.00 | 88.00 |

Table 3 indicates a substantial improvement in the experimental group. The mean score increased from 65.30 in the pretest to 82.46 in the posttest. The minimum score improved from 52 to 68, while the maximum score increased from 78 to 95. In contrast, the control group also showed improvement, although the increase was less pronounced, with mean scores rising from 64.80 to 74.20. The minimum score increased from 50 to 60, and the maximum score improved from 77 to 88. Furthermore, the posttest standard deviation of the experimental group (6.05) was lower than that of the control group (7.17), indicating a more homogeneous distribution of scientific literacy achievement among students in the experimental group.

Table 4. Results of the Normality Test

| Group | Data | Sig | Interpretation |
|---|---|---|---|
| Experimental | Pretest | 0.20 | Normal |
| Experimental | Posttest | 0.18 | Normal |
| Control | Pretest | 0.19 | Normal |
| Control | Posttest | 0.17 | Normal |

The Kolmogorov–Smirnov test results revealed that all p-values exceeded 0.05, indicating that the data were normally distributed and met the assumptions for parametric statistical analysis.

Table 5. Results of the Homogeneity Test

| Data | Sig | Interpretation |
|---|---|---|
| Pretest | 0.41 | Homogeneous Variance |
| Posttest | 0.36 | Homogeneous Variance |

The results of Levene's test indicated that the significance values for both the pretest ($p = 0.41$) and posttest ($p = 0.36$) were greater than 0.05, suggesting that the variances of the two groups were homogeneous. Therefore, the assumption of homogeneity of variance was satisfied.

Table 6. Independent Samples t-Test Results

| Data | t-value | df | Sig. (2-tailed) | Interpretation |
|---|---|---|---|---|
| Posttest | 4.83 | 58 | < 0.00 | Significant |

The hypothesis test revealed a p-value of $< 0.00$, which was lower than the significance threshold of 0.05. Therefore, a statistically significant difference existed between the experimental and control groups. These findings indicate that implementing the STEAM-based educational game had a significant effect on students' scientific literacy.

Table 7. N-Gain Results

| Group | Mean Pretest | Mean Posttest | N-Gain | Category |
|---|---|---|---|---|
| Experimental | 65.30 | 82.46 | 0.58 | Moderate |
| Control | 64.80 | 74.20 | 0.41 | Moderate |

The n-gain analysis further supported the improvement in scientific literacy. The experimental group achieved an n-gain score of 0.58, categorized as moderate, whereas the control group obtained an n-gain score of 0.41, also categorized as moderate. These results demonstrate that the STEAM-based educational game was more effective in improving students' scientific literacy than conventional instruction.

### 3.2 Discussion

The findings of this study indicate that STEAM-based educational games significantly improved elementary school students' scientific literacy compared to conventional instruction. Students who participated in STEAM-based game learning achieved higher scientific literacy scores than those who learned through teacher-centered approaches. These findings suggest that integrating STEAM principles into educational games provides learning experiences that effectively support the development of scientific literacy.

The effectiveness of the STEAM-based educational game can be explained by constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction with the environment rather than passively received from teachers. During the learning process, students engaged in exploration, discussion, problem-solving, and decision-making activities embedded in the game. These activities encouraged students to actively construct scientific understanding and apply their knowledge to solve contextual problems. Such learning experiences closely align with the scientific literacy framework, which emphasizes not only conceptual understanding but also the ability to apply scientific knowledge in real-world contexts.

The integration of STEAM elements into the educational game also improved scientific literacy. The science component enabled students to understand concepts of the human respiratory system, while the technology component was delivered through a digital learning platform. Engineering elements were incorporated through problem-solving tasks and challenge-based activities that required students to identify solutions to contextual problems. Arts elements were reflected in the visual design, illustrations, and interactive features that enhanced students' engagement, whereas mathematics supported logical reasoning and analytical thinking. The integration of these disciplines provided students with interdisciplinary learning experiences that facilitated deeper understanding and meaningful knowledge construction. This finding is consistent with previous studies reporting that STEAM learning promotes critical thinking, creativity, problem-solving skills, and interdisciplinary understanding (Safitri, 2022; Wahyuningsih, Nurjanah, Rasmani, Hafidah, Pudyaningtyas, & Syamsuddin, 2020).

Another factor that may explain the improvement in scientific literacy is the game-based learning environment itself. Educational games create interactive and enjoyable learning experiences that can increase students' motivation, attention, and participation during instruction. Unlike conventional learning, which often relies on lectures and passive information transfer, game-based learning encourages students to actively interact with learning content and receive immediate feedback on their actions. Such conditions

enable students to become more engaged in the learning process and support deeper cognitive processing of scientific concepts. This finding supports Afidah & Subekti (2024), who reported that educational games enhance students' engagement and learning effectiveness through interactive learning experiences.

In terms of application, the STEAM-based educational game helped students connect scientific concepts to real-life situations through embedded contextual problems within the game environment. Students were not only exposed to theoretical content but also required to apply scientific concepts to solve authentic problems in their daily lives. This contextualized learning experience enabled students to recognize the relevance of science beyond the classroom and to deepen their understanding of scientific concepts.

Furthermore, integrating STEAM elements into the educational game facilitated interdisciplinary learning. Students were encouraged to understand scientific concepts, use technology, engage in problem-solving activities, appreciate visual and creative representations, and apply logical reasoning during the learning process. Such integration is consistent with the fundamental principles of STEAM learning, which promote interdisciplinary problem-solving and meaningful knowledge construction (Kurniawati & Muhsinin, 2025). Through these experiences, students were encouraged not only to understand scientific concepts theoretically but also to apply them in authentic contexts (Wulandari, Wahyuni, & Siregar, 2024). Active involvement in solving real-world problems also contributed to the development of essential twenty-first-century skills, including critical thinking, creativity, communication, and problem-solving (Sitepu & Sinaga, 2023).

Another important factor contributing to the improvement of scientific literacy is the use of educational games as interactive learning media. Educational games provide engaging and meaningful learning experiences that encourage students to think critically, make decisions, and solve problems independently (Afidah & Subekti, 2024). The game's interactive nature increased students' motivation and engagement throughout the learning process, creating a more enjoyable, participatory learning environment than conventional instruction. Such conditions promote active knowledge construction and transform learning from a passive process into an interactive and student-centered experience.

Overall, the findings suggest that STEAM-based educational games not only improve students' learning outcomes but also foster scientific literacy through meaningful, contextual, and interdisciplinary learning experiences. This result is consistent with Zaid, Razak, & Alam (2022), who reported that STEAM-based learning media can improve the quality of science learning by providing interactive learning experiences that encourage active student participation. Therefore, integrating STEAM principles and educational games is a promising instructional strategy for fostering scientific literacy and improving the quality of elementary science education. Nevertheless, several limitations should be acknowledged. First, the study involved participants from only one elementary school, which may limit the generalizability of the findings to broader educational contexts. Second, the intervention lasted only a relatively short period, making it difficult to determine the long-term impact of STEAM-based educational games on students' scientific literacy. Third, this study focused primarily on scientific literacy outcomes and did not investigate other potential benefits, such as creativity, collaboration, communication skills, or learning motivation.

## 4. Conclusion

This study concludes that STEAM-based educational games are effective in enhancing elementary school students' scientific literacy. By integrating science, technology, engineering, arts, and mathematics into interactive, context-based learning activities, the educational game provided students with opportunities to actively construct knowledge, engage in problem-solving processes, and apply scientific concepts to real-life situations. These learning experiences contributed to the development of scientific literacy through meaningful, student-centered instruction. The findings of this study have both theoretical and practical implications. Theoretically, this study contributes to the growing body of literature on STEAM and game-based learning by providing empirical evidence that this approach can support the development of scientific literacy among elementary school students. In practice, the findings suggest that STEAM-based educational games can be used as an innovative instructional medium to create more engaging, contextual, and interactive science learning environments. Therefore, teachers and schools may consider incorporating STEAM-oriented digital games into science instruction to support students' active participation and literacy development. Future studies are therefore recommended to involve larger, more diverse samples, implement longer intervention periods, and examine the effects of STEAM-based educational games on various twenty-first-century competencies. Further research may also explore different game designs and learning contexts to strengthen the evidence regarding the effectiveness of STEAM-based educational games in elementary science education.

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