

Effects of Video Sensing in Scratch-Based Educational Games on Learning and Perceived Juiciness: An Educational Intervention

Mohsen Rahim Beygi¹, Yousef Mahdavinab^{2*}, Masoumeh Sadat Abtahi³, Mahdi Ashoori⁴

¹Department of Educational Studies and Curriculum Planning, Science and Research Branch, Islamic Azad University, Tehran, Iran

²Department of Educational Technology, Kharazmi University, Tehran, Iran

³Department of Educational Studies and Curriculum Development, SR.C., Islamic Azad University, City, Iran

⁴Department of Educational Sciences, Farhangian University, Tehran, Iran

ABSTRACT

Background: Video sensing is a feature in Scratch 3.0 that enables the webcam to function as a sensor for detecting motion and color. This study examined whether incorporating video sensing into Scratch-based educational games could improve perceived juiciness and interaction among elementary school students.

Methods: A randomized pretest–posttest controlled design was conducted with 54 second-grade students recruited through convenience sampling in Ilam, Iran, between September 2024 and January 2025. Participants were randomly assigned to either a video-sensing intervention group or a control group, with 27 students in each group. Both groups used the same Scratch-based educational game during six 20-minute sessions; however, only students in the intervention group interacted with the game through video sensing. Mathematics achievement was assessed using a researcher-developed 20-item test, while perceived juiciness was measured using a researcher-developed questionnaire. Data were analyzed using IBM SPSS Statistics, Version 22, with Analysis of Covariance (ANCOVA), paired- and independent-samples t-tests, and Pearson’s correlation coefficient.

Results: Mathematics achievement in the video-sensing group increased markedly from pretest ($M = 11.37$, $SD = 3.07$) to posttest ($M = 16.67$, $SD = 1.36$), $t(26) = 10.77$, $p < 0.001$. The control group also demonstrated a statistically significant, although smaller, improvement from pretest ($M = 11.89$, $SD = 3.72$) to posttest ($M = 13.56$, $SD = 2.52$), $t(26) = 3.24$, $p = 0.003$. After controlling for baseline mathematics achievement, posttest scores were significantly higher in the video-sensing group than in the control group, $F(1, 51) = 60.21$, $p < 0.001$, $\eta^2 = .541$. In addition, the video-sensing group reported significantly higher overall perceived-juiciness scores than the control group ($M = 3.49$, $SD = 0.37$ vs. $M = 2.80$, $SD = 0.45$), $t(52) = 6.15$, $p < 0.001$, Cohen’s $d = 1.67$. However, within the video-sensing group, perceived juiciness was not significantly correlated with gains in mathematics achievement, $r = -0.17$, $p = 0.404$.

Conclusion: The incorporation of video sensing into Scratch-based educational games improved both mathematics achievement and perceived juiciness. Nevertheless, perceived juiciness was not related to learning gains, indicating that the quality of the gameplay experience and academic improvement may constitute separate outcomes.

Keywords: Computer-Assisted Instruction; Juiciness; Educational Technology; Scratch Programming; Learning; Academic Success

*Corresponding author:

Yousef Mahdavinab,
Department of Educational
Technology, Kharazmi
University, Tehran, Iran.

Tel: +98 9191499683

Email: yousef.m@khu.ac.ir

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Introduction

In recent years, incorporating game-based elements into educational settings has received increasing attention as an effective approach for improving student engagement and creating interactive and meaningful learning experiences (1). At the same time, the rapid development of digital technologies has introduced both major challenges and significant opportunities for educational systems (2, 3). The widespread presence of digital tools in everyday life has substantially transformed the ways individuals communicate, obtain information, and develop knowledge. Consequently, educational systems need to adapt in order to prepare learners to function successfully in an increasingly digital environment; otherwise, their educational relevance and pedagogical effectiveness may gradually decline (4, 5).

One promising way of responding to these changing educational demands is through the use of digital educational games, which employ engaging, interactive, and motivating features to encourage learner participation and support deeper conceptual understanding (6). Research suggests that appropriately designed digital games can support learning and the development of cognitive skills, while collaborative forms of digital learning may also promote interaction among learners (7, 8). Consequently, educational games have become widely acknowledged as an innovative and evidence-based instructional approach (9).

Educational games combine instructional content with entertainment, enabling learners to experience learning in an enjoyable and memorable manner (10). Since the 1960s, educational scholars and practitioners have emphasized experiential and play-based learning because of its potential to increase motivation, improve conceptual understanding, and contribute to children's overall development (11). Play is particularly important during childhood because it provides a fundamental means through which children investigate their surroundings, experiment with ideas, and internalize new knowledge.

A wide range of benefits associated with educational games has been documented in formal learning environments. Studies consistently demonstrate that such games can increase motivation and active participation by providing engaging, appropriately challenging, and highly interactive environments that encourage learners to remain voluntarily involved in learning activities (12). Unlike conventional instructional methods, which often position students as passive recipients of information, educational games support constructivist learning by enabling learners to interact directly with content and participate in authentic, hands-on experiences (10). In addition, the repetitive and feedback-oriented structure of game-based learning can promote deeper cognitive processing, facilitate the development of knowledge structures, and improve long-term retention (11). Many modern educational games are also intentionally designed to develop higher-order abilities, including complex problem-solving, critical analysis, creativity, and collaborative skills (12). Furthermore, their adaptability and potential for personalization enable educators to respond to differences in learners' abilities, preferences, and learning pace while making difficult or abstract concepts easier to understand (13).

Mathematics education during the elementary school years involves particular and persistent difficulties because mathematics is inherently abstract and requires conceptual understanding rather than simple mechanical memorization. Young learners commonly struggle with foundational topics such as differentiating between even and odd numbers, recognizing and explaining geometric characteristics, and reading both analog and digital clocks, all of which require spatial reasoning, symbolic representation, and flexible mental processing (14, 15). These cognitive challenges may be further intensified by mathematics anxiety (math anxiety), an affective difficulty experienced by approximately 20–30% of students worldwide and observable from

as early as the first or second grade. Math anxiety can involve strong feelings of worry, physiological reactions, and avoidance behaviors that negatively affect motivation, persistence, and academic achievement. It may also create a continuing negative cycle in which fear of failure limits opportunities for practice, weakens self-efficacy, and eventually contributes to persistent underachievement (16-20). Traditional teaching approaches, which are frequently passive, abstract, and largely dependent on screens or paper-based materials, may further aggravate these problems because they provide few concrete or embodied representations of abstract mathematical concepts. Embodied interaction, which involves intentionally using physical movement and bodily actions to represent and investigate mathematical concepts, offers a potentially effective alternative that is supported by theories of embodied cognition and constructionist learning (21–23). Technologies such as the video sensing extension in Scratch make embodied learning more accessible by converting natural body movements into immediate and observable digital responses, potentially reducing emotional barriers, improving conceptual grounding, and encouraging more confident and intuitive mathematical reasoning.

Juiciness is an important concept in contemporary digital game design and describes the intentional provision of abundant and rich multisensory feedback, including visual, auditory, haptic, and interactive responses, following a player's actions (24). A game with a high degree of appropriate juiciness tends to feel dynamic, responsive, and emotionally satisfying even when the player's input is minimal. Such experiences may include particle effects, animated responses, rewarding sound effects, screen movement, and other expressive forms of feedback that strengthen the player's sense of control and enjoyment (24). Empirical studies suggest that moderate levels of juiciness can significantly improve player engagement, intrinsic motivation, enjoyment, and flow by continuously rewarding successful actions and

increasing the perceived responsiveness of the system (25). In contrast, insufficient juiciness may cause actions to appear unnoticed or unrewarded, thereby reducing extrinsic motivation, whereas excessive juiciness may become distracting, overwhelming, or cognitively demanding and can shift attention away from meaningful challenges and mastery, potentially weakening intrinsic motivation (24, 25). When appropriately balanced, juiciness can therefore strengthen immersion, emotional involvement, aesthetic satisfaction, and sustained attention without creating unnecessary cognitive load (25).

The Video Sensing extension in Scratch 3.0 enables the platform to function as an embodied interaction environment by using a device's webcam as a real-time sensor capable of identifying motion and color (26, 27). Through this functionality, learners can control digital objects and animations using natural physical movements and visual information from their surroundings, thereby reducing the separation between physical and virtual environments (26). The immediacy of this interaction, in which bodily movements produce visible and dynamic changes on the screen, contributes to highly responsive and engaging experiences that can support sustained attention, immersion, and emotional involvement (28). These characteristics may be especially valuable in elementary education, where combining physical movement with digital creation can increase motivation, encourage creativity, and contribute to memorable and lasting learning experiences (27, 28).

Drawing on the theoretical and empirical foundations discussed above, the present study proposes an explanatory model in which video sensing facilitates embodied interaction, embodied interaction contributes to stronger perceptions of juiciness through responsive and multisensory feedback, greater perceived juiciness supports increased engagement and motivation, and these processes ultimately contribute to improved mathematics learning outcomes. More specifically, video sensing allows students to connect abstract

mathematical concepts with concrete bodily actions, such as using gestures to classify numbers or manipulate clock hands. At the same time, juiciness strengthens the rewarding and emotionally meaningful nature of these interactions, which may help maintain attention, reduce mathematics anxiety, and support deeper conceptual processing and transfer. Although research on game-based mathematics education has expanded, relatively little attention has been directed toward the specific contribution of video sensing as an accessible form of embodied interaction or toward the mediating role of experiential design characteristics such as perceived juiciness in elementary education. In addition, the lack of validated instruments for directly assessing juiciness in educational games represents an important methodological limitation. The present study therefore seeks to address these gaps by examining whether incorporating video sensing into Scratch-based mathematics games produces better learning outcomes and by investigating the extent to which embodied interaction and perceived juiciness are associated with these improvements.

Juiciness, particularly when expressed through rich and immediate audiovisual feedback, may contribute to mathematics learning through several cognitive and motivational mechanisms. First, the enhanced sensory feedback associated with juicy game design may improve attentional focus and decrease cognitive load by making abstract mathematical processes more concrete and perceptually noticeable (29). Second, the immediate reinforcement provided through juicy feedback may strengthen the consolidation of procedural memory and increase learners' sense of competence, thereby helping them remain engaged during demanding problem-solving activities (30). Third, when juiciness is combined with embodied interaction through video sensing, the resulting sensorimotor experience may contribute to the development of grounded mathematical representations, consistent with theories of embodied cognition (31, 32).

Despite the increasing research interest in game-based learning within mathematics education (33), the specific function of video sensing as an embodied interaction mechanism and its contribution to learning beyond the novelty of the technology remain insufficiently explored. Previous research has particularly rarely investigated how video sensing may improve mathematics learning through experiential design features associated with perceived juiciness, such as enjoyment, engagement, and the quality of interaction, especially among elementary school students. Furthermore, the absence of direct instruments for measuring juiciness has resulted in limited investigation of its explanatory significance within educational game design.

To address these important research gaps, the present study aimed to examine the effects of incorporating video sensing technology into educational games designed for elementary school students. More specifically, the study investigated whether the use of video sensing significantly improves students' mathematics learning outcomes while also examining its potential to enhance their overall gaming experience and perceived juiciness, defined as the satisfying sensory feedback provided by the game. Finally, the study investigated the relationship between these dimensions by examining the extent to which stronger perceptions of game juiciness are associated with students' actual gains in mathematics learning within a video-sensing environment.

Methods

Study Design and Setting

The study was conducted from September 2024 to January 2025 among second-grade students at Omid Elementary School in Ilam, Iran. The school was a public, tuition-free institution operating within Iran's national education system and was purposively selected based on its availability of the Information and Communication Technology (ICT) infrastructure required for the implementation of the video-sensing educational games.

The study employed a randomized controlled pre-test–post-test design involving both an intervention group and a control group. To provide further insight into the learning outcomes, the researchers also included an explanatory quantitative component using standardized questionnaires to assess students' game experiences and "perceived juiciness."

Students' academic development was evaluated by administering a pre-test to determine their initial understanding of essential second-grade mathematics topics. These included distinguishing between even and odd numbers, identifying geometric shapes and their characteristics, and telling time using a clock. The pre-test scores were then compared with the post-test results to determine the extent of students' learning gains associated with the game-based interventions.

Video Sensing Implementation

The Video Sensing extension in Scratch 3.0 was used to enable embodied interaction in the interventional group. This extension utilizes the device's webcam as an interactive sensor to detect motion and color in real time. The four core functional blocks employed were:

- (1) Turn video on – activates the webcam and initiates motion-based interaction.
- (2) Set video transparency (0–100) – adjusts the visibility of the live camera feed behind sprites, allowing seamless integration of physical and digital elements.
- (3) Video motion sensing – measures the intensity of learner movement across the stage or specific sprites, enabling gesture-based control.
- (4) Video color sensing – identifies predefined colors within the camera's field of view for color-triggered interactions.

These blocks were configured to create responsive, immediate feedback loops in the three mathematics games: Adventure on Number Island (hand gestures to sort even/odd numbers), Shape Sorter (motion-based shape classification), and Time Explorer

(gesture-controlled clock hand rotation). Screenshots illustrating the video sensing implementation are provided in Figure 1.

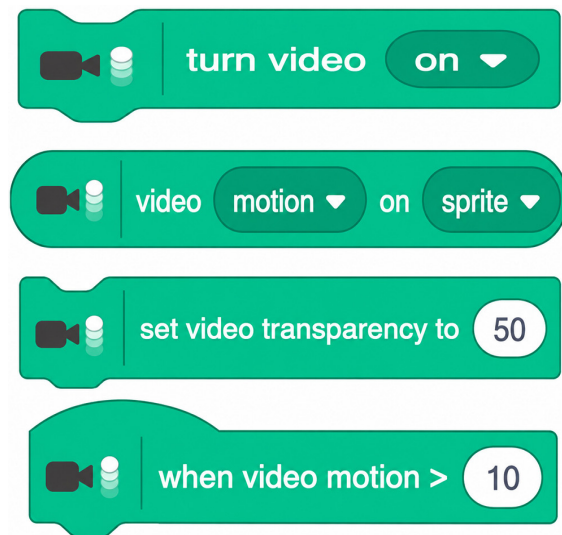


Figure 1: Overview of the four core functional blocks used to implement video sensing

The interventional design with random assignment was chosen to enable systematic comparisons between the interventional group, which engaged with video sensing–based educational games, and the control group, which received instruction without video sensing. This approach allowed for reasonable control of major extraneous variables through random assignment to conditions and statistical control of pre-test differences using Analysis of Covariance (ANCOVA), and ensured consistent implementation of the intervention across groups. However, as both groups were drawn from a single school using a convenience sample, and given that cluster-level variables such as class and teacher effects were not explicitly controlled, the extent of this control remains partial. Notably, while random assignment strengthens internal validity, the use of a convenience sample limits the external validity and generalizability of the findings. By maintaining comparable conditions for both groups except for the independent variable, the design supported valid and reliable comparisons of learning outcomes and interaction quality.

Participants and Sampling

A convenience sampling approach was used to recruit participants by selecting a school that satisfied the predefined eligibility criteria, including willingness to participate, access to at least two intact second-grade classrooms, and adequate ICT infrastructure to support the video-sensing intervention. Among the 60 students initially screened, 54 fulfilled all inclusion criteria and were enrolled in the study. Six students were excluded because parental consent forms were incomplete or they did not meet the required attendance criteria.

The sample size was determined a priori based on evidence from research on game-assisted mathematics education. Turgut and Doğan Temur (2017) reported an average effect size of Hedges's $g = 0.792$ for mathematics achievement (34). For the power analysis, this value was treated as approximately equivalent to Cohen's $d = 0.79$. An a priori power analysis conducted using G*Power, Version 3.1.9.7, with a two-sided alpha level of .05, statistical power of .80, and equal allocation between groups indicated a minimum total sample size of 54 participants, corresponding to 27 participants per group.

Group allocation was performed by an independent researcher who was not involved in delivering instruction or administering assessments. Each eligible student was assigned a unique numeric code (01–54), and a published random number table was used to allocate participants sequentially to the interventional or control condition until each group comprised 27 students. To maintain allocation concealment, group assignments were placed in a sealed envelope and kept from both the classroom teacher and the lead investigator until the pre-test was completed and all responses had been collected and securely stored. This approach ensured that participants' pre-test results could not affect group allocation and minimized the possibility of bias in teacher behavior during the baseline assessment. Thereafter, both groups were exposed to the same administrative procedures, hardware

resources, and instructional materials. The only distinction between the two groups was the interaction method used, namely video-based sensing or conventional input.

Participation in the study was completely voluntary. To be included in the final analysis, students were expected to attend all instructional sessions, complete both the pre-test and post-test assessments, and respond to the questionnaires administered during the second phase of the study. Participants were excluded if they withdrew their consent, missed one or more instructional sessions, or submitted incomplete questionnaire data, defined as responding to fewer than 20% of the questionnaire items.

Intervention/Procedures

At the beginning of the study, students in both groups completed a pre-test to assess their initial knowledge in three key areas of the second-grade mathematics curriculum: differentiating between even and odd numbers, identifying geometric shapes and their defining characteristics, and reading time from an analog clock. The assessment items were developed to evaluate students' ability to categorize numbers, recognize and describe basic properties of geometric figures, and correctly interpret time displayed on an analog clock.

Following the pre-test, all participants took part in a structured instructional phase delivered by a single classroom teacher across both groups, thereby eliminating teacher variability as a potential confound. To prevent cross-group contamination (i.e., the risk that students in the control group might learn about the video sensing feature through peers in the interventional group), three measures were implemented. First, temporal separation: the control group received their sessions in the morning, while the interventional group received their sessions in the afternoon, ensuring that students from the two groups did not encounter each other during the intervention period. Second, spatial separation: the two groups were placed in separate classrooms located in different hallways of the school,

minimizing the possibility of students observing or overhearing the activities of the other group. Third, a confidentiality protocol: at the beginning of the study, students in both groups were explicitly instructed not to discuss their classroom activities with peers from the other group; the classroom teacher was trained to refrain from sharing any details of the intervention between groups and avoided making comparisons or references to the other group's activities; additionally, students in the control group were not informed about the existence of the video sensing feature, as it was not activated in their version of the games. Both the interventional and control groups received an identical total of six structured 20-minute sessions (120 minutes of total instructional time) conducted over Three week. Within each session, the first 10 minutes were devoted to teacher-led mathematical instruction and the remaining 10 minutes to game-based practice using Scratch-based educational games delivered via laptop computers. The instructional content, learning objectives, and session duration were identical for both groups; the

sole differentiating factor was the mode of interaction (video sensing technology in the interventional group versus conventional mouse-based input in the control group).

Control Group: Following the pre-test, students in the control group engaged with Scratch-based mathematics games without video sensing (Figure 2). In the first activity, numbers appeared randomly on the screen, and students clicked to categorize each number as even or odd. The game incorporated number sprites, an engaging background, sound effects, a scoring system, and a results screen. In the second activity, geometric shapes appeared on the screen, and students identified each shape by name and described its key properties through guided rotation and visual exploration. In the third activity, students practiced reading analog and digital clocks through an interactive time-telling module developed in Scratch. All activities were delivered across six 20-minute sessions (two sessions per week) over three weeks, with each session structured as ten minutes of teacher-led instruction followed by ten minutes of game-based practice.

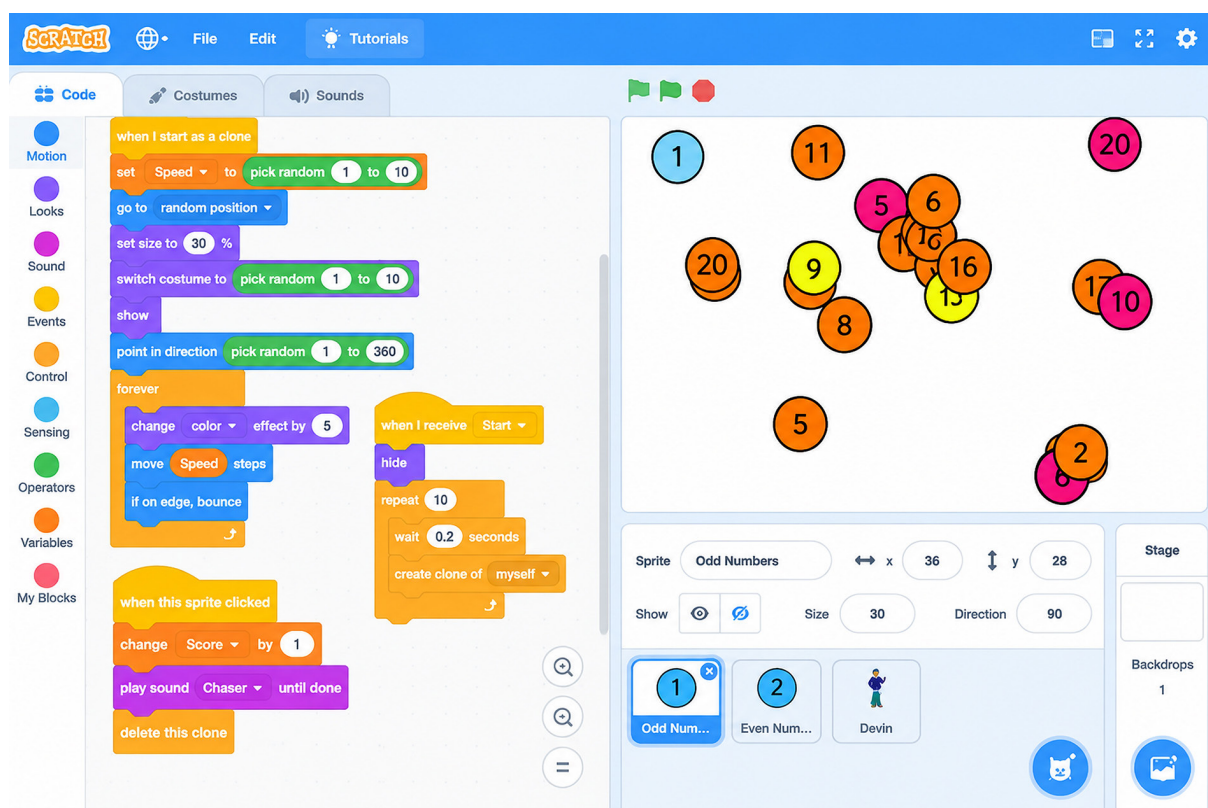


Figure 2: Mathematics educational game developed in Scratch without video-sensing features

Interventional Group (Video Sensing):

Pre-tests were administered at the beginning of the study, after which students in the intervention group engaged with three Scratch-based educational games enhanced with video-sensing technology (Figure 3). In the first game, *Adventure on Number Island*, students used the webcam to control a pointer through hand movements, guiding falling numbers into the appropriate bins representing even and odd categories. Hand movements were detected in real time, and the system provided immediate visual and auditory feedback in response to the students' actions.

The second game focused on geometric concepts. In this activity, geometric shapes appeared on the screen, and students used hand movements detected by the webcam to direct each shape into its corresponding basket. This motion-based sorting activity was designed to support students in identifying geometric shapes and recognizing their key properties through active and embodied interaction.

The third game addressed the concept of time. In this activity, the clock hand was

controlled through video sensing, allowing students to rotate it by moving their hand in front of the webcam until it matched the target time displayed on the screen. This interaction enabled students to practice reading and adjusting both analog and digital clocks in an engaging and intuitive manner.

The three games were rotated across the six sessions, with each game played twice. After the completion of all instructional sessions, a post-test was administered to both groups.

Tools/Instruments

Data were collected using a combination of achievement-based measures and questionnaire-based instruments, corresponding to the two-stage quantitative design of the study. In the first stage, mathematics learning outcomes were assessed using a researcher-developed 20-item achievement test aligned with the second-grade mathematics curriculum. The test covered three core content areas: identifying even and odd numbers, recognizing geometric shapes and their essential properties, and

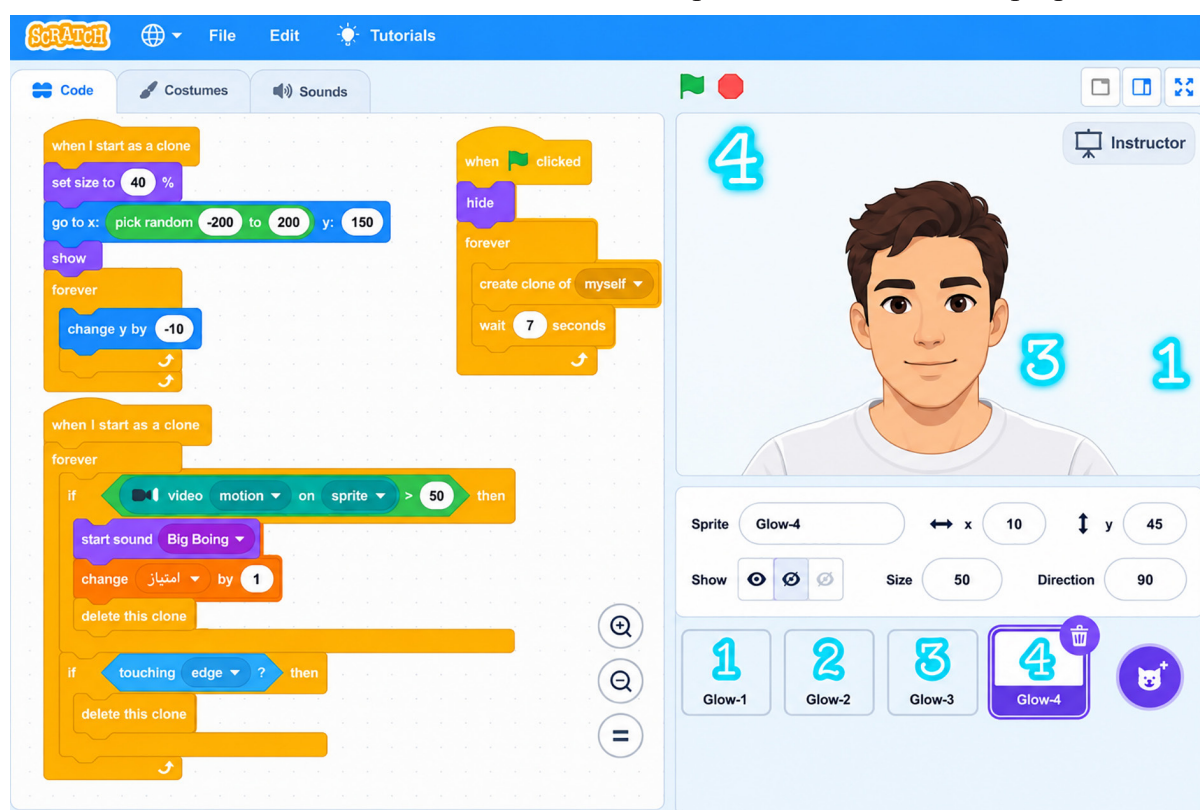


Figure 3: Mathematics educational game developed in Scratch with video-sensing features

reading time on analog clocks. Test items were designed in multiple-choice format to assess students' conceptual understanding and procedural knowledge. Content validity was confirmed by subject-matter experts, and reliability analyses indicated acceptable internal consistency.

In the second stage of the study, a researcher-developed questionnaire was used to evaluate students' perceived juiciness and overall game experience. As no validated instrument currently exists for measuring juiciness specifically in educational games, the questionnaire was created by integrating and adapting relevant items from three established measures: the Game Experience Questionnaire (GEQ) (35), the Interest/Enjoyment subscale of the Intrinsic Motivation Inventory (IMI) (36), and the User Experience Questionnaire (UEQ) (37).

Four GEQ subscales were incorporated: Competence (5 items), Immersion (6 items), Flow (5 items), and Positive Affect (5 items) (35). The complete 7-item Interest/Enjoyment subscale from the IMI was also included (36). In addition, three UEQ dimensions were selected: Attractiveness (6 items), Stimulation (4 items), and Novelty (4 items) (37). These dimensions were considered relevant because they encompass several experiential features commonly associated with juiciness, including enjoyment, engagement, responsive feedback, and interaction quality.

All questionnaire items were linguistically modified to ensure that they were understandable and developmentally appropriate for second-grade students. The instrument was administered using a simplified 5-point Likert-type response format supported by pictorial cues in the form of smiley faces.

For each subscale, a score was calculated by averaging the responses to its corresponding items, which were rated on a 1–5 scale. An overall juiciness score was subsequently derived for each participant by averaging the mean scores across all eight subscales. This composite score represented perceived juiciness as a higher-order experiential construct encompassing enjoyment,

engagement, sensory richness, and novelty. Analyses were conducted and reported at both the individual subscale level and the overall composite level.

Validity and Reliability - The validity and reliability of the research instruments were examined separately for the mathematics achievement test and the perceived juiciness questionnaire, given their different measurement formats and purposes.

Mathematics Achievement Test

The content validity of the researcher-developed mathematics achievement test was evaluated by a panel of 10 subject-matter experts in elementary mathematics education. The experts reviewed the test items for their relevance, clarity, and alignment with the second-grade mathematics curriculum and intended learning objectives. Based on their evaluations, the items were revised accordingly, resulting in an overall item acceptance rate of 93%.

Regarding reliability, due to the dichotomous scoring format of the 20-item test, internal consistency was assessed using the Kuder–Richardson Formula 20 (KR-20). The analysis yielded a reliability coefficient of 0.82, indicating acceptable internal consistency for the achievement measure.

Perceived Juiciness Questionnaire

The content validity of the adapted questionnaire, which assessed perceived juiciness and game experience, was evaluated using the Content Validity Ratio (CVR) method. A panel of 10 elementary school teachers and educational technology experts assessed the relevance and clarity of the adapted items. The analysis yielded an overall CVR value of 0.90, indicating strong content validity.

Reliability was assessed using Cronbach's alpha because the questionnaire items employed Likert-type response scales. The reliability coefficients for the eight subscales were as follows: Competence ($\alpha = 0.85$), Immersion ($\alpha = 0.82$), Flow ($\alpha = 0.80$), Positive Affect ($\alpha = 0.84$), Interest/Enjoyment ($\alpha =$

0.88), Attractiveness ($\alpha = 0.83$), Stimulation ($\alpha = 0.79$), and Novelty ($\alpha = 0.81$). These coefficients indicate satisfactory internal consistency across all subscales.

It should be noted that the factorial structure of the questionnaire was not formally examined using Exploratory Factor Analysis (EFA) or Confirmatory Factor Analysis (CFA). Therefore, the composite juiciness score should be regarded as a provisional measure based on the theoretically defined grouping of items and subscales, pending further psychometric validation. For each participant, a composite juiciness score was calculated by averaging the mean scores of the eight subscales, providing an overall indicator of perceived juiciness.

Data Collection

Data were collected in two phases: first, pre- and post-test achievement measures were used to assess mathematics learning gains; second, a questionnaire assessment was conducted immediately following the intervention to provide explanatory insight into students' experiential perceptions.

Data collection was conducted between September 2024 and January 2025 at Omid Elementary School in Ilam, Iran, following a structured two-stage procedure aligned with the study's quantitative interventional design with random assignment. The first phase involved assessing learning outcomes through Google Forms pre- and post-tests administered via social media. To ensure that students responded independently and without external assistance, the following controls were implemented: the tests were completed in the classroom under direct teacher supervision; students were not allowed to use any resources, including books, notes, or peer assistance; a maximum time limit of 30 minutes was set for the 20-item test; and Google Forms was configured to allow only one submission per student and to log any exit from the test page. Classroom teachers provided students with access to the test links and offered guidance on completing and submitting their responses to ensure accurate

data collection. The pre-test was administered prior to the instructional intervention, while the post-test was conducted immediately after the completion of all instructional sessions.

During the instructional phase, the Scratch-based educational games Adventure on Number Island, Shape Sorter, and Time Explorer were implemented on school laptops during regular class time. Each instructional session lasted 20 minutes, and all students had equal access to the required hardware and learning materials. The intervention group interacted with the games using video-sensing technology, whereas the control group used the same games without video sensing, ensuring that the mode of interaction was the only differentiating factor between the groups.

In the second stage of data collection, students' perceived juiciness and game experience were assessed using questionnaire-based measures. The questionnaires were administered electronically after completion of the post-test to capture students' immediate perceptions of enjoyment, engagement, feedback immediacy, and interaction quality during gameplay. Teachers assisted students in understanding the questionnaire items when necessary, without influencing their responses. This two-stage data collection procedure ensured a clear separation between the measurement of learning outcomes and the explanatory assessment of game experience.

Data Analysis

Statistical analyses were conducted using IBM SPSS Statistics, Version 22. Continuous variables were summarized using Means and Standard Deviations (SD), and categorical variables were reported using frequencies and percentages. All statistical tests were two-sided, and the significance level was set at $p < 0.05$. Effect sizes and 95% confidence intervals were reported where appropriate.

To evaluate the effect of video sensing on students' mathematics achievement, an Analysis of Covariance (ANCOVA) was performed, with post-test mathematics scores specified as the dependent variable, study group as the fixed factor, and pre-test

achievement as the covariate. ANCOVA served as the primary statistical analysis for estimating the intervention effect. Prior to interpreting the results, relevant assumptions were assessed, including linearity between pre-test and post-test scores, normality of residuals, homogeneity of regression slopes, and homogeneity of error variances. The homogeneity of regression slopes assumption was examined by testing the interaction between study group and pre-test achievement. Partial eta squared (η^2) was reported as the measure of effect size for the adjusted between-group comparison. Because the assumption of equal error variances was violated, the ANCOVA results were further examined through a sensitivity analysis using Heteroskedasticity-Consistent type 3 (HC3) robust standard errors. This additional analysis was conducted to determine whether the statistical conclusions remained stable despite the presence of unequal error variances.

Paired-samples t-tests were performed as supplementary analyses to assess changes in mathematics achievement from pre-test to post-test within each study group. Mean change scores and their corresponding 95% confidence intervals were reported, while Cohen's d_z was used to estimate the standardized within-group effect size. These analyses were intended to describe the extent of improvement within each group and were not considered the primary test of the intervention effect.

To determine whether video sensing influenced students' perceived juiciness, composite perceived-juiciness scores were compared between the video-sensing and control groups using an independent-samples t-test. The between-group mean difference, its 95% confidence interval, and Cohen's d were reported. Higher composite scores indicated a greater level of perceived juiciness.

Finally, the association between perceived juiciness and mathematics learning gains was examined within the video-sensing group. A learning-gain score was calculated for each student by subtracting the pre-test score from the post-test score. Pearson's correlation

coefficient was then computed to assess the relationship between composite perceived-juiciness scores and learning-gain scores among students in the video-sensing condition.

Ethics - The camera was used exclusively to enable real-time video sensing interaction within the educational games and was not employed for recording, storing, or identifying students. No video or image data were saved, reviewed, or analyzed, and the camera function operated solely as a motion-detection input mechanism. Students' identities were not visible to the researchers through the system, and no facial recognition or biometric data were collected at any stage of the study.

All collected data, including test scores, questionnaire responses, and system-generated performance indicators, were treated as confidential and were anonymized prior to analysis. Data were stored securely and were used solely for academic research purposes. Access to the data was restricted to the research team, and no personal identifying information was disclosed in any reports or publications. The study protocol was reviewed and approved by the Ilam Department of Education, Ilam, Iran. All research procedures were conducted in accordance with ethical standards for research involving human participants, particularly those applicable to studies involving children and technology-enhanced learning environments.

Results

Of the 60 students initially assessed for eligibility, six were excluded because of incomplete parental consent or failure to meet the attendance requirements. The final sample therefore comprised 54 second-grade male students from Omid Elementary School in Ilam, Iran. These participants were randomly assigned in equal numbers to the video-sensing intervention group ($n = 27$) and the control group ($n = 27$). All enrolled students completed the intervention and study assessments and were included in the final analysis. The participant recruitment and study flow diagram is illustrated in Figure 4.

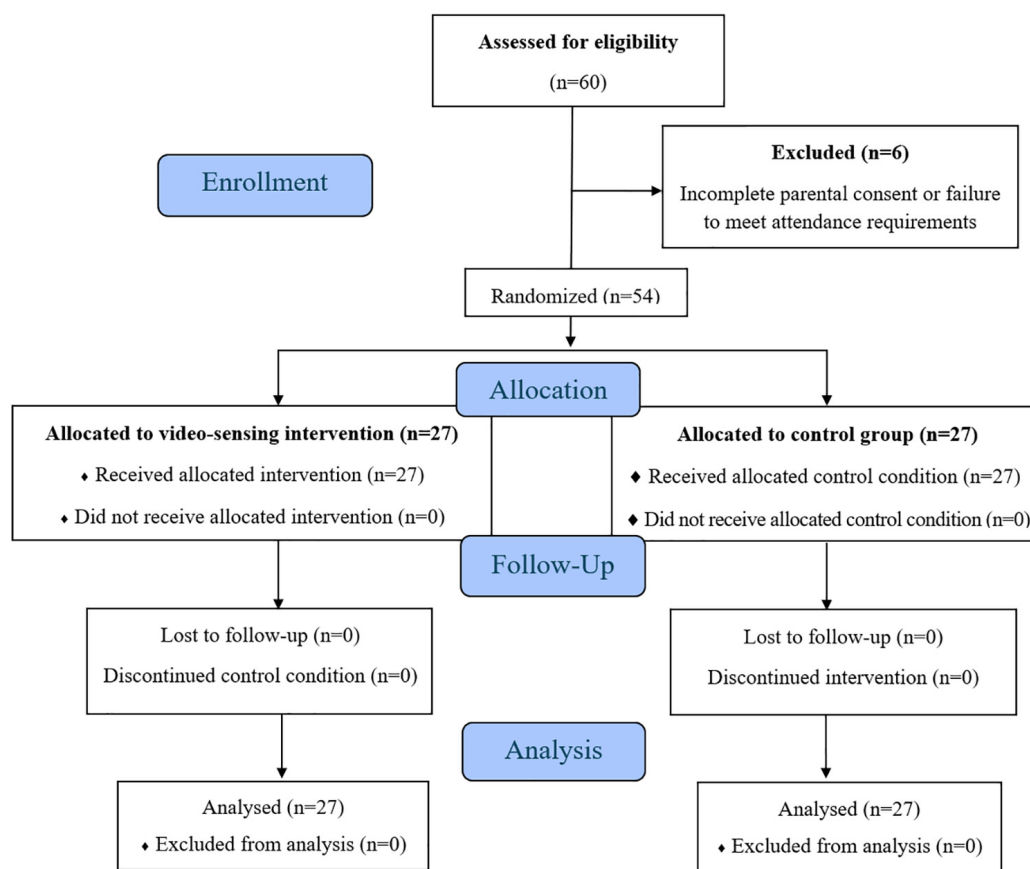


Figure 4: Participant recruitment and study flow diagram

Participants Characteristics

A total of 60 students were assessed for eligibility, of whom six were excluded. The final sample consisted of 54 second-grade male students, who were randomly assigned to the video-sensing group ($n = 27$) or the control group ($n = 27$). All participants completed the intervention and study assessments and were included in the final analysis. As shown in Table 1, the groups were descriptively comparable in age. The mean age was 8.10 years in the video-sensing group and 8.15 years in the control group. All participants were male.

Mathematics Learning Outcomes Descriptive Statistics

Table 2 summarizes mathematics achievement scores. At baseline, the video-sensing and control groups showed similar pre-test performance, with mean scores of 11.37 and 11.89, respectively. This difference was not statistically significant, $t(52) = -0.56$,

$p = 0.579$. After the intervention, mean post-test scores increased to 16.67 in the video-sensing group and 13.56 in the control group, indicating greater improvement in the video-sensing group.

Within-Group Changes in Mathematics Achievement

Paired-samples t-tests were conducted as complementary analyses to determine whether mathematics achievement changed significantly within each group. As shown in Table 3, both groups demonstrated statistically significant improvement from pre-test to post-test.

In the video-sensing group, the mean score increased from 11.37 ± 3.07 to 16.67 ± 1.36 . The mean improvement of 5.30 points was statistically significant, $t(26) = 10.77$, $p < 0.001$, 95% CI [4.29, 6.31], with a large within-group effect size, Cohen's $d_z = 2.07$.

The control group also showed a statistically significant improvement.

Table 1: Demographic characteristics of the participants

Variable	Characteristic	Video-sensing group (n = 27)	Control group (n = 27)
Age	Mean±SD*	8.10±0.30	8.15±0.35
Gender	Male, n (%)	27 (100%)	27 (100%)
	Female, n (%)	0 (0%)	0 (0%)

*SD = Standard Deviation.

Table 2: Descriptive statistics for mathematics achievement scores

Group	n	Pre-test Mean±SD	Post-test Mean±SD	Change score Mean±SD
Video sensing	27	11.37±3.07	16.67±1.36	5.30±2.55
Control	27	11.89±3.72	13.56±2.52	1.67±2.67

Change score was calculated as post-test minus pre-test. The maximum possible mathematics achievement score was 20.

Table 3: Within-group changes in mathematics achievement scores

Group	n	Pre-test, Mean±SD	Post-test, Mean±SD	Mean change±SD	95 % CI for t change	df	p	Cohen's <i>d_z</i>	
Video sensing	27	11.37±3.07	16.67±1.3	5.30±2.55	[4.29, 6.31]	10.77	26	< 0.001	2.07
Control	27	11.89±3.72	13.56±2.52	1.67±2.67	[0.61, 2.72]	3.24	26	0.003	0.62

Mean change was calculated as post-test minus pre-test. Cohen's d_z represents the standardized within-group mean change. The paired-samples analyses describe change within each group; the intervention effect was evaluated using Analysis of Covariance.

The mean score increased from 11.89±3.72 to 13.56±2.52. The mean improvement of 1.67 points was statistically significant, $t(26)=3.24$, $p=0.003$, 95% CI [0.61, 2.72], with a moderate within-group effect size, Cohen's $d_z = 0.62$.

Effect of Video Sensing After Adjustment for Baseline Achievement

The ANCOVA was performed to compare post-test mathematics achievement between the two groups after controlling for pre-test scores. The interaction between group and pre-test achievement was not statistically significant, $F(1,50)=2.98$, $p=0.090$, supporting the assumption of homogeneous regression slopes.

Levene's test was statistically significant, $F(1,52)=8.55$, $p=0.005$, indicating unequal post-test variances between the groups. Therefore, the ANCOVA finding was supplemented by a sensitivity analysis using HC3 robust standard errors.

As presented in Table 4, pre-test achievement was significantly associated

with post-test achievement, $F(1,51)=36.14$, $p<0.001$, $\eta^2=0.415$. More importantly, after adjustment for pre-test achievement, the effect of study group was statistically significant, $F(1,51)=60.21$, $p<0.001$, $\eta^2=0.541$.

The adjusted mean difference between the video-sensing and control groups was 3.31 points, 95% CI [2.45, 4.17], indicating higher post-test achievement in the video-sensing group.

The HC3 robust sensitivity analysis supported the same conclusion. The estimated group difference remained 3.31 points, robust (SE=0.44), $t(51)=7.54$, ($p<0.001$), 95% CI [2.43, 4.19]. Therefore, the significant intervention effect was not dependent on the equality-of-variances assumption.

Perceived Juiciness

To determine whether video sensing improved students' overall game experience, composite perceived-juiciness scores were compared between the two groups using an independent-samples t-test.

Table 4: Analysis of Covariance comparing post-test mathematics achievement between the study groups

Panel A. ANCOVA results						
Source	Sum of squares	df	Mean square	F	p	Partial η^2
Pre-test achievement	88.21	1	88.21	36.14	<0.001	0.415
Study group	146.95	1	146.95	60.21	<0.001	0.541
Error	124.46	51	2.44	—	—	—
Panel B. Adjusted post-test means						
Group	Adjusted mean	SE	95% CI			
Video sensing	16.77	0.30	[16.16, 17.37]			
Control	13.46	0.30	[12.85, 14.06]			

Post-test mathematics achievement was entered as the dependent variable, and pre-test achievement was entered as the covariate. ANCOVA= Analysis of Covariance; SE = Standard Error; CI = Confidence Interval.

Table 5: Comparison of composite perceived-juiciness scores between groups

Group	n	Mean $\pm$ SD	Mean difference	95% CI for difference	t	df	p	Cohen's d	95% CI for d
Video sensing	27	3.49 $\pm$ 0.37	0.69	[0.47, 0.92]	6.15	52	< 0.001	1.67	[1.05, 2.29]
Control	27	2.80 $\pm$ 0.45							

Composite perceived-juiciness scores ranged from 1 to 5, with higher scores indicating greater perceived juiciness.

As shown in Table 5, students in the video-sensing group reported a mean perceived-juiciness score of 3.49 $\pm$ 0.37, compared with 2.80 $\pm$ 0.45 in the control group. The mean difference of 0.69 points was statistically significant, $t(52)=6.15$, ($p<0.001$), 95% CI [0.47, 0.92].

The standardized difference was large, Cohen's $d = 1.67$, 95% CI [1.05, 2.29]. These findings indicate that students who interacted with the educational games through video sensing perceived the games as more responsive and satisfying than students who used conventional interaction.

Association Between Perceived Juiciness and Mathematics Learning Gains

The final research objective investigated whether students' perceptions of juiciness were related to improvements in mathematics performance within the video-sensing group. For each student, a learning-gain score was computed by subtracting the pre-test score from the post-test score.

The analysis showed a weak negative correlation between composite perceived juiciness and mathematics learning gains.

This relationship was not statistically significant, $r = -0.17$, $p = 0.404$.

Although students in the video-sensing group reported higher levels of perceived juiciness and achieved better mathematics performance than those in the control group, variation in perceived juiciness among students in the video-sensing group was not significantly associated with the extent of their improvement in mathematics. Thus, the hypothesis proposing that greater perceived juiciness would be linked to larger learning gains was not supported.

Discussion

This study investigated whether integrating video-sensing interaction into Scratch-based educational games could improve mathematics achievement and perceived juiciness among second-grade students.

Three main findings were identified. First, although both groups improved following the intervention, gains in mathematics performance were substantially greater in the video-sensing group. After controlling for baseline achievement, students in this group scored 3.31 points higher than those

in the control group, corresponding to a large adjusted group effect. Second, students who interacted with the games through video sensing reported significantly higher perceived juiciness than those who used conventional mouse-based interaction, with a large standardized between-group difference. Third, within the video-sensing group, perceived juiciness was not significantly associated with gains in mathematics performance.

Overall, these findings indicate that video-sensing interaction may contribute to both stronger academic outcomes and a more engaging or responsive game experience. However, the absence of a significant relationship between perceived juiciness and learning gains suggests that these benefits may arise through different underlying processes rather than through a single shared mechanism.

The superior mathematics performance observed in the video-sensing group is consistent with research demonstrating that embodied interaction and appropriately designed digital games can facilitate learning (21–23, 38–41). Previous reviews of serious games and educational games have generally reported positive effects on learning outcomes, although these effects vary according to instructional design, learner characteristics, content area, and implementation conditions (38–41). Research focusing specifically on embodied mathematics learning further suggests that bodily movement can support conceptual understanding when physical actions are meaningfully connected to the mathematical relationships being learned (21–23, 29, 38).

An important feature of the present study is that both groups used Scratch-based educational games. Therefore, the observed difference cannot simply be attributed to exposure to digital games. Students in both conditions received the same mathematical content, teacher-led instruction, duration of practice, learning objectives, and access to comparable hardware. The principal difference between the conditions was the

mode of interaction. Consequently, the findings are more appropriately interpreted as evidence of the added value of video-sensing interaction within an otherwise comparable game-based learning environment.

This distinction also has important theoretical implications. From the perspective of embodied cognition, conceptual learning may be strengthened when perceptual and motor experiences are integrated with cognitive representations (21, 22, 29). Within mathematics education, in particular, movement appears to be most effective when it serves a meaningful instructional function rather than being included merely to increase engagement. Its educational value is likely to be greater when learners' physical actions are systematically coordinated with the underlying mathematical structure of the task (21, 29).

The video-sensing activities in the present study were designed according to this principle. Students' movements were directly linked to mathematically relevant actions. In the even–odd activity, hand movements were used to classify numbers; in the geometry game, bodily actions were linked to the classification and manipulation of shapes; and in the time-telling activity, students rotated their hands to control the movement of a clock hand. In this way, physical action formed part of the representational structure of the learning task rather than functioning as an unrelated activity.

This interpretation is consistent with Abrahamson and Bakker's account of embodied learning, in which educational movement becomes meaningful through coordinated relationships between sensorimotor activity and conceptual structures (29). Similarly, Tran and colleagues suggest that embodied experiences can support mathematical reasoning by grounding abstract relationships in perceptual and motor activity (22). Research on embodied mathematics education likewise emphasizes that the effectiveness of movement depends substantially on its congruence with the mathematical concepts being represented (21, 38).

Studies of technology-enhanced embodied learning provide further support for this interpretation. Digital environments incorporating whole-body or gesture-based interaction have been associated with improved learning and engagement when physical actions are meaningfully integrated into instructional tasks (38, 42–44). For instance, Lindgren and colleagues found that embodied interaction in a mixed-reality environment supported learning and engagement by allowing learners to participate physically in representations of otherwise abstract content (42).

Another possible explanation concerns the immediacy of feedback. In the video-sensing games, students' movements generated rapid visual and auditory responses. Correct or incorrect actions were therefore followed almost immediately by perceptible consequences. Such tight action–feedback coupling may help learners detect errors, adjust their responses, and reinforce correct conceptual relationships. Feedback research in mathematics education has consistently emphasized that feedback is most educationally useful when it is timely, interpretable, and directly connected with learners' actions (30).

The larger improvement observed in the video-sensing group should nevertheless not be interpreted as evidence that the control condition was ineffective. Students who used conventional Scratch interaction also demonstrated meaningful improvement. The average learning gain was approximately 5.30 points in the video-sensing group compared with 1.67 points in the control group. This pattern suggests that Scratch-based mathematics practice combined with teacher instruction was beneficial in both conditions, but that the video-sensing mode of interaction provided additional educational value.

The principal evidence for this added value comes from the adjusted between-group analysis rather than from the separate within-group tests. After baseline differences were statistically controlled, the video-sensing group retained a 3.31-point advantage,

corresponding to a large effect. Moreover, the HC3 robust sensitivity analysis led to the same substantive conclusion despite the inequality of variances. This consistency increases confidence that the observed group difference was not merely a consequence of the statistical assumptions underlying the conventional ANCOVA.

Nevertheless, the magnitude of the observed effect should be interpreted cautiously. Effect estimates obtained from relatively small, single-site studies may be less stable than those obtained from larger multisite trials. Furthermore, the achievement test was specifically aligned with the mathematics content taught during the intervention. Such alignment is appropriate for assessing mastery of the targeted material, but it may produce larger effects than standardized assessments or measures of far transfer. The findings therefore provide relatively strong evidence of short-term learning within the targeted mathematical domains but should not yet be generalized to mathematics achievement more broadly.

The second major finding was the substantially higher perceived-juiciness score in the video-sensing group. Students using video sensing obtained an average composite score of 3.49 compared with 2.80 in the control group, corresponding to a large standardized difference. This finding is consistent with the literature on game feel and juicy game design. Juiciness generally refers to the richness, immediacy, responsiveness, and perceptual salience of feedback generated in response to player actions (24, 25). Hicks and colleagues describe juicy game design as a form of interaction in which player actions produce clear and satisfying audiovisual consequences, strengthening the perceived responsiveness of the game system (24). Kao similarly demonstrated experimentally that manipulation of juiciness can meaningfully influence player experience, motivation, and behavior (25).

Video sensing may enhance juiciness because it creates a relatively direct relationship between bodily intention and

digital consequence. With conventional mouse interaction, students first manipulate an external device, which subsequently changes an object on the screen. In video-sensing interaction, the learner's own bodily movement becomes the input. A hand gesture can directly reposition a game object, rotate a clock hand, trigger audiovisual feedback, or produce a change in score. This closer coupling of intention, action, and system response may increase students' sense that the digital environment reacts immediately and meaningfully to their actions.

Importantly, the present finding refers to the composite perceived-juiciness score. The questionnaire incorporated dimensions adapted from the GEQ, IMI, and UEQ questionnaires, including competence, immersion, flow, positive affect, interest/enjoyment, attractiveness, stimulation, and novelty (36, 37). However, because the present inferential analysis focused on the composite score, the results should not be interpreted as demonstrating statistically significant intervention effects on every individual subscale unless those dimensions are separately tested. This is particularly important because the composite juiciness measure remains provisional.

Although the adapted questionnaire demonstrated satisfactory content validity and internal consistency, its factorial structure was not formally examined. The study therefore provides evidence that students perceived the overall video-sensing game experience more positively and responsively, but it does not establish that all eight experiential dimensions form a single psychometrically validated latent construct.

The large difference in perceived juiciness may also partly reflect novelty. For young students, interacting with an educational game through their own bodily movements may be less familiar and therefore more stimulating than conventional mouse-based interaction. Novelty could contribute to initial enthusiasm and stronger subjective evaluations. However, the present design did not manipulate novelty independently or assess how perceptions

changed across individual sessions. It is therefore not possible to determine how much of the juiciness advantage resulted from sustained interaction quality and how much resulted from initial technological novelty.

The third finding is particularly important for interpreting the mechanism of the intervention. Despite substantial between-group advantages in both mathematics achievement and perceived juiciness, perceived juiciness was not significantly associated with learning gains within the video-sensing group. The correlation was small and negative and was not statistically significant.

This result means that the present study does not support the conclusion that video sensing improved mathematics achievement because students perceived the games as juicier. Such a causal interpretation would go beyond the available evidence.

There is no inconsistency between observing significant intervention effects on both outcomes and finding no significant association between them within the video-sensing group, because the analyses address different questions. The between-group analyses assess whether video-sensing interaction affects the average levels of mathematics achievement and perceived juiciness. By contrast, the within-group correlation examines whether students who experienced greater juiciness also showed larger individual learning gains. The findings support differences between the intervention conditions but do not provide evidence that variation in perceived juiciness within the video-sensing group was associated with variation in mathematics gains.

This distinction is consistent with the broader game-based learning literature. Cognitive learning outcomes and motivational or experiential outcomes can respond differently to educational games (38–41). Wouters and colleagues, for instance, distinguished cognitive and motivational outcomes in their meta-analysis of serious games and found that benefits in one domain do not necessarily imply equivalent benefits

in another (39). Similarly, research on educational games indicates that engagement, enjoyment, achievement emotions, satisfaction, and academic performance are related but conceptually distinct constructs (41, 45).

Kao's findings regarding juiciness are also relevant in this context (25). Experimental studies that manipulate the level of game juiciness indicate that the connection between sensory richness and player performance is neither simple nor necessarily linear. Providing more feedback does not automatically lead to corresponding improvements in performance, while overly intense feedback may disrupt the player's experience. In educational games, the aim should therefore be not to maximize juiciness, but to design feedback that is pedagogically meaningful and helps direct learners' attention toward the intended learning task.

Several methodological considerations may help explain the lack of a statistically significant correlation. The analysis included only 27 participants from the video-sensing condition, resulting in limited statistical power to identify small or moderate relationships. Moreover, perceived juiciness scores displayed relatively little variation within this subgroup. Such restricted variability can weaken observed correlations, even when a meaningful association may be present in the wider population.

The intervention group also achieved relatively high and less variable post-test scores, potentially limiting the amount of individual variation available to correlate with perceived juiciness. Consequently, the non-significant finding should not be interpreted as evidence that experiential quality is irrelevant to educational learning. A more appropriate conclusion is that this study found no evidence that students who experienced greater perceived juiciness learned more than other students receiving the same video-sensing intervention.

The timing of the measurement also constrains causal inference. Perceived juiciness was evaluated only after the

intervention had been completed, rather than at multiple points during the learning process. As a result, the current findings do not allow juiciness to be established as a mediator of the effects of video sensing. Future research specifically designed to test mediation should measure experiential factors throughout the intervention and examine whether earlier shifts in engagement or responsiveness are associated with later learning outcomes after accounting for prior achievement.

The findings also offer several practical implications for the design of educational games. First, physical interaction should be meaningfully connected to the concept being taught. The present results should not be taken to suggest that movement alone necessarily enhances mathematics learning. Rather, research on embodied learning indicates that benefits are more likely to occur when learners' movements correspond directly to the underlying structure of the target concept (21–23, 29).

For instance, moving numbers toward different categories can physically represent the mathematical process of classification. Similarly, directing geometric shapes toward designated locations can reflect categorization according to visual or spatial characteristics. Rotating the hand to manipulate a clock hand can also create a meaningful link between bodily rotation and changes in angle. In such cases, movement functions as part of the representation of mathematical knowledge rather than simply as an entertaining feature of the game.

Second, system responsiveness should be treated as a key design consideration. Delays in motion detection, inaccurate gesture recognition, or ambiguous feedback may weaken the connection between a learner's physical action and its mathematical outcome. In contrast, immediate and easily interpretable feedback can help learners determine whether their responses are appropriate and adjust their actions accordingly (24, 30).

Third, juiciness should be carefully calibrated rather than simply increased. Although students perceived the video-sensing

games as more engaging and responsive, the lack of a significant relationship between perceived juiciness and learning outcomes suggests that greater experiential intensity does not necessarily produce proportional improvements in learning. Visual effects, sound, scoring mechanisms, and motion-based feedback should therefore be designed to reinforce the instructional goal rather than distract attention from it.

Fourth, video sensing may offer practical implementation benefits because Scratch supports camera-based interaction without requiring advanced motion-capture equipment. As a result, schools with standard computers equipped with webcams may be able to introduce basic forms of embodied digital interaction with relatively little additional expense. Nevertheless, successful implementation depends on suitable lighting conditions, sufficient physical space, appropriate camera placement, dependable hardware, and teachers' familiarity with the technology.

Finally, video sensing is best viewed as a complement to, rather than a replacement for, teacher-led instruction. In the present study, the intervention combined structured mathematics teaching with interactive game-based practice. The findings therefore support the use of video sensing as one component of a blended instructional approach rather than as a standalone alternative to formal mathematics instruction.

Limitations and Suggestions

Several limitations should be acknowledged when interpreting the findings. First, the study included only 54 male students from a single public school, which limits the generalizability of the results to female students, other age groups, different cultural or geographic settings, and schools with varying levels of technological resources. The relatively small sample also reduces the precision of effect-size estimates and limits the strength of conclusions regarding the relationship between perceived juiciness and learning gains. Future research should

therefore involve larger and more diverse samples across multiple schools.

Second, the intervention was relatively brief, consisting of six sessions over three weeks, and learning outcomes were assessed immediately afterward. Consequently, the findings primarily reflect short-term achievement and do not establish whether the observed benefits are retained over time or transferred to new mathematical tasks. Future studies should include delayed post-tests and transfer assessments to evaluate the durability and broader applicability of learning.

Third, the novelty of video-sensing technology may have influenced students' engagement and perceptions. Because the interaction method was unfamiliar, some of the observed experiential benefits may reflect an initial novelty effect. Longer interventions are needed to determine whether these effects persist as students become more accustomed to the technology.

Fourth, the scheduling of the two groups introduced a possible time-of-day confound. The control group received instruction in the morning, whereas the video-sensing group participated in the afternoon. Although this arrangement helped minimize interaction between groups, differences in fatigue, alertness, or classroom routines may have influenced the results. Future studies should randomize or counterbalance instructional times across conditions.

Fifth, the mathematics achievement test was developed by the researchers and closely matched the instructional content. Although the measure demonstrated satisfactory reliability and content validity, it mainly assessed learning directly related to the intervention. Future research should include standardized assessments and measures of transfer to determine whether the benefits extend beyond the specific material taught.

Sixth, the perceived-juiciness measure was adapted from existing constructs rather than drawn from an established and fully validated educational-juiciness scale. Although the questionnaire showed satisfactory content validity and internal consistency, its

underlying factor structure has not yet been established. The composite measure should therefore be interpreted cautiously until it is replicated and psychometrically validated with larger samples.

Seventh, reliance on self-report data from young learners may have introduced measurement error. Responses can be affected by comprehension difficulties, social desirability, acquiescence, or excitement associated with a novel activity. Although pictorial response scales and teacher clarification were used, future studies should combine self-report measures with behavioral indicators of engagement and interaction.

Finally, the study did not directly assess the mechanisms that may have produced the learning advantage, such as the amount of bodily movement, gesture accuracy, motion-detection latency, feedback frequency, attentional focus, or successful interaction. As a result, embodied cognition and immediate feedback remain plausible explanations rather than confirmed mechanisms.

Future research should therefore focus on several areas. Larger multisite studies including both boys and girls could improve generalizability and examine whether the effects of video sensing differ according to factors such as age, prior achievement, technological experience, or motor ability. Researchers should also compare mathematical topics that vary in their suitability for embodied representation, as concepts involving classification, geometry, spatial transformation, measurement, or rotation may be particularly compatible with motion-based interaction.

Mechanism-focused experiments would also be valuable. Features such as embodied action, audiovisual feedback, interaction latency, novelty, and feedback intensity could be manipulated independently to determine their specific contribution to learning and game experience. In addition, further psychometric research is needed to establish whether dimensions such as competence, immersion, flow, affect, enjoyment, attractiveness, stimulation, and novelty represent a single

higher-order juiciness construct or should be treated as distinct dimensions.

Finally, repeated measurement of learners' experiences throughout the intervention would provide a stronger basis for examining how engagement and responsiveness develop over time. With larger samples and appropriate temporal sequencing, future studies could test whether these experiential factors mediate the relationship between embodied interaction and mathematics learning.

Conclusion

The findings indicate that integrating video sensing into Scratch-based mathematics games can support both mathematics learning and students' game experience. Students who used video sensing achieved better learning outcomes and reported a richer, more responsive experience than those who used conventional interaction.

These results are consistent with embodied-learning theory, which suggests that physical movement can enhance understanding when it is meaningfully connected to the concept being learned. In this study, students used bodily actions to interact with mathematical content, making movement part of the learning process rather than simply an additional game feature.

However, perceived juiciness was not significantly related to individual learning gains. This suggests that although video sensing improved both learning and game experience, a more stimulating experience did not necessarily lead to greater achievement for each student. Juiciness therefore should not be regarded as the primary mechanism underlying the learning benefit.

Overall, educational effectiveness and game experience should be considered related but distinct outcomes. Educational games should prioritize meaningful physical interaction and clear feedback that reinforce the learning task. When movement, feedback, and mathematical representations are carefully aligned, video sensing may offer a useful and accessible way to enrich elementary mathematics learning.

Abbreviations

ANCOVA: Analysis of Covariance
CFA: Confirmatory Factor Analysis
CI: Confidence Interval
CVR: Content Validity Ratio
EFA: Exploratory Factor Analysis
GEQ: Game Experience Questionnaire
HC3: Heteroskedasticity-Consistent Type 3
ICT: Information and Communication Technology
IMI: Intrinsic Motivation Inventory
KR-20: Kuder–Richardson Formula 20
SD: Standard Deviation
SE: Standard Error
SPSS: Statistical Package for the Social Sciences
UEQ: User Experience Questionnaire

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Authors' Contribution

MRB and YM contributed to the conceptualization of the study, development of the theoretical framework, design of the educational games, and preparation of the initial manuscript draft. MSA and MA provided supervision and methodological guidance, particularly in relation to validity and reliability procedures and statistical analysis. All authors participated in interpreting the findings, critically revising the manuscript for intellectual content, and overseeing the project. All authors reviewed and approved the final version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

Ethical Considerations

In this study, all participants were informed about the objectives of the research prior to participation, and informed consent was obtained. Participation was entirely voluntary, and students were free to withdraw from the study at any stage without any consequences. Upon completion of the research, participants were granted access to the instructional methods implemented in both the interventional and control groups. All collected data were treated with strict confidentiality throughout the research process. Prior to the commencement of the intervention, ethical approval was obtained from the Ilam Department of Education, Ilam, Iran, under approval code 9609/64.

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Availability of Data and Materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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