# Effects of Computer-Based (Scratch) and Robotic (Cozmo) Coding Instruction on Seventh Grade Students' Computational Thinking, Competency Beliefs, and Engagement

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**Abstract.** The purpose of this pre-/posttest quasi-experimental study was to examine the effects of coding activities supported by the emotional educational robot Cozmo on seventh grade students' computational thinking, competency beliefs, and engagement compared to the computer-based program of Scratch. Two versions of the coding curriculum were developed that shared the same content and instructional features but differed in the code blocks used in each program. Two intact classes at a public middle school in the Midwestern United States participated in the study during the regularly scheduled Technology course. One class received the Scratch coding curriculum ($n = 21$), and the other class received the robotics coding curriculum ($n = 22$).

Results revealed non-significant posttest differences in computational thinking and competency beliefs among the Scratch and Cozmo interventions. However, students found Cozmo to be significantly more engaging than Scratch. Both interventions significantly improved students' computational thinking and competency beliefs from pre- to posttest.

This study contributes to the emerging literature on coding education in a public school setting. The positive gains in the cognitive and affective domains of learning can serve as a point of reference for researchers, designers, and educators with the desire to introduce students to coding.

**Keywords:** Educational robotics · Scratch · Cozmo · Computational thinking · Competency beliefs · Engagement

## 1 Introduction

The U.S. Bureau of Labor Statistics (2020) projected a much faster than average increase for computer occupations (11%) than all others from 2019 to 2029. Yet it has been found that high school students have negative attitudes toward computer science [1] and middle school students perceive programming as less meaningful and themselves less competent than younger students [2]. Researchers suggest early STEM exposure to attract students to these fields later on [3]. This study developed and implemented a coding curriculum


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for seventh grade students to increase interest and participation in computer science. Specifically, we examined the educational benefits of two block-based coding activities using Cozmo, an emotional educational robot, and a more traditional approach of Scratch.

The visual programming language Scratch is a common approach to introduce younger students to coding [4] because Scratch blocks fit together only in syntactically correct ways, eliminating the need to learn complex syntax required by traditional programming languages. But, student interviews showed conceptual gaps, the inability to explain how code worked [5] and lack of computational concepts in projects [6]. Robots are also used to introduce coding to novices because they reify code rather than just using virtual characters like Scratch [7] and robots provide direct evidence of solution accuracy making it faster and easier to find and fix errors [8]. However, research on emotional educational robotics is relatively limited [9] and classroom implementation focuses mainly on robotics research goals rather than introducing the robot into regular teaching practice [10].

### 1.1 Theoretical Foundation

Constructionism paradigm of Papert has been adopted in numerous robotic curricula because it engages students in a process-oriented task and makes the process of thinking and learning visible [11]. Constructionism suggests that people learn by doing [12] and Papert proposed using new technologies (e.g., computers and robots) to change the nature of learning at school [13]. Technological advances in affective computing are demonstrating the potential of emotional (social) educational robots.

People typically have positive feelings and are willing to interact with social robots [14]; however, examination of teen-robot interaction has been limited compared to other age groups [15]. Many studies of social robots in education compare versions of the same robot with different behaviors rather than against an alternative (e.g., computer-based) [16]. The limited studies comparing robots found a positive contribution with a medium effect size for affective and cognitive outcomes largely because of the physical presence of the robot [16].

This study examined the effects of using the emotional educational robot Cozmo to teach coding skills to seventh grade students. Code Lab is part of the Cozmo app that can run on a smartphone or tablet. It uses Scratch Blocks, making it similar to coding in Scratch. Dragging and dropping colorful blocks allows the user to get Cozmo to do many custom behaviors (e.g., controlling body, navigation, speech, and accessing facial recognition and emotion engine that replicates personality traits and behaviors).

Cozmo is proving to be beneficial for a variety of applications [17–20]; however, none of these studies took place in public schools or with students who had not self-selected into special camps or programs. Researchers found a positive influence of using Cozmo to teach math to middle school students [21], but there were only eight students who self-rated their knowledge gains. Moreover, a review of social robots in classrooms revealed lack of an appropriate curriculum and methodology for involving robots in learning activities, and most research is still focused mainly on further developing robotic technology rather than implementing it for educational purposes [10].

### 1.2 Research Goals

This study examined the effect of coding activities supported by the emotional educational robot Cozmo on seventh grade students' computational thinking, competency beliefs, and engagement compared to the more traditional computer-based program of Scratch with the following three working hypotheses:

*Hypothesis 1: Cozmo will produce greater gains in computational thinking than Scratch.* Computational thinking is operationally defined as "the ability to formulate and solve programs by relying on the fundamental concepts of computing, using logic-syntax of programming languages: basic sequences, loops, iteration, conditionals, functions and variables" [22]. Empirical findings show improved computational thinking using robots compared to virtual environments [23]. Direct comparison of user interface on computational thinking found that students in the robotics group performed better on every task and mastered sequencing and debugging significantly better than the ScratchJr group [24]. The current study parallels the situation of comparing Scratch to a robotics platform except both use Scratch blocks, thus it is reasoned that robotics activities will make coding results more concrete and improve computational thinking compared to computer-based simulations in Scratch.

*Hypothesis 2: Both Cozmo and Scratch training groups will increase their competency beliefs.* Competency beliefs were defined as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" [25]. Empirical findings show that robotics and Scratch can increase student self-efficacy [26, 27]. In this study, it is expected that competency beliefs will increase similarly among Cozmo and Scratch learners because it is their first formal introduction to coding, and using visual programming blocks to introduce coding instead of more complex text-based programming languages can decrease cognitive load.

*Hypothesis 3: Cozmo will produce greater student engagement than Scratch.* Observations and reports of students and teachers participating in empirical studies show increased engagement using robotics [24, 28–30]. Teachers attributed increased learning gains after using a virtual robotics curriculum to the use of physical robots [29] compared to decreased interest using the same curriculum with simulated online robots [30]. Robot use improved student interest and enjoyment of programming [28], and robotics sessions were more popular than ScratchJr sessions [24]. Ozobots that make sounds meant to mimic human emotions elicited high student motivation [31]. Cozmo is highly interactive with more advanced features lending support to the hypothesis that it will be more engaging than working with two-dimensional Scratch characters on a computer screen.

## 2 Method

### 2.1 Participants

Two intact classes of seventh grade students enrolled in a course called "Technology" at a public middle school in the Midwestern United States participated in the study. The technology course is typically filled with students who did not select any electives or did not get their top choice(s), thus it reflects a group of students who are reluctant to be there. The technology classes that participated in the study were filled with a mix of student ability levels. The researcher did not have access to students' Individualized Education Plans (IEP) or English Language Proficiency Assessment data, so no accommodations were provided to individual students during the study. One class received a Scratch curriculum ($n = 21$), and another class received a Cozmo curriculum ($n = 22$). While all students in both classes received all of the training interventions, data are only reported for those students who returned signed Parent Consent and Student Assent forms. Table 1 presents demographic information for all study participants.

**Table 1.** Student demographics

| Characteristic | Scratch ($n = 21$) | | Cozmo ($n = 22$) | |
|---|---|---|---|---|
| Gender | Female = 17 | Male = 4 | Female = 14 | Male = 8 |
| Age | M = 12.62 | SD = .109 | M = 12.36 | SD = .155 |
| ELL | 5 | | 2 | |
| Gifted | 2 | | 1 | |
| Special Needs (IEP) | 2 | | 3 | |

*Note.* ELL = English Language Learner. IEP = Individualized Education Plan

## 2.2 Curriculum

The current study adapted a Creative Computing curriculum unit developed by the ScratchEd research team at the Harvard Graduate School of Education [32] to create two versions of the coding curriculum for seventh grade students. Both curricula included a series of eight lessons that used a scaffolded approach (from step-by-step tutorial to open-ended exploration) to help students become acquainted with the key computational concept of sequencing.

The Scratch group used the Creative Computing curriculum lessons without modification, and the materials for the Cozmo group were modified to fit the blocks available in the Code Lab app using the same or closest equivalent block when possible. The curriculum used a project-based learning approach and ended with an open-ended coding project. A planning sheet and rubric that outlined cohesiveness elements and types of blocks was implemented to ensure similarity between the two training conditions.

## 2.3 Instruments

All instruments were pilot tested before the study to ensure student understanding and attain a time estimate. Table 2 presents an overview of the study instruments.

**Table 2.** Study instruments

| Dependent variable | Instrument | Total item number | Score range | Cronbach's alpha |
|---|---|---|---|---|
| Computational thinking | Computational Thinking Test (CTt) [22] | 28 | 0–28 | .78 (pre) |
| | | | | .83 (post) |
| Competency beliefs | Technology Competency Beliefs Scale [33]* | 12 | 12–48 | .88 (pre) |
| | | | | .91 (post) |
| Engagement | Engagement Scale [34] | 8 | 8–32 | .76 (pre) |
| | | | | .89 (post) |

*Some wording was changed to focus on technology and coding to fit the current study.

### 2.4 Procedures

Both groups completed the Demographics Survey, Competency Beliefs Survey and Computational Thinking Pretest before winter break (December) and began learning coding lessons after returning from break (January). The first, second, and last (post-testing) class periods took place in the computer lab. During class periods 3–9, the Scratch group remained in the computer lab while the Cozmo group worked in the high school library due to Wi-Fi configuration. The computer-based training method (Scratch) presented students with lessons after which they created and ran code using personal Scratch accounts on the desktop computers in the computer lab. Students were seated between friends and could collaborate as desired, but each student completed all work individually at the computer of the self-selected seat because of seating and wiring configuration constraints. The robotics-based training method (Cozmo) presented students with lessons after which they collaborated and wrote code in the Cozmo Code Lab app on an iPad with at least one other student and then tested the code on the Cozmo robot. Limited availability of bandwidth and iPads required students in the Cozmo class to work in groups (with a cap of three).

An Engagement Survey was given five minutes before the end of each day's lesson (class periods 2–9). A catch-up class period was added after period 6 (debugging lesson) for the Cozmo group because more students were absent (Cozmo $n = 9$, Scratch $n = 4$) and the Cozmo app crashed repeatedly on the older iPads used all four instructional days (Lessons 4–6) due to bandwidth reduction caused by high school classes coming to the library to use both computer labs at the same time that the intervention was taking place. The Competency Beliefs posttest was given at the conclusion of the final lesson (class period 9) and the Computational Thinking posttest was given during class period 10. Due to school scheduling, students in the Cozmo group had less time to complete the computational thinking posttest because they had to take two more non-related assessments during the class period on the day it was given.

### 2.5 Data Analysis

This quasi-experimental quantitative study used repeated measures analysis of variance (ANOVA) with a between-subjects factor of intervention (Scratch/Cozmo) and within-subjects factor of time (pre/posttest) to analyze the effects of the two training methods on computational thinking and competency beliefs. Two analyses were run for each variable: one for all students and one excluding scores for students with special education needs (IEP) and English Language Learners (ELL), because of comprehension issues. A linear mixed model was used to analyze the effects of the two different instructional interventions on student engagement.

## 3 Results

Additional demographic information was collected using a survey modeled after [27] as part of the Demographics questionnaire. ANOVA revealed no significant differences in availability of resources and types of learning assistance available at home between the Scratch and Cozmo groups. Analysis of student background questionnaires revealed that none of the participants had previous formal training in coding.

Table 3 provides a summary of means and standard deviations for pre- and posttest data for computational thinking and competency beliefs for all students and excluding ELL and IEP student data. Table 4 provides a summary of means and standard deviations for student engagement during each day of the study.

**Table 3.** Means and standard deviations for CTt and Competency Beliefs by intervention group

| Dependent variable | Scratch | | | | Cozmo | | | |
|---|---|---|---|---|---|---|---|---|
| | All students (*n* = 20) | | Minus ELL/IEP (*n* = 13) | | All students (*n* = 22) | | Minus ELL/IEP (*n* = 17) | |
| | Pre *M (SD)* | Post *M (SD)* | Pre *M (SD)* | Post *M (SD)* | Pre *M (SD)* | Post *M (SD)* | Pre *M (SD)* | Post *M (SD)* |
| CTt Total score[a] | 16.65 (4.31) | 17.30 (5.25) | 18.46 (3.53) | 19.85 (4.47) | 16.27 (5.07) | 16.82 (5.32) | 17.00 (5.45) | 18.53 (4.11) |
| Competency Beliefs[b] | 30.70 (6.66) | 33.85 (7.61) | 32.00 (6.61) | 36.23 (7.40) | 30.86 (6.62) | 34.09 (6.57) | 30.71 (6.90) | 35.53 (6.66) |

[a]Possible score range: 0–28.
[b]Possible score range: 12–48.

### 3.1 Assumptions

Shapiro-Wilk test showed that scores for all dependent variables did not deviate significantly from normal and Levene's test showed equal variances for all dependent variables. ANOVA revealed non-significant ($p > .05$) differences between the Scratch and Cozmo interventions for all variables measured at the outset of the study.

**Table 4.** Means and standard deviations for daily engagement by intervention group*

| Time | Scratch | | Cozmo | |
|---|---|---|---|---|
| | All students | Minus ELL/IEP | All students | Minus ELL/IEP |
| | *M* *(SD)* | *M* *(SD)* | *M* *(SD)* | *M* *(SD)* |
| Period 2 | ($n = 19$) 2.93 (.51) | ($n = 13$) 2.89 (.38) | ($n = 22$) 3.19 (.54) | ($n = 17$) 3.18 (.59) |
| Period 3 | ($n = 21$) 3.11 (.49) | ($n = 14$) 3.04 (.49) | ($n = 20$) 3.56 (.41) | ($n = 15$) 3.61 (.41) |
| Period 4 | ($n = 19$) 3.03 (.44) | ($n = 12$) 3.00 (.41) | ($n = 21$) 3.43 (.43) | ($n = 16$) 3.47 (.43) |
| Period 5 | ($n = 20$) 3.05 (.40) | ($n = 13$) 3.07 (.40) | ($n = 22$) 3.35 (.45) | ($n = 17$) 3.39 (.44) |
| Period 6 | ($n = 21$) 3.01 (.46) | ($n = 14$) 2.93 (.46) | ($n = 19$) 3.11 (.67) | ($n = 15$) 3.15 (.68) |
| Make-up | | | ($n = 19$) 3.13 (.54) | ($n = 17$) 3.06 (.58) |
| Period 7 | ($n = 21$) 2.98 (.51) | ($n = 14$) 2.96 (.47) | ($n = 21$) 2.98 (.69) | ($n = 14$) 3.19 (.58) |
| Period 8 | ($n = 20$) 3.06 (.47) | ($n = 14$) 3.02 (.46) | ($n = 22$) 3.26 (.64) | ($n = 17$) 3.30 (.67) |
| Period 9 | ($n = 19$) 2.97 (.50) | ($n = 12$) 2.96 (.47) | ($n = 22$) 3.26 (.45) | ($n = 17$) 3.34 (.44) |

*Scores were calculated by averaging the total number of items; possible score range: 1–4.

## 3.2 Computational Thinking

Using a repeated measures ANOVA with a between-subjects factor (Cozmo versus Scratch) and within-subjects factor (CTt pre-/posttest), there was a non-significant main effect of intervention when including all students in the analysis, $F$ (1, 40) = 0.090, $p$ = .766, $d = -.09$, and when excluding IEP and ELL student data, $F$ (1, 28) = 0.839, $p$ = .367, $d = -.31$, indicating insufficient evidence that posttest computational thinking scores were different between the Scratch and Cozmo groups.

There was a non-significant main effect of time when including all students in the analysis, $F$ (1, 40) = 1.012, $p = .321$, $d_{Scratch} = .14$, $d_{Cozmo} = .11$; however, there was a significant main effect of time when excluding IEP and ELL student data, $F$ (1,28) = 4.692, $p = .039$, $d_{Scratch} = .35$, $d_{Cozmo} = .32$, indicating that computational thinking skills improved significantly from pre- to posttest for both the Scratch and Cozmo groups.

There was a non-significant interaction between time and intervention for all students, $F$ (1, 40) = 0.008, $p = .930$ and when excluding IEP and ELL student data, $F$ (1, 28) = 0.012, $p = .915$, indicating that, on average, students in both interventions improved their computational thinking skills similarly over time.

### 3.3 Competency Beliefs

Using a repeated measures ANOVA with a between-subjects factor (Cozmo versus Scratch) and within-subjects factor (Competency Beliefs pre/posttest), there was a non-significant main effect of intervention when including all students in the analysis, $F$ (1, 40) = 0.012, $p = .914$, $d = .03$, and when excluding IEP and ELL student data, $F$ (1, 28) = 0.202, $p = .656$, $d = -.10$, indicating insufficient evidence that posttest competency beliefs were different between the Scratch and Cozmo groups.

There was a significant main effect of time for all students, $F$ (1, 40) = 10.058, $p = .003$, $d_{Scratch} = .44$, $d_{Cozmo} = .49$, and when excluding IEP and ELL student data, $F$ (1, 28) = 13. 563, $p = .001$, $d_{Scratch} = .60$, $d_{Cozmo} = .71$, indicating that competency beliefs improved significantly from pre- to posttest for both the Scratch and Cozmo groups.

There was a non-significant interaction between time and intervention for all students, $F$ (1, 40) = 0.001, $p = .970$, and when excluding IEP and ELL student data, $F$ (1, 28) = 0.058, $p = .811$, indicating that, on average, students in both interventions improved their competency beliefs similarly over time.

### 3.4 Engagement

Engagement was measured each day of the intervention. A linear mixed model was performed to test the intervention's effects on engagement to avoid loss of data and provide a clearer picture of daily engagement. Intervention (Scratch versus Cozmo), class period, and the interaction of intervention by class period were set as fixed factors, and class period was set as the repeated factor with compound symmetry covariance structure. This analysis provided information about whether students found Scratch or Cozmo more engaging, which class periods students found more engaging, and whether engagement varied between the Scratch and Cozmo groups during any of the class periods.

Intervention significantly predicted engagement when including all students in the analysis, $F$ (1, 41.492) = 4.654, $p = .037$, and intervention significantly predicted engagement when excluding IEP and ELL student data, $F$ (1, 29.544) = 6.963, $p = .013$. Class period significantly predicted engagement for all students, $F$ (8, 290.547) = 4.965, $p = .000$, and when excluding IEP and ELL student data, $F$ (8, 205.462) = 3.550, $p = .001$.

The interaction of intervention and class period significantly predicted engagement for all students, $F$ (7, 290.481) = 2.380, $p = .022$, but not when excluding IEP and ELL student data, $F$ (7, 205.516) = 1.152, $p = .332$.

After controlling for the class period interaction, these analyses showed that intervention significantly predicted engagement for all students, $b = -320$, $t$ (114.228) = $-2.017$, $p = .046$, and when excluding IEP and ELL student data, $b = -.433$, $t$ (97.243) = $-2.318$, $p = .023$. Pairwise comparisons showed that the Cozmo group was significantly more engaged than the Scratch group with a medium effect $d$ = (.45) for all students and when excluding IEP and ELL student data with a medium effect $d$ = (.63).

## 4 Discussion

There was a significant pre-/posttest gain in computational thinking skills for both the Scratch and Cozmo groups when ELL and students with special education needs were excluded. However, the hypothesis that Cozmo would produce greater gains in computational thinking was not supported. These results are similar to other studies comparing computer-based and physical robots that found no significant difference in computational thinking [35]. However, the results of the present study should be interpreted with caution. The Cozmo group faced additional limitations including more absences, less accountability when students switched groups, and less time to complete the CTt posttest. Limited number of devices and school Wi-Fi configuration required students to work in small groups in the high school library, where the app crashed repeatedly during all four instructional days due to bandwidth limitations. Even with the make-up day, many students were unable to complete all of the lesson objectives. Additionally, students were administered a paper version of the CTt, which can be demotivating for students accustomed to using computers in a course [35]. It is also possible that Scratch is better aligned with the CTt because both use two-dimensional images. Additional data collection methods (e.g., interviews) could provide more information about student thought processes. In the current study, pre-/posttest gains in computational thinking combined with successful completion of student coding projects provide encouraging evidence for using Cozmo and Scratch as a learning tool for introducing middle school students to coding and enhancing their computational thinking.

The hypothesis that both the Cozmo and Scratch groups would experience an increase in competency beliefs was confirmed with practically meaningful effect sizes and a larger effect for the Cozmo group. The current study took place in a public seventh grade classroom rather than a self-selected STEM activity thus the improved competency beliefs found in both groups are reassuring. This is contrary to studies of middle school students that found decreased student self-efficacy after programming robots [27] and after using a virtual robotics curriculum [30].

While the current study was the initial exposure of both groups to coding, using the same visual programming language may have contributed to the finding of increased competency beliefs by reducing the cognitive load compared to that required for complex text-based programming languages Additionally, the curriculum used a scaffolded learning approach which may have helped build student confidence. These results are encouraging because providing students with learning opportunities that develop their beliefs about their coding abilities is important for encouraging continued participation in computer science [30].

The hypothesis that Cozmo would produce greater student engagement was confirmed. Pairwise comparisons showed that the Cozmo group was significantly more engaged than the Scratch group with a medium effect size. The high level of interactivity and emotions offered by Cozmo resulted in a higher level of engagement compared to two-dimensional Scratch characters on a computer screen. This is supported by findings that students were more engaged working with physical rather than simulated robots [36] and that emotional stimuli embedded into interfaces increase learners' engagement [37]. The Scratch group experienced no technical issues and their engagement scores were similar throughout the intervention, but engagement in the Cozmo group steadily declined on each consecutive day when the app was crashing; however, engagement scores increased after the technology began working again.

Written reflections collected at the end of the intervention provided additional support that Cozmo was more engaging. When asked what students might want to do next, responses in the Scratch group included: Nothing involving coding; Take a break from coding; Scratch is not my favorite; Scratch is boring; Try something less boring than Scratch. All feedback from the Cozmo group was positive and expressed a desire to make more complex projects with Cozmo. Several students wrote that they wanted to buy their own Cozmo, one wanted to keep Cozmo, and one wrote "Cozmo is cute and I love him."

### 4.1 Implications and Conclusion

There is a lack of research on integrating robotics in the classroom [38] and the outcomes reported in the literature tend to use small samples, are mostly descriptive, and are not integrated into classroom activities [9]. This study empirically investigated the use of Cozmo compared to Scratch where students did not self-select into the course. This elucidated some real-world implications of integrating robotics interventions including technical (older mobile devices, lack of adequate bandwidth), physical (limited space and classroom configurations), and scheduling (calamity days) challenges. English Language Learners and students with special needs faced challenges reading and comprehending assessments; however, they were able to successfully complete the open-ended challenge projects. Thus, using multiple means of assessment can provide a clearer picture of coding competence.

Regardless of these challenges, the Creative Computing curriculum unit used to introduce students to coding resulted in statistically significant increases in computational thinking and competency beliefs for both the Scratch and Cozmo groups. This shows that the scaffolded approach to coding instruction was effective and can be adapted to other programming languages and technologies. Clarifying an effective pedagogical approach for coding instruction is important, but so is considering the tools that can assist educators in meeting instructional goals. Cozmo proved to be an effective tool to cognitively and affectively engage students in learning and students were more engaged with Cozmo than Scratch. As such, future research is needed to investigate whether similar results can be achieved with other types of physical robots as well as realistic 3D simulated robots.

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