The Effect of Tangible Artifacts, Gender and Subjective Technical Competence on Teaching Programming to Seventh Graders

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Abstract. This study compares the effect of using tangible robots to using visual representations for introducing seventh graders (12 to 13 year old) to computer programming. The impact was measured on learning outcome, self-efficacy, class feedback and attitudes towards STEM (science, technology, engeneering and mathematics) topics. Results show that using robots to learn computer programming is beneficial, although no overall effect towards STEM topics could be shown. A huge gender gap in regard to subjective technical competence (STC) was found that negatively affected the participants' performance. We provide approaches to leverage this gap and increase learning outcome and interest in STEM topics.

Keywords: Gender effects, subjective technical competence, introductionary programming, CS0, Robots, LEGO Mindstorms, self-efficacy.

1 Introduction

Despite the economic crisis, demand for IT-professionals persists. In addition to the possibility of occupational retraining of professionals, the goal must be to optimize teaching at schools in quality and quantity. Therefore education in school has to improve young students' interest in technology and in particular in STEM subjects. Another aspect is the low number of female students in STEM subjects. According to studies of the German education system women more often than men choose disciplines like linguistics, cultural studies, fine arts and human or veterinary medicine [1]. Already in school girls show less interest in topics of computer science in Germany [2].

To increase the participation in STEM in general and the participation of women in particular a lot of projects have been initiated. One popular concept is to utilize robots as a tool to increase interest in programming. One of our research goals was to determine if

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the tangibility of a robot is actually necessary. In a controlled experiment we compared the effect of tangible robots to the use of visual representations of robots for introducing school students to programming. We measured their impact on learning outcome, self-efficacy, class feedback and attitudes towards STEM topics.

2 Related Work

2.1 Importance of Self-efficacy and Self confidence

Self-efficacy [3] refers to the individual confidence in one's capability to execute a certain behavior or archive a certain goal. Specifically technology self-efficacy is an effective variable as it determines not only users emotional attitudes towards own abilities, but also the open-mindedness to frequently interact with technology, as any anticipated failure when interacting with technology is avoided, which also results in a low computer experience. Studies have shown that high scores in computer self-efficacy are related to performance with and acceptance of technology [4, 5, 6]. In addition, there are profound gender differences regarding technical self-confidence. Women usually report lower levels of computer-related self-efficacy and higher computer anxiety [7], which in turn, reduces the probability of active computer interaction and may lead to a generally lower computer-expertise level. Furthermore it was found that self-efficacy is an important factor for academic decisions and the career development of women working in the STEM area [8, 9]. Self-efficacy is mainly constituted by role models and social persuasion. It is assumed that high self-efficacy is especially important for women due to their low representation in STEM.

2.2 Effect of Robot Courses

Various experiences indicate high learning motivation by girls and young women in robot courses [10]. Thus learning with and about robots, as an analogy to learning about engineering, is a well established measure. However, the learning objective in STEM classes must also be experienced as useful. This approach follows the assumption that girls reject the principle of "technology for technology's sake" and, in contrast to boys, do not regard the "feasible" as the "useful" [11].

3 Method

To evaluate whether programming tangible artifacts like robots is advantageous over programming virtual agents displayed solely on a computer screen, a controlled experiment in form of a school lesson was carried out. The modality of the robot was a between-subject variable, i.e. one group of students interacted with a tangible robot in form of a LEGO Mindstorms NXT and one group worked with a visual image of a robot presented solely on the computer screen.

This section describes the targeted audience and the composition of our groups, the teaching unit and the programming language used in this experiment, as well as the experimental setup and the variables assessed.

3.1 Targeted Audience and Group Composition

The experiment was carried out with seventh graders (12 to 13 years old), because the projects "*Mädchen machen Informatik*" ("girls do informatics") at TU Munich[1] and "*go4IT!*" at RWTH Aachen University[2] both successfully concentrate their STEM-support-projects on students at that age. The projects try to achieve sustainable effects with their interventions at important points in the students' biography, e.g. when seventh graders select their specialization courses for the eighth grade. Here, foreign languages compete with STEM courses and an early decision for the students' future career is made.

According to recommendations of the Roberta project[3] in courses the student to tutor ratio should not exceed eight to ten pupils per tutor. The projects "*go4IT!*" and "*Mädchen machen Informatik*" choose a lower supervision ratio of six pupils per tutor. Also they suggest learning in pairs. This approach is based on the recognition that girls and young women use computers cooperatively and utility-oriented [12].

The groups were mixed-gender and thereby followed the latest concepts of gender sensitive workshop design [13]. This is based on the finding of the research project "Roberta", that no gender effects are expected in coeducational courses as long as one follows a gender sensitive course design. We followed recommendations like promoting interest, self-awareness and self-confidence, recognition of learning achievement, activating of social competences and avoid interferences [10].

3.2 Programming Environment

The programming language Scratch [14] was used in this study, as syntax errors are avoided by arranging command blocks by mouse and textual commands need not be remembered as they can be looked. A simple robot program is "written" by connecting movement blocks with rotation commands. Adding blocks for loops or conditions allow the development of more complex programs.

In addition, Scratch innately supports the turtle metaphor we based our teaching unit on. Originally the visual turtles on Scratch's stage are controlled by movement and sensory commands. These commands were modified in a way that they could be linked with a LEGO Mindstorms NXT robot over a Bluetooth connection. To make sure that both experimental conditions perform similarly aside from the different representation of the robot, we made sure that the same delays were present in both conditions. In addition the sprite of the robot was hidden for the group with the actual robot to avoid presenting them the robot twice.

3.3 Teaching Unit

We developed a teaching unit of 90 minutes that each group had to undergo. The course started with an introduction of ourselves and assured that we're not interested in rating the students but in finding better approaches for teaching introductory programming. The students filled out the first questionnaire (see below) and learned how

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[1] http://portal.mytum.de/am/mmi/

[2] http://lehramt.informatik.rwth-aachen.de/go4it

[3] http://www.roberta-home.de/de

the robot can be programmed by connecting Scratch's command blocks (15 min.). The robot was programmed using "turtle talk" [15], i.e. by issuing relative movement commands like forward, turn left 90°, etc. This programming concept is easy to understand by students without prior programming knowledge.

The first task was writing a computer program that let the turtle follow simple geometric patterns by using only movement commands (20 min.). In the second task more complex geometric figures had to be programmed which made the introduction of loops necessary (20 min.). After the first two tasks the final questionnaire was filled out. To let every student get in touch with a LEGO Mindstorms robot, the third assignment was to write a robot program that used the light sensor as input for preventing the robot to fall off the table. This task was carried out after the final questionnaires, therefore it had no impact on the data presented in the results section.

3.4 Experimental Setup

The experiment was carried out with 31 children from a 7th grade of a local school. The children were 13 or 14 years old; 16 of them were male, 15 were female. Due to sickness or shifts in the schools time tables we were not able to balance the groups perfectly: Thus the first group consisted of four girls and four boys, the second of five girls and four boys, the third of four girls and three boys, and the last of three girls and four boys. The first two groups worked with the tangible robot, the third and forth group worked with the visual turtle presented on the computer screen.

Each group of students was separated into teams of two with each team sitting in front of one of four tables. The tables were evenly arranged around two center tables that formed a shared space for testing the robots' actions. Each team had a pre-constructed LEGO Mindstorms NXT robot and a laptop with Scratch running in full screen mode. Changing window size or switching tasks was disabled.

3.5 Variables

The participants' sex and the modality of the turtle were used as independent variables. As depended variables we assessed subjective ratings of the students' competencies, their weekly computer usage, learning outcome, and class feedback.

3.5.1 Learning Outcome

For measuring learning outcomes the students had to work on two tasks. The first was understanding a given Scratch program by drawing the path of the robot. The second task was writing a program that makes the robot move along a given path. As we wanted to assess the students' understanding of computer programming concepts and not their ability to remember commands, all command blocks necessary were printed on the exercise sheet, as well as some additional ones as dummies.

For each of the tasks a list of five criteria was defined (e.g. correct number of loop repetitions, turning the robot in the right direction). For each criterion present in the students' solution a point was given. Therefore in each task the students could earn zero (no or completely wrong solution) to five points (correct solution). Much effort was put into the grading as some students did not use the puzzle syntax for writing down their code. One student consecutively numbered the pieces and wrote down a (correct) sequence of numbers instead. Hence his solution was graded five points.

3.5.2 Class Feedback

We assessed four factors as class feedback whereby each factor consisted of multiple questions: The liking of the class (3 items such as "I found the class interesting"), the perceived simplicity of the class (3 items such as "I understood the class well"), the attitude towards STEM topics (4 items such as "I want to program more often"), and how much the students felt that they tried out a lot by themselves (2 items such as "I have tried out a lot by myself").

3.5.3 Individual Competencies

Participants' subjective technical competence (STC) was measured by the STC-questionnaire [16]. It determines person's subjective confidence in his or her own ability to solve technical problems. The short version of the test containing eight items (e.g. "Usually, I successfully cope with technical problems", "I really enjoy cracking technical problems") had to be rated on a six-point scale from 1 (strongly disagree) to 6 (strongly agree). According to Beier's own studies the reliability of the STC short version reaches satisfactory values (Cronbach´s alpha = 0.89). In order to be age sensitive, the wording of some questions was modified.

In addition to the STC we assessed the subjective abilities in arithmetic, geometry and math in general and the subjective competency in dealing with computers. All variables were assessed through bipolar graphical rating scales. Their orientation was randomized on the questionnaires and normalized to the range between 0 and 100 before the statistical evaluation. Low values represent negative and high values represent positive ratings.

4 Results

We analyzed the data using bivariate correlations, χ^2, uni- and multivariate analyses of variance ((M)ANOVA) with a significance level of.05. Pillai values were used for the significance of the omnibus F-tests in the MANOVAs. See Table 1 for an overview of the results.

Four out of 31 questionnaires were not completed by the students. On two questionnaires one answer was missing, on another one two answers were missing and on one questionnaire six answers were missing. To avoid reducing the sample size through the exclusion of questionnaires missing values were substituted by the arithmetic mean of the other participant's answers. This method does not affect the arithmetic mean of the variable in question.

The results section is designed as follows: First, we present the effect of the independent variable gender, second, the effect of the modality of the turtle is shown, and third, the influence of the STC is presented.

4.1 Effect of the Factor Gender

The reported weekly computer usage differed between boys and girls, yielding a significant result ($F(1,29) = 6.19$, $p \leq .05$). On average, the boys use computers 12.8 hours a week, the girls use computers 8.4 hours a week.

The boys had a significantly higher STC (M=73/100 points, SD=13) than the girls (M=55, SD=9, $F(1,29) = 30.67$, $p \leq .01$), corroborating findings of earlier studies

[5, 7, 9]. It is not known however whether this difference results from actual differences in the intrinsic sense of being able to master technological issues or whether girls just answered more modest than the boys on the subjective rating scales provided on the questionnaires. Either ways the results from the girls cannot be compared easily with the results from the boys, as the factor sex is influenced by the STC (η=.717). In the following the STC was used as a covariate to compensate their influence on the factor gender. The median over all students was 64 out of 100 points to be reached at most. It will be used for separating the sample in a group with high and a group with lower STC values (median split).

4.1.1 Self Reported Math and Computer Competencies

The reported arithmetic, geometry and general math competency differed between boys and girls by about 20 points. Girls reported lower arithmetic (M=66, SD=31), geometry (M=57, SD=27) and general math competencies (M=58, SD=18) than the boys (arithmetic (M=85, SD=21), geometry (M=74, SD=28), general math (M=74, SD=30)). The self-reported computer competency differed by 19 points between the boys (M=86, SD=12) and the girls (M=67, SD=27). A MANOVA (taking sex and the turtle's display modality as main factors) showed that these differences are significant ($F(4,24) = 3.08$, $p \leq .05$). If the effect of the STC is controlled the differences vanish. We therefore assume that differences are predominantly influenced by differences in the subjective technical competency.

Additionally we found that the nexus between different aspects of math and computer competency differed between boys and girls. We found a linkage between the boys' self reported arithmetic and math competency ($r = .539$, $p \leq .05$) and their arithmetic and geometric competency ($r = .568$, $p \leq .05$). In contrast, for girls, a significant correlation between the self-reported arithmetic competency and computer competency ($r=.571$, $p \leq .05$) was found.

4.1.2 Learning Outcome

To evaluate effects of gender on learning outcomes for each task the students were divided into a group with a lower performance (i.e. three points or below) and a group with good results (four or five points).

Between boys and girls, no difference in the understanding of a given program was found (girls: M=3.2; boys M=3.0). Though, a difference was revealed when girls and boys had to write a software program. With 4.3 points the boys achieved a higher performance than girls (M = 3.6 points). A χ^2 test showed that this difference is marginally significant ($\chi^2 = 2.761$, $p = .097 > .05$, n.s.).

4.1.3 Class Feedback

The class was equally liked by girls (M=85, SD=13) and boys (M=88, SD=16). Though, the boys found the class more easy to follow (M=88, SD=10) than did girls (M=79, SD=12), revealing a significant effect ($F(1,26) = 1.8$, $p \leq .05$).

The attitude towards STEM topics was more positive for boys (M=87, SD=16) than for girls (M=73, SD=20).This difference did not reach statistical significance when the effect of the subjective technical competency was controlled. We assume that attitudes toward STEM topics are carried by gender, but that the main influencing factor is the technical self competence (which is significantly lower in girls compared to boys).

Specifically, the boys had a stronger wish to work on computers more often (M=95, SD=3) than the girls (M=77, SD=24). Also, trial and error behavior and is much more frequent in boys (M=91, SD=13) than in girls (M=75, SD=17), $F(2,25) = 4.49$, $p \leq .05$).

4.2 Effect of the Tangible Artifact

Before the effect of the tangible artifact in regard to class feedback and learning outcome was evaluated, we checked whether both groups are comparable regarding user characteristics. In both groups (the tangible turtle group (8 boys, 6 girls) and the visual turtle group (8 boys, 9 girls)), STC values were equal, reaching on average 64 points. While the reported computer and math competencies did not differ (within 3 points), the reported geometric and arithmetic skills differed by 7 resp. 8 points in favor for the visual turtle group (M=69 vs. M=78). Regarding computer experience, there was a small, but non significant difference in the weekly computer usage (tangible turtle: M=12.4 hours (SD = 5.4); visual turtle: M=9.2, SD=4.9). Overall, we can assume that user characteristics are matched across both experimental groups.

4.2.1 Learning Outcome

The understanding of a given program task was equally large in both groups (M = 3.1). Regarding the task of writing a program the tangible turtle group achieved 4.4 points whereas the visual turtle group achieved 3.7 points. The students were again divided into a group with inadequate results (i.d. three points or below) and a group with good results (four or five points). A χ^2 test showed that this difference is marginally significant ($\chi^2 = 3.774$, $p= .052 > .05$).

4.2.2 Class Feedback

Both groups were found to have a comparable interest in the class: The tangible turtle group liked the class (M=88, SD=8) about as much as the visual turtle group (M=85, SD=18). The representation of the turtle also had no effect on the perceived simplicity of the class: The visual turtle group (M=83, SD=14) found the class as easy as the tangible turtle group (M=84, SD=9).

The tangible turtle group had a more positive attitude towards STEM topics (M=88, SD=8) than the visual turtle group (M=75, SD=23), though the difference did not reach statistical significance. As this subject area is of special interest for our research we peeked into the individual values of this index. Students of the tangible turtle group were more curious about computer programming (M=88, SD=13) than the visual turtle group (M=71, SD=30), revealing a marginally significant effect ($F(1,26) = 3.6$, $p <.1$). Even though students of the tangible turtle group (M=81, SD=14) reported to be inclined to use such a program more often in the future compared to the visual group (M=64, SD=33), the difference missed statistical significance ($F(1,26) = 2.7$, $p = .112 > .05$). The same applies for the question if students would like to use more technology in their school education. Even though the tangible turtle group approved this more firmly (M=92, SD=6) than the visual turtle group (M=78, SD=30), no significant effect appeared ($F(1,26) = 1.9$, $p = .179 > .05$).

No effect was found for the questions whether the students tried out a lot by themselves. The tangible turtle group answered at about the same level (M=84, SD=15) as the visual turtle group (M=82, SD=19).

4.3 Effect of the Subjective Technical Competence

To understand the effect of the STC on the learning outcome and on class feedback we divided the students along the median ($\tilde{x} = 64$) into a group with low and a group with high STC. Three boys and 13 girls were in the low group and 13 boys and two girls were in the group with high STC values.

We found an almost significant dependency between the STC and the weekly computer usage (($F(1,29) = 4.2$, $p = 0.51 > .05$). The group with high STC used computers 12.6 hours a week whereas the group with low STC had a computer usage of 4 hours less (8.9 hours a week).

4.3.1 Self Reported Math and Computer Competencies

We also found a significant dependency between STC values and the reported computer competency (($F(1,27) = 4.3$, $p \leq .05$). The group of students with high STC rated their computer competency 16 points higher (M=85, SD=11) than the group with low STC (M=69, SD=28).

4.3.2 Learning Outcome

The group with high STC values achieved slightly more points in the task of understanding a given program (M=3.4, $\tilde{x} = 2$) than the group with low STC values (M=2.8, $\tilde{x} = 2$). A χ^2 test showed that this difference is not significant ($\chi^2=2.620$, $p=0.106 > 0.05$). The STC has indeed an impact on the task of writing a program. The group with high STC values scored over one point better (M=4.5, $\tilde{x} = 5$) than the group with low STC values (M=3.4, $\tilde{x} = 3$). A χ^2 test shows that this difference is significant ($\chi^2 = 4.8$, $p \leq .05$).

4.3.3 Class Feedback

For the reported interest in the class, STC values did not play a significant role. The group with high STC rated their interest with 89 out of 100 points whereas the other group rated it slightly lower with 85 points. Analogically no difference in the perceived difficulty of the class showed up. The High STC group rated the classes difficulty slightly simpler (M=85, SD=12) than the low STC group (M=82, SD=11).

We found no effect of the STC on the question whether the students tried out a lot by themselves. Students with high STC values rated these questions slightly higher (M=86, SD=17) than those with low STC values (M=80, SD=17). An important finding is that the group with high STC had a more positive attitude towards STEM topics (M=84, SD=24) than the low STC group (M=77, SD=13), indicating a significant effect ($F(4,24) = 3.6$, $p \leq .05$). To assess the effect of the individual items of the four item scale, correlation analyses were used (Spearman's r). We found no connection between the STC and the interest of using more technology in school ($r=.11$, $p>.05$). The wish for using computers in school more frequently is connected to the STC ($r=.35$, $p=.055 >.05$). A strong correlation existed between STC and the question whether the students would like to computer program more often ($r = .450$, $p \leq .05$) and the question whether the students had become curious about computer programming in general ($p = .45$, $p \leq .05$).

Table 1. Overview of the factors gender, tangible artifact and subjective technical competence

	Factor Gender		Factor Turtle		Factor STC	
	Boys	Girls	Visual	Tangible	Low	High
Weekly Computer Usage [h]	12.8	8.4	9.2	12.4	8.9	12.6
Subjective technical competence	73	55	64	64	-	-
Reading a Program (0..5)	3.0	3.2	3.1	3.1	2.8	3.4
Writing a Program (0..5)	4.3	3.6	3.7	4.4	3.4	4.5
Number of students	16	15	17	14	16	15

5 Discussion and Conclusions

5.1 Using Robots in Computer Science Education

The empirical evidence suggests that tangible turtles have mild advantages over turtles presented visually. We saw no differences regarding the understanding of a given computer program, however the learning outcome was increased for writing a computer program. The data suggests that using tangible robots encourages a positive attitude towards STEM topics, although no considerable effects were found.

These findings are similar to those from the Roberta project that states that robots put computer science into a meaningful perspective. But we must also acknowledge that using robots in computer science education won't solve the problem that too few school students strive for a career in computer science and that the participation of women in STEM and computer science in particular is highly asymmetrical.

5.2 Gender and Technology

It's not surprising that we found a huge gender gap with regard to the subjective competencies in math, computers and general subjective technology competence. We could confirm that these subjective feelings affected the learning outcome, especially for the task of writing a computer program. These results fit into Busch's study that stated that women have lower self-efficacy that negatively impacts performance outcomes. This was especially true for the complex task of writing a program. Our results contradict the promising findings that gender differences in school math are dissolving in the USA were boys and girls archive similar results in standardized math tests [17]. The girls in our study reported much lower competencies that are accompanied by lower performance in writing computer programs.

A cautionary note refers to the fact that our findings rely on subjective measures that might be affected by systematic under- or overestimations. Although this effect was statistically controlled, gender differences were still present. It is an interesting finding that girls and boys showed different profiles: Boys found that math related aspects belong together, whereas girls saw computers and math strongly related.

We were surprised that such gender differences were present in the seventh grade and that these differences influenced the girls' performance negatively. Future research must focus on the question of when girls and boys drift apart and what methods can hinder that. We firmly believe that the STC is a mediating factor for interest and success in scientific education and career building.

5.3 Subjective Technical Competence as a Mediator for Successful Learning

We learned that the STC is an important mediator for interest in STEM topics and successful learning. It also strongly influences the self attributed competencies in geometry and dealing with computers. We found out that high STC leads to better scores in understanding a given computer program and especially writing a computer program. We also revealed that the STC is usually much lower for girls than for boys. Therefore measures to increase interest in STEM topic and measures to level gender differences in science and technology must focus on building subjective competences for boys and girls in addition to just teaching hard facts. The belief to be able to master technology seems to have a great impact on the actual performance. This study also reveals that measures to increase interest in science and technology should start earlier than in the seventh grade, because the STC in this age is already much lower for girls than for boys.

5.4 Limitations

Our study was carried out with a limited number of participants so a balancing of girls and boys with similar STC was not feasible. Additionally most of the variables assessed are based on subjective statements so the analysis is prone to systematic over- or underestimations of the students.

To generalize the results from this study we need to complement the attitudes towards science and math classes with performance outcomes. Here, the link between attitudes and school success (i.e. grades) are of interest as well as cognitive abilities and aptitudes which are connected to science and math performance, as e.g. problem solving abilities, speed of information processing, or spatial abilities [9, 18].

Class feedback was very positive in both conditions. We suspect however that this was mainly caused by the alternation from school routine, absence of the pressure to perform and the small group size. To hedge the results the study needs to be repeated under realistic conditions, i.e. with regular class sizes, over a longer period of time and with grading throughout the course.

5.5 Outlook

During this study we developed a ten item computer programming self-efficacy scale modeled after a previous scale [19]. We found a meaningful connection between our scale and the standardized STC, as students with a high STC also had a high computer programming self-efficacy. Its internal consistency was satisfying for the first iteration of the scale (Cronbach's $\alpha = .615$). However, it is not ready yet for practical use as its clarity is blurred by the combination of multiple items into one scalar variable. As self-efficacy is an important factor in career theories further research on creating a usable scale for assessing school students programming self-efficacy has to be developed.

Our study revealed that teaching scientific understanding must start way before the seventh grade. Too few research projects focus on the scientific and technical education of younger children to help constructing scientific understanding and the feeling that the adults of tomorrow are able to master technological devices with ease.

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