4-2019

Group Roles Matter in Computational Robotic Activities

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Publication Information

Taylor, Kellie and Baek, Youngkyun. (2019). "Group Roles Matter in Computational Robotic Activities". *Computers in Human Behavior, 93*, 99-105. https://doi.org/10.1016/j.chb.2018.12.010

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Abstract

This study examines the impact of grouping by gender and group roles on robotics performance, computational thinking skills, and learning motivation towards computer programming. One hundred ninety-one students in fourth and fifth grade completed the project. LEGO Mindstorms EV3 robotics were used to compose and program music in groups of three to four students. The robotics project was completed over the course of fourteen weeks for one hour each week. Gender-structured groups of all female, all male and mixed female and male were randomly assigned in each class. All groups in participating six classrooms were assigned one of three group roles implementation, which were fixed, rotating and no role. This study is significant towards identifying group scaffolds and supports that can produce benefits for all students in robotic activities. Results indicated that group roles matter when students are working on collaborative robotics projects. Three different implementations of group roles in robotics activities demonstrated an impact on robotics performance scores. Gender composition of the group did not impact groups' robotics performance. Group roles also impacted student computational thinking skills, while gender composition of the group still demonstrated no significant difference. Finally, while group roles demonstrated a difference in learning motivation towards computer programming, gender composition demonstrated no difference in learning motivation towards computer programming.

Keywords: Computational Robotics; STEM education; Computational thinking; Robotics performance; Learning motivation towards computer programming; Robotics in music composition

Introduction

The number of robotics platforms for educational purposes continues to grow at a rapid pace. Educational integration of robots has expanded as well. Limited classroom robotics materials lead to group robotics projects to accommodate sharing resources among the students (Taylor & Baek, 2017). The use of collaborative group work is increasing in the classroom setting for reasons other than limited materials and can be used intentionally in various content areas, including robotics and engineering. Student group work can provide a supportive structure for the completion of larger real-world projects and offers peer support

(Chambers, Carbonaro, Rex, & Grove, 2007; Eguchi, 2012; Robinson, 2005). Stump, Hilpert, Husman, Chung, and Kim (2011) highlight the need for collaborative groups specifically in engineering programs to prepare students to engage in the collaborative partnerships of real-world practicing engineers and develop innovative engineers for the future. In addition, the active learning taking place in collaborative group projects moves students beyond passive and compartmentalized learning and demonstrates the potential for positive impacts on student achievement and attitudes (Barker & Ansorge, 2007; Blanchard, Freiman, & Lirrete-Pitre, 2010; Chambers et al., 2007; Hwang & Wu, 2014; Papert, 1993; Stump et al., 2011).

The purpose or goal for collaborative groups may vary between content areas and educators (Stump et al., 2011). No matter the instructional goal, students groups can be difficult to facilitate in the classroom setting. The focus for this study was to optimize student benefits of collaborative robotics projects by identifying strategies and supports to allow all group members to participate equally, support each other's academic achievement on the project, and improve attitudes towards collaborative work. Since group dynamics and structure can impact student benefits and outcomes in collaborative groups, roles within these groups may provide necessary structure to create student benefits (Chambers et al., 2007). Yuen, Boecking, Tiger, Gomez, Guillen, Arreguin, and Stone (2014) also emphasize the importance for groups to have purpose and structure for group activities. Roles may be a guide for providing needed structure. Most of us have experiences group work at one time or another. Group work can be challenging even when groups have a purpose or common goal and a structure to follow for the collaborative process. Students working in groups can struggle with sharing ideas and dividing the workload equally when working on group projects, which seems to limit the potential for positive benefits for all students. Identifying supports to minimize negative experiences and support beneficial student collaboration is important to support teachers and students in collaborative projects.

Previous studies have indicated positive impacts of having group roles to support collaborative group work (Chambers et al., 2007; Taylor & Baek, 2017), but do not necessarily provide specifics for how to structure groups to promote benefits for all students.

Engaging all learners in science, technology, engineering, and mathematics (STEM) like robotics can also be a challenging prospect. Females are underrepresented and at times unwelcomed in STEM education and career areas (Stump et al., 2011). In order to make STEM education a more hospitable option for females, strategies that promote positive student achievement and attitudes may make strides towards bridging the gap in the number of males and females in STEM. This study seeks to further examine the use of roles and group gender composition to determine if these two aspects in collaborative robotics project impacts student robotics performance, computational thinking skills, and learning motivation towards computer programming.

Research problems

This study examines possible impact of grouping in robotic activities in terms of robotics performance, computational thinking skills, and learning motivation towards computer programming. Grouping in this study was done by gender and group role. Groups by gender are Males, Females, and Mixed. Groups by assigned role are Fixed, Rotate, and None. The research questions in this study are as follows:

1) Does grouping by gender (males, females, mixed) impact students' robotics performance, computational thinking skills, and learning motivation towards computer programming?

2) Does grouping by roles (fixed, rotate, none) impact students' robotics performance, computational thinking skills, and learning motivation towards computer programming?

3) Are there any interaction effects of grouping by gender and group role in robotics performance, computational thinking skills, and learning motivation towards computer programming?

Research Method

1) Participants and Procedure

The participants in this study consisted of fourth and fifth grade students from six classes at a school in suburban Idaho USA. They were ninety-six fourth grade students from three classes and ninety-five fifth grade students from another three classes. Among them, eighty-six students were females and one hundred five students were males. They ranged in age from 8 to 11. Students attended engineering classes of one hour for fourteen weeks. The engineering teacher, who has been teaching robotics in the elementary engineering classroom since 2012, also participated as one of the primary researchers. All student participants have the elementary engineering class each year, similar to what happens with specialists such as music and physical education. The majority of the groups consisted of four student members for a total of 48 groups during the study. The smallest group size consisted of three students.

Prior to the start of the study, permission for the study was secured through the school principal and district administration. Approval included an informed consent letter to parents of students involved in the study. The purpose of the study was shared with all the students emphasizing the process as a learning experience for the teacher/researcher rather than as an assessment of the students. Identities of the students were also protected with a coded system that provided anonymity. However, the data collected was also used to guide instruction and determine student growth in concepts and attitudes.

Each fourth and fifth grade classroom was randomly assigned one of the three group roles implementation, which were fixed, rotated and no role. Gender-structured groups of all female, all male and mixed female and male were randomly assigned in each class. After groups were assigned, all participants completed pre-tests of the Computational Thinking and the Learning Motivation towards Computer Programming before the computational robotic activities. All groups completed the EV3 robotics music composing project over the course of fourteen weeks for one hour each week. At the end of robotics activities, post-tests of the Computational Thinking and the Learning Motivation towards Computer Programming were completed by all participants. The robotics performance was scored on the final project for all students.

2) Grouping of Participants

Group Roles: In order to attempt to give all members of the group a voice and the opportunity to participate fully in the group, students in Rotate and Fixed roles groups used the modified Thinking Hat roles (Table 1) from de Bono (2016). Students were all randomly assigned a role at the start of the project. In the cases where group roles where systematically implemented, two different practices were used. Groups where the roles were Fixed, kept those roles throughout the entire project. Groups in Rotate roles switched roles each week, rotating through the four different roles multiple times as the project progressed.

Each role had a description, as well as guiding questions to help support student discussion and aid the group in the assigned project. These roles were not specific to programming but rather group work. All students, no matter their roles, were asked to assist with programming. The roles are designed to support the project aspect with shared responsibilities while giving all students the hands-on opportunity of programming and testing code. All students had the modified Thinking Hat roles stapled in the front of their engineering notebooks. Classes assigned to Rotate roles rotated through the different Thinking Hats each class. Each group in classes with Fixed roles were randomly assigned a hat and asked to be that hat for the entire project. The third set of students had the Thinking Hats available to them but were not assigned or reminded to use the hats. The variation in practices for group roles was intended to identify if there is an impact on student outcomes.

<Insert Table 1 here>

Gender Structured Groups: Gender-structured groups were randomly assigned in each class consisting of group structures of all female, all male, and mixed female and male. Participants drew from a deck of cards as they entered the classroom for their group assignments on the first day of the project. If students were absent on the day groups were created, they were assigned to the groups with the smallest numbers. All three group assignments were represented in each class. There was a total of 10 all-female groups, 15 all-male groups, and 23 groups with female and male students. Student numbers did not allow for the 23 groups of mixed females and males to be equally comprised of male and female students. Of those 23 groups, 18 groups had two females and two males. The remaining five groups were uneven numbers of males and females.

3) Questionnaires

Computational Thinking: The Computational Thinking Test (CT-test) was first developed by Marcos Román González as a 40-item test but was later refined into a 28-item test (CT-test 2.0). The CT-test can be used as a pre-test to measure students' initial CT levels and to detect special skills or special needs in programming (Román-Gonzalez, 2015). Another aim of the CT-test, according to Román-González, Pérez-González, and Jiménez-Fernández (2016), is to assess the development level of CT in the subject among students (grades K-5 and K-10).

The CT-test assesses the user's computational thinking levels on five dimensions: computational concept addressed, environment-interface of the item, answer alternatives style, existence or non-existence of nesting, and required tasks (Román-González et al., 2016). Regarding the first dimension, the test comprises items that address computational concepts such as Basic directions and sequences (4 items); Loops- repeat times (4 items); Loops- repeat until (4 items); If- simple conditional (4 items); If/else- complex conditional (4 items); While conditional (4 items); and Simple functions (4 items). All these items are arranged in order of increasing difficulty. For the second dimension, there are 23 items that are presented in 'The Maze' environment-interface while 5 items are in 'The Canvas' interface. Both interfaces are commonly used for learning programming (Román-González et al., 2016). Another commonly used feature for learning programming is the use of visual arrows and visual blocks which are included as answer alternatives style in the third dimension (8 items use visual arrows and 20 items use visual blocks). Regarding the fourth and the fifth dimension, Román-González et al., (2016) point out 29 items where nesting of computational concepts exists and 11 items where these concepts are non-existent. The required task dimension, however, is more focused on the cognitive tasks, which include sequencing, a set of commands, completion, and debugging. These tasks are fundamental in solving problems that relate to CT. As for the reliability of the CT-test, Román-González et al., (2016) report a good internal consistency of the 28 items (α =0.793).

<u>Learning Motivation towards Computer Programming</u>: This test created by Law, et al. (2010) examines the key motivating factors affecting students learning computer programming courses. This test consisted of intrinsic and extrinsic factors and of 19 items: Intrinsic factors focus on the individuals rather than the environmental setting. The factors generally include individual attitude and expectation, challenging goals including emotions. Extrinsic factors stem from the environment external to the learning. Six factors affecting motivation of students towards computer programming were: 'individual attitude and expectation (4 items)', 'challenging goals (3 items)', 'clear direction (3 items)', 'reward and recognition (3 items)', 'punishment (2 items)', and 'social pressure and competition (4 items)'. 'individual attitude and expectation' and 'challenging goals' are classified as intrinsic factors. 'Clear direction', 'reward and recognition', 'punishment', and 'social pressure and competition' are classified as extrinsic factors.

The validity of six constructs is verified through the oblique rotation exploratory factor analysis. The value of factor loadings verifies the validity of all the constructs, except that one of the items of 'Punishment'. The discriminant validity of each construct is checked using a multi-trait matrix and it ranges .66 to .89, which shows a high validity coefficients of individual constructs. The Cronbach Alpha value of this test is .95 which shows a high level of internal reliability. Overall, the internal reliability of an individual construct is higher than the inter-construct reliability (Churchill, 1979), which, in turn, shows strong empirical support for discriminant validity.

4) Computational Robotic Activities

Each of the 48 groups completed a robotics project with the LEGO MINDSTORMS EV3. The Mindstorms robotics platform uses LEGO pieces for construction along with a brick for controlling the robot. Construction was not needed for music composition project, only the programming brick was used. Programming was completed using the LEGO EV3 drag-and-drop software. Students were introduced to the software and then the process of creating music with the software at the beginning of the project. The project combined robotics programming with music composition by using the programming brick to create music. The EV3 software allowed students to create tones and musical notes when programming using the drag and drop user interface. Integrating music composition with the robotics programming created an opportunity for students to connect with other content areas during elementary engineering and bring in prior knowledge from music class.

The project was completed over the course of fourteen weeks in the engineering lab with one hour each week. The learning sequence moved from specific directions on programming with the interface, creating musical notes, creating a program of an existing song, and creating new compositions that are designed a particular emotion. The use of the robots promoted the cross-curricular aspect of STEM in real world practices.

Programming an existing song required students to convert musical notes into EV3 programming language. The “Happy Birthday” song was used so a majority, if not all, students had a familiarity and clear recollection of how the song should sound. Students used the EV3 Sound Block and chose the musical note options. Students then had to identify the musical note names on the music to be able to select the appropriate option on the Sound Block. They also had to know the length of the note to be able to program the time length for the note to be played. Students were given programming times in a resource package to program eighth, quarter, half, and whole notes. The various aspects of programming the musical sequence and analyzing it for accuracy required computational thinking. Students were required to do pre-thinking and planning, a component of computational thinking, by preparing measures of the song in their notes prior to programming and then changing their notes as the program needed changes.

Once programming for original music compositions began, students had to think about the sound and feeling the notes created with their length and organization. Furthermore, students had to consider the provided rubrics and work to create repeating rhythm patterns, use a variety of notes both in name and length, and create a minimum of eight measures all while evoking a feeling of happiness from the listener. While the rubric was designed to provide a scaffold for students during the project and a performance assessment for completion of the project, it emphasized different components of computational thinking during the music composition process.

Different approaches to the group work were implemented through random class assignment. Three classes completed the project through the use of a collaborative process. Students worked together in one program file to complete the preexisting song and the music composition. The collaborative process required that students open one programming file and students added to the program when it was their turn to contribute. Students took turns programming each measure of the song. They could prewrite their upcoming measure and then be ready to add it to the program.

Students working cooperatively worked to compose their measures in separate program files and then compile those individual measures into a larger complete program. The individual programs for each group member's measures, when compiled together into a final program, created the full song. This allowed students to work on their portions of the project independently until it came time to put all the measures together. The goal for this method was to create an environment within the group that required individual accountability and assurance each group member would equally practice programming within the group. All groups, including the collaborative and cooperative, were encouraged to provide peer support by staying aware of what their group members were creating.

5) Robotics Performance Score

Students were scored on the final project using two rubrics. One rubric measured the music composition component while a second rubric measured the programming process. To determine student understanding of programming music on the EV3, students were also assessed on their programming of the existing songs such as Happy Birthday and You are My Sunshine. The assessment used a rubric similar to what would be used on the original composition with a combination of successfully programming the song to play and the programming process (Table 2). While individual components were measured during the performance assessment, they were not necessarily assigned a score. In order to determine the overall score, points were assigned to each level, Advanced-4, Proficient-3, Strategic-2, and Basic-1. Then the individual components could be averaged to determine the overall score for the project. Any half scores were rounded up to the next level. For example, an averaged score of 2.5 would have been recorded as Proficient. Scoring method and point assignment was the same for all rubrics.

<Insert Table 2 here>

6) Statistical Analysis

In order to test homogeneity of participants according to grouping by gender (males, females, and mixed) and group roles (fixed, rotate, and none) in terms of robotics performance, computational thinking skills, and learning motivation towards computer programming, one-way ANOVA procedure was applied to the pre-test scores of the two tests. After the intervention, two-way ANOVA with three levels of each factor was applied to the post-test scores of two tests in order to see the two factors' main and any interaction between the effects.

Results

The ANOVA procedure applied before the intervention to determine the homogeneity of three groups by gender and another three groups by group role did not produce any significant difference. Therefore, the participants were homogeneous in computational thinking skills and learning motivation towards computer programming regardless of the groups to which they belonged either by gender or by group roles.

After the robotics project, two factors of grouping by gender and assigned group role were compared in terms of robotics performance, computational thinking skills, and learning motivation towards computer programming. The results are presented below.

1) Robotics Performance

Means and standard deviations for robotics performance is presented in Table 3.

<Insert Table 3 here>

According to Table 3, the female group's mean for robotics performance is the highest (M = 2.68, SD = 0.474), that of male group is the next (M = 2.66, SD = 0.542), and the mixed group's mean is the lowest (M = 2.58, SD = 0.498). Per assigned role groups, the fixed role group's mean is the highest (M = 2.83, SD = 0.380), that of the rotate role group is the next (M = 2.74, SD = 0.441), and none role group is the lowest (M = 2.34, SD = 0.570). In order to determine if these differences are significant, two-way of ANOVA was carried out and the result is presented in Table 4.

<Insert Table 4 here>

According to Table 4, there is a main effect of Assigned Role, F (2, 190) = 19.449, MS = 4.360, $p < 0.01$. No main effect of Group by Gender was found, F (2, 190) = 0.098, MS = 0.022, $p > 0.05$). No interaction effect exists, F (2, 190) = 0.875, MS = 0.196, $p > 0.05$. Therefore, three different assigned roles in robotics activities make difference in robotics performance. Group by Gender makes no difference in robotics performance. To identify where any difference exists, the post hoc analysis with Tuckey's HSD was carried out. As results, the significant differences were found between Fixed and None roles (Mean Difference = 0.48, SE = 0.084, $p < 0.01$), and Rotate and None roles (Mean Difference = 0.40, SE = 0.084, $p < 0.01$). No significant difference existed between Fixed and Rotate roles (Mean Difference = 0.09, SE = 0.084, $p > 0.05$). These results are depicted in Figure 1 below.

<Insert Figure 1 here>

2) Computational Thinking Skills

Means and standard deviations for computational thinking skills is presented in Table 5.

<Insert Table 5 here>

According to Table 5, the male group's mean for computational thinking skills is the highest (M = 45.32, SD = 3.929), that of the mixed group is the next (M = 45.23, SD = 3.552), and the female group's mean is the lowest (M = 45.18, SD = 4.197). Per assigned role groups, the fixed role group's mean is the highest (M = 47.03, SD = 3.427), that of none role group is the next (M = 45.05, SD = 3.873), and the rotate role group is the lowest (M = 43.65, SD = 3.536). In order to determine if these differences are significant, two-way of ANOVA was carried out and the result is presented in Table 6.

<Insert Table 6 here>

According to Table 6, there is a main effect of Assigned Role, $F (2, 187) = 13.451$, $MS = 180.747$, $p < 0.01$. No main effect of Group by Gender was found, $F (2, 187) = 0.144$, $MS = 1.930$, $p > 0.05$). No interaction effect exists, $F (2, 187) = 0.294$, $MS = 3.949$, $p > 0.05$). Therefore, the three different assigned group roles in robotics activities make a difference in computational thinking skills. Group by Gender makes no difference in computational thinking skills. To identify where any difference exists, the post hoc analysis with Tuckey's HSD was carried out. As results, the significant differences were found between Fixed and Rotate roles (Mean Difference = 3.38, SE = 0.661, $p < 0.01$), and Fixed and None roles (Mean Difference = 1.98, SE = 0.651, $p < 0.01$). No significant difference existed between Rotate and None roles (Mean Difference = -1.40, SE = 0.659, $p > 0.05$). These results are depicted in Figure 2 below.

<Insert Figure 2 here>

3) Learning Motivation towards computer programming

Means and standard deviations for learning motivation towards computer programming is presented in Table 7.

<Insert Table 7 here>

According to Table 7, the male group's mean for learning motivation towards computer programming is the highest (M = 76.78, SD = 13.035), that of the mixed group is the next (M = 76.07, SD = 12.054), and the female group's mean is the lowest (M = 55.26, SD = 10.247). Per assigned role groups, the rotate role group's mean is the highest (M = 79.63, SD = 12.334), that of the fixed role group is the next (M = 76.62, SD = 11.925), and none role group is the lowest (M = 72.75, SD = 11.479). In order to determine if these differences are significant, two-way of ANOVA was carried out and the result is presented in Table 8.

<Insert Table 8 here>

According to Table 8, there is a main effect of Assigned Role, F (2, 187) = 4.203, MS = 603.122, $p < 0.05$. No main effect of Group by Gender was found, F (2, 187) = 0.184, MS = 26.371, p > 0.05. No interaction effect exists, F (2, 187) = 0.877, MS = 125.815, p > 0.05. Therefore, three different assigned roles in robotics activities make difference in learning motivation towards computer programming. Group by Gender makes no difference in learning motivation towards computer programming. To identify where any difference exists, the post hoc analysis with Tuckey's HSD was carried out. As results, the significant difference was found between Rotate and None roles (Mean Difference = 6.88, SE = 2.153, p < 0.01). No significant difference existed between Fixed and Rotate roles (Mean Difference = -3.01, SE = 2.161, p > 0.05), and Fixed and None roles (Mean Difference = 3.87, SE = 2.126, p > 0.05). These results are depicted in Figure 3 below.

<Insert Figure 3 here>

Discussions and Conclusion

Group supports and structure matter when students are working on collaborative robotics projects. While collaborative group work is identified as beneficial when working with robotics, specifications for best practices are not clearly identified. How do we promote benefits for all students during collaborative work? There is still a need to identify specific group supports and best practices for collaborative robotics projects.

Three different implementations of roles during a robotics project demonstrated an impact on robotics performance scores. Having assigned roles, whether Fixed or Rotate, produced significant impact on group outcomes of the robotics performance scores. A significant difference existed between Fixed roles and None, and Rotate roles and None, confirming the results of an earlier study (Taylor & Young, 2017). Fixed role groups performed better than None, and Rotate group roles did better than the None, no group roles. These results support findings of Hwang and Wu (2014) and Chambers et al. (2007). The assigned roles offered students guidance on using different perspectives to analyze the challenges of the project from all angles. Gender composition of the group did not impact groups' robotics performance. Nevertheless, Stump et al. (2011) asserts the importance of positive collaborative experiences for females in STEM. Examining the impact of gender composition on the collaborative experience for female students on the collaborative robotics project was worthwhile.

Student computational thinking skills were impacted by assigned group roles, while gender composition of the group still demonstrated no significant difference. Fixed role groups outperformed groups with Rotate or None, no assigned role. A significant difference exists between Fixed and Rotate roles, and Fixed and None. No significant difference was demonstrated between Rotate and None roles. Perhaps the fixed roles made it clear which jobs and perspectives students had each week rather than moving from role to role.

Gender composition of the group did not demonstrate any difference in learning motivation towards computer programming. Possibly the existing collaborative nature of the project with supports to promote successful student interactions was enough to create a positive collaborative experience as mentioned by Stump et al. (2011). In addition, there was no significant difference in learning motivation towards computer programming for students in Fixed or Rotate roles. However, significant differences for learning motivation towards computer programming were identified between Fixed and None and Rotate and None. Providing group roles, whether fixed or rotating, supported higher learning motivation towards computer programming than no group roles, None. Did the use of roles provide an example of how to share the work of the project, how to take turns using the single computer and brick for programming? The use of roles in general provided support that promoted learning motivation towards computer programming.

This study was able to work with 191 student participants in both fourth and fifth grades. Instruction was consistent for each group type since the same teacher was providing the instruction for all the grade-levels and classes. These same aspects of the study also provide some limitations. Using one teacher and one school for implementation of the group supports does not account for diverse teachers or students. Additional studies with additional educators and students would help determine if universal group scaffolds and supports demonstrate similar results.

While the results seem to shed more light on how to structure groups in the classroom setting, with Fixed group roles seeming to produce the best results for student benefits, important questions are also raised. With the challenges of retaining females in the STEM pipeline, how is it that gender composition of the group does not seem to impact the outcomes even for learning motivation? Is it possible that scaffolds and supports provided by having roles for the group members creates a positive enough collaborative environment to support female students? Past studies have demonstrated that gender composition of the group can impact learning motivation. Does the nature of the robotics project, music composition, neutralize any possible negative impacts from gender composition of the group? In addition, even though assigned Fixed roles increases student benefit in robotics performance scores, computational thinking skills, and learning motivation for computer programming, it still does not insure that all students are equally engaged. Nevertheless, the use of roles in collaborative robotics projects does seem to be an important step forward, supporting Hwang and Wu (2014) claims that connecting science of daily life with collaborative groups can deepen understandings for students. Further development of roles to create additional scaffolds and positive experiences in the classroom setting with collaborative robotics projects is recommended.

References

Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education, 39*(3), 229–243.

Blanchard, S., Freiman, V., & Lirrete-Pitre, N. (2010). Strategies used by elementary school children solving robotics-based complex tasks: innovative potential of technology. *Procedia - Social and Behavioral Sciences, 2*(2), 2851–2857. http://doi.org/10.1016/j.sbspro.2010.03.427

Chambers, J. M., Carbonaro, M., Rex, M., & Grove, S. (2007). Scaffolding knowledge construction through robotic technology: A middle school case study. *Electronic Journal for the Integration of Technology in Education, 6*, 55–70.

Churchill, G. A. (1979). A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research, 16*, 64–73.

De Bono, E. (2016). *Six Thinking Hats*. Little, Brown and Company. New York. Retrieved from http://www.debonogroup.com/six_thinking_hats.php

Eguchi, A. (2012). *Educational robotics theories and practice: Tips for how to do it right.* In B. Barker, G. Nugent, N. Grandgenett, & V. Adamchuk (Eds.) Robots in K-12 education: A new technology for learning (pp. 1-30). Hershey, PA: Information Science Reference. doi:10.4018/978-1-4666-0182-6.ch001

Hwang, W.-Y., & Wu, S.-Y. (2014). A case study of collaboration with multi-robots and its effect on children's interaction. *Interactive Learning Environments, 22*(4), 429–443. http://doi.org/10.1080/10494820.2012.680968

Law, K. M., Lee, V. C., & Yu, Y. T. (2010). Learning motivation in e-learning facilitated computer programming courses. *Computers & Education*, *55*(1), 218-228. https://doi.org/10.1016/j.compedu.2010.01.007

Robinson, M. (2005). Robotics-driven activities: Can they improve middle school science learning? *Bulletin of Science, Technology & Society*, *25*(1), 73–84. http://doi.org/10.1177/0270467604271244

Román-González, M. (2015). Computational thinking test: Design guidelines and content validation. *Proceedings of EDULEARN15 Conference* (pp. 2436-2444). Barcelona, Spain.

Román-González, M., Pérez-González, J. C., & Jiménez-Fernández, C. (2016). Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test. *Computers in Human Behavior*, *30*, 1e14.

Stump, G., Hilpert, J., Husman, J., Chung, W., Kim, W. (2011). Collaborative Learning in Engineering Students: Gender and Achievement. *Journal of Engineering Education, Vol: 100* (3) (pp. 475-497).

Taylor, K. and Baek, Y. (2017). Collaborative Robotics, more than just working in groups. *Journal of Educational Computing Research*. https://doi.org/10.1177/0735633117731382

Yuen, T. T., Boecking, M., Tiger, E. P., Gomez, A., Guillen, A., Arreguin, A., & Stone, J. (2014). Group tasks, activities, dynamics, and interactions in collaborative robotics projects with elementary and middle school children. *Journal of STEM Education: Innovations and Research*, *15*(1), 39–46.