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Teaching Newtonian physics with LEGO EV3 robots: An integrated STEM approach

Johannes Addido [1*], Andrea C. Borowczak [2], Godfrey B. Walwema [3]

[1] College of Education, University of Wyoming, Laramie, WY, USA
[2] School of Teacher Education, University of Central Florida, Orlando, FL, USA
[3] The Indiana Academy for Science, Mathematics, and Humanities, Ball State University, Muncie, IN, USA

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Abstract

This paper investigated the effect of using LEGO EV3 robots to teach Newton's second law with conceptual understanding to a group of 14 to 18-year-olds in an after-school STEM education program. 74 teenagers participated in this research study. A quantitative methods approach involving descriptive analyses, paired-sample t-test, and repeated measures ANOVA were used to answer the research questions. The results showed that the LEGO EV3 robots positively affected participants' understanding of Newton's second law of motion and their interest in pursuing STEM education and careers. In addition, the descriptive analyses from the pre- and post-interest questionnaire revealed that participants were more confident and willing to learn with robotic devices after the activity than before. Repeated measures ANOVA analysis indicated that scaffolded programming tasks affected participants' computational thinking skills. Implications include the purposeful use of LEGO EV3 robotics and potentially other educationally focused programmable devices (e.g., micro:bit, Spheros, Arduinos, etc.).

Keywords: Newtonian physics, conceptual understanding, robotics-based education, experiential learning, integrated STEM, K-12 science education

INTRODUCTION

Science education has seen a growing push in using robotic devices as tools to teach STEM (science, technology, engineering, mathematics) subjects in K-12 classrooms; robotic devices have the potential to advance the study of STEM subjects by providing opportunities that help students establish connections between diverse topics/subject matters, restructure scientific and mathematical concepts in new ways and proffer solutions to complex problems in novel ways (Altin & Pedaste, 2013; Yang & Baldwin, 2020). This is indicative that a combination of robotics and integrated STEM education will contribute to the enrichment of the United States workforce and increase the country's global technology competitiveness; it is imperative to connect with integrated STEM learning and robotic devices to support student learning and tackle the challenges educating 21st century students (Ntemngwa & Oliver, 2018; Yang & Baldwin, 2020).

Various studies have shown that robotic devices provide experiential, hands-on education and motivation for learning new material (Ferrarelli & Iocchi, 2021; Jaipal-Jamani & Angeli, 2017). Teaching with robotic devices is an instructional approach that provides real-world meaning to the otherwise abstract knowledge in physical sciences, and students showed improvements in their ability to explain physics concepts, according to Karim et al. (2015). The integration of robotics in the teaching of science offers rich opportunities to involve students in the hands-on application of science as it happens in the real world, enabling students to build a conceptual understanding of physics principles by using investigation, data analysis, engineering design, and construction (Church et al., 2010).

Education in 21st century makes it essential to integrate technological tools in the teaching and learning process to allow students to be actively involved in their learning, achieve an in-depth understanding of science

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✉ johannesaddido@gmail.com **(*Correspondence)** ✉ Andrea.Borowczak@ucf.edu ✉ godfrey.walwema@bsu.edu

Contribution to the literature

- This research contributes to the integrated STEM and robotics-based education literature by providing empirical evidence to show the effect of teaching Newton's Second Law of Motion using LEGO EV3 robots.
- This research study presents results that show how participating teenagers' conceptual understanding, computational skills, and desire to pursue STEM courses and careers were positively influenced by the robotic device and the integrated STEM learning environment in which the research was conducted.
- The significant implication of this study is that it provides further evidence in support of pedagogical approaches that teach integrated STEM topics with robotic devices to augment the experiential learning opportunities available to elementary, middle, and high school students.

topics, and have meaningful learning experiences through interactions with science content (Guastella & Antonella, 2020). Implementing robotics instruction in K-12 setting can equip students with means of making tangible abstract concepts; in a robotics-based learning environment, students get to see the effect of their software codes on the actions of the robotic devices (Deliberto, 2014).

The usage of robotics in education is grounded on the work of Seymour Papert. Seymour Papert was interested in building an environment, where students used computer programming to manipulate robotic devices; he held the view that being concrete objects, robotic devices will help students understand abstract concepts because they experience it in the real world (Jomento-Cruz, 2010). This approach builds on Piaget's constructivist theory, which proclaims that knowledge is not passed on from teacher to student but actively fashioned by the mind of the student (Driscoll, 1994; (Jomento-Cruz, 2010) and Kolb's experiential learning theory, which posits that knowledge is the product of understanding and transforming an experience (Rihtaršič et al., 2016).

The authors of this research study sought to help solve the problem of students' disinterest in physics and science topics. This problem affects enrollment in STEM-related courses and shrinks the STEM career pipeline (Staus et al., 2020). Using robotics to teach physics is a small way of getting students interested in the subject, enrolling in STEM courses, and eventually pursuing STEM careers. This proposed study places students in an environment, where they need evidence for claims. The robotics activities help students build their understanding instead of being provided answers in a teacher-centered manner. Singer et al. (2012) list current areas in physics education research; some focus areas are developing curricular materials and pedagogies to facilitate conceptual change, improve problem-solving skills and attitudes toward learning physics, and provide experiences with science practices. The authors of this research study address these in the broader sphere of physics education.

The authors investigated the impact of robotics-based instruction on teenage student participants' understanding of Newton's second law of motion. LEGO robotic device (Mindstorms EV3) is the manipulative tool used in this study. The contributions of this research study include the development and implementation of a lesson for teaching students how to program an EV3 robot to perform actions relevant to Newton's second law of motion, a quasi-experimental procedure to evaluate the effectiveness of the lesson in promoting computational thinking skills; and the impact of the robotic-based instruction on students' understanding of Newton's second law of motion.

LITERATURE REVIEW

This section reviews the literature on robotics-based education studies. Integrated STEM is a part of the review and is embedded in promoting the understanding of science concepts as a multi and interdisciplinary quest to recognize STEM as a unitary idea, and conversely integrated STEM is not just a grouping of the four disciplines into an expedient and catchy acronym (Burrows & Slater, 2015; Kennedy & Odell, 2014). The writings on theoretical frameworks such as constructionism and experiential learning are reviewed to ascertain their theoretical perspectives supporting teaching and learning with robotics. The concluding part of the literature review outlines the purpose and research questions underpinning this research study.

Robotics-Based Education

In education, robotics or robotic devices are used in multiple ways and purposes. Robotics as a teaching and learning tool is valuable in the didactic process across numerous schools in the country (Danahy et al., 2014). Students are taught how to build and program robotic devices in engaging and hands-on ways and promote learning in a playful environment (Johnson, 2003; Malec, 2001; Yuan et al., 2019). The findings on the impact of robotics/robotic devices in education show that it generates a significant level of students' interest and desire to pursue STEM careers (Chen & Chang, 2018; Hendricks et al., 2012; Nugent et al., 2010). Afari and Khine (2017), in their study exploring the educational use of robotics in schools, concluded that the use of robotics improved students' problem-solving and computational skills. In another study, the author posits that a curriculum designed around robotics provides tangible materials for students to manipulate and experiment with as they begin understanding abstract scientific concepts and gaining practical knowledge (Addido et al., 2022a; Nall, 2016).

In studies, where robotics is used to teach STEM subjects, the general outcome of these studies is that the use of robotics in K-12 educational settings improved students' understanding of certain STEM concepts and overall academic performance (Athanasiou et al., 2019; Benitti, 2012). However, not all the studies on teaching with robotics have conveyed affirmative outcomes, and there has not been statistically significant improvement in participating students' transformative inquiry skills (Altin & Pedaste, 2013; Chen & Chang, 2018). In addition, a decade-long study on robotics-based education found that a few studies had focused on students' learning outcomes as outlined in the standards; a much less number had studied STEM subjects in an integrated manner (Altin & Pedaste, 2013; Benitti, 2012; Chen & Chang, 2018; López-Belmonte et al., 2021). It is worth noting that a more significant percentage of the research references students' robotics skills or attitudes towards robotics education, however for robotics to have the desired impact on science education, it should be effectively integrated with all the STEM disciplines, hence the need for intra-disciplinary studies that will lead to the development of suitable robotics curricula and teaching strategies (Benitti, 2012; Borowczak & Burrows, 2019; Chen & Chang, 2018; Jomento-Cruz, 2010; Sullivan & Heffernan, 2016).

Integrated STEM Education

STEM education is now an integrated subject that removes the traditional lines of separation between science and mathematics subjects; integrated STEM incorporates innovation and the pragmatic process of designing solutions to complex problems using modern tools and technologies (Kennedy & Odell, 2014).

Integrated STEM education is a pedagogical approach whereby concepts and ideas from the individual STEM fields are amalgamated into a single discipline to enable students to build the connections between the various concepts that have been combined, study the concepts concurrently instead of in separation, and connect them to real-world conditions (Ntemngwa & Oliver, 2018; Yang & Baldwin, 2020). Teaching with robotic devices emboldens students to alter scientific and mathematical ideas in new ways, such as building and programming robotic devices to perform automated tasks; these integrated learning environments provide the platform for students to address real-world challenges using manipulatives such as robots (Burrows et al., 2017; Yang & Baldwin, 2020). The learning activity used for this research study was designed as a physics instructional module in which the learning of Newton's second law of motion is taught as an integrated STEM activity. The integrated STEM learning environment in which this robotics-based physics lesson was taught collapses disciplinary boundaries and permits students to create their learning and multidisciplinary knowledge experientially.

The literature presents a good case for integrated STEM. It posits that integrated STEM learning environments foster scientific inquiry and the inculcation of engineering design skills; promote technological and scientific literacy (Addido et al., 2022a; Kennedy & Odell, 2014; Yang & Baldwin, 2020). Conversely, some studies point out that students' learning might be inhibited by teachers who are not sufficiently prepared to teach STEM in an integrated manner (Epstein & Miller, 2011; Yang & Baldwin, 2020). For students' knowledge of scientific concepts, mathematical formulas, and engineering practices to be augmented in an integrated STEM learning environment, it calls for teacher preparation and cooperation among technologically proficient educators and subject matter experts to build successful learning environments (Ortiz et al., 2015; Yang & Baldwin, 2020).

THEORETICAL FRAMEWORK

In this research study, the theoretical paradigms of constructivism and experiential learning were the underlying theories upon which the robotics-based physics lesson was developed. In this section, we detail how constructivism and experiential learning underpin the pedagogical activity of learning Newton's second law of motion using a LEGO robotic device.

Constructionism

Constructionism as an educational theory postulates that knowledge exists in the mind of humans and needs not match real-world reality (Driscoll, 1994; Narayan et al., 2013). Students constantly try to develop their mental model of the natural world from their perceptions of that world. In a classroom, where constructionism is practiced, students have the autonomy to study scientific concepts and build their understanding conceptually through individual findings (Deliberto, 2014). This theory is backed by research studies that show that pedagogies based on rote learning and memorization are unsuccessful in supporting students' future application of what has been learned; on the contrary, constructivist pedagogies that challenge students' preconceptions about particular science concepts lead to the minimization of misconceptions and promotion of conceptual understanding (Church et al., 2010; Danahy et al., 2014).

Several studies have posited that the definitive learning theory behind robotics-based instruction is constructivism (Altin & Pedaste, 2013; Danahy et al., 2014; Nall, 2016; Wei et al., 2011), this supports the view that LEGO robotics is primarily a constructivist tool, which helps students to actively construct knowledge by bringing prior cultural knowledge or experiences to learning situations that impact the new knowledge to tackle real-world challenges (Danahy et al., 2014).

Experiential Learning

Experiential learning theory is based on a constructivist philosophy that postulates that the learning process is dynamic, whereby students learn and understand by integrating new knowledge with existing knowledge (Habib et al., 2021; Verner & Korchnoy, 2006). Kolb is credited with developing experiential learning theory based on the works of educational theorists like Dewey, Freire, and Piaget, to name a few (Baker & Robinson, 2016). The underlining conception is that students learn concepts through realistic experiences and challenges; this learning takes place in small cooperative groups with teachers being facilitators of learning (Baker & Robinson, 2016; Rihtaršič et al., 2016). Kolb's experiential learning theory, popularly called the four-stage cycle of learning or Kolb cycle, is based on the following: concrete experience, reflective observation, abstract conceptualization, and active experimentation, which are repeated several times to ultimately achieve the desired learning objectives of a particular lesson (Addido et al., 2022b; Rihtaršič et al., 2016).

The robotics-based physics activity used in conducting this research study is based on the experiential learning paradigm developed by Kolb; students are exposed to concrete/hands-on learning experience through assembling parts into functional robots, observing their work, and reflecting on ways to improve it, abstractly thinking of how to make the robotic device perform the tasks at hand through active experimentation. Some studies have also concluded that experiential lessons increase students' social and academic development by promoting social interaction and cooperative learning (Baker & Robinson, 2016; Habib et al., 2021; Walwema et al., 2016). It is fair to acknowledge that the constructivist and experiential learning theories are most effectively implemented with the aid of robotic devices, where students can build their understanding of abstract concepts, such as Newton's second law of motion, through programmable devices to validate scientific concepts that are difficult for students to understand conceptually because real-world examples lead to misconceptions.

Research Purpose and Questions

The authors of this research study conducted a lesson on Newton's second law of motion using a LEGO robotic device (Mindstorms EV3) with a group of 14 to 18 years old student participants. The problem that this study addressed is the challenge in teaching Newton's second law of motion because the notion of force is an intangible concept, and the typical Newtonian physics lab usually oversimplifies the notion of force by reducing it to a single force acting on the object in question; hence an approach is needed to help students understand the relationship between force and acceleration of an object as well as building students' interest to practice force-motion activities (Gates, 2014; Setyanto et al., 2018). This study investigates the impact of robotics-based instruction on participants' computational thinking skills and conceptual understanding of Newton's second law of motion. This research study also contributes empirical evidence regarding the efficacy of robotic devices in teaching physical science concepts.

This study provides a better understanding of how robotic devices influence the teaching and learning process and contributes from an informed position to the suggestions that robotics should be made an integral part of the education curriculum of students to improve their problem-solving and creativity (Badeleh, 2021). It also helps to ascertain whether using robotics in teaching high school physical science concepts would lead to new instructional methods for successfully combining robotics experiments with specific physics lessons (Ferrarelli & Iocchi, 2021).

The questions addressed explicitly in this study are:

1. How does the robotics activity affect participating students' computational thinking skills?
2. What is the impact of the robotics activity on participating students' conceptual understanding of Newton's second law of motion?
3. How does the robotics activity affect participating students' interest in learning physical science concepts?

This research study's gap is linked to the recommendation that Jaipal-Jamani and Angeli (2017) offers in their article, where the authors entreat other researchers to explore the utility of robotic devices in developing scientific knowledge of topics such as pulleys, energy transfer, and doppler effect that can be taught through the construction and function of robots (Jaipal-Jamani & Angeli, 2017).

METHODS

The researchers addressed the research questions using quantitative data and statistical analysis. The researchers applied a pre- and post-test, repeated measures, and descriptive statistics quasi-experimental research design within a quantitative methods approach (Creswell, 2014). This method was used for practical and ethical reasons that prevented the randomization of participants.

Participants

The sample for this research study is teenagers between 14 and 18 enrolled in an after-school education program at a university in the Northwestern United States. There was a total number of 74 participants. Recruitment was completed by the first author, who leveraged his connections as a certified 4H instructor and liaised with managers of the after-school hands-on makerspace education programs at student innovation center to assist with participant recruitment. Participant selection was based on age and willingness to participate in a robotics STEM learning activity by signing a consent form.

Participation was contingent on signing and submitting an informed consent form to the principal investigator. Exclusion from participating in the research was based on failure to submit an informed consent form, not falling within the age range, and not being a high school student. In this regard, some participants younger than the age range of interest to the researchers were allowed to participate, but their data were excluded from the data analyses. Participants and parents/guardians were asked to consent so that the data collected can be used for research and publication purposes.

Research Procedure

In this study, participants spent, on average, three hours on the research activity for one day. Lesson units were designed based on the physics topics of forces and motion and involved using LEGO EV3 robotic device in the teaching and learning process. Participants were tasked with building and programming a LEGO EV3 robotic device to perform some tasks and carry loads of different masses. The first author provided all the needed materials and robotic devices. Throughout the research activity phase, participants worked in groups of three or four. This hands-on activity required participants working in groups to:

- Build an EV3 robot and program it to perform some tasks using Scratch-based graphical programming software.
- Modify EV3 robot to carry loads of varying weights.
- Program EV3 robot.
- Collect data on the time it takes for EV3 to travel a square-shaped distance as its carrying three different loads, e.g., 500 grams, 1 kilogram, and 1.5 kilograms.
- Use data collected to calculate the robot's velocity, acceleration, and force.
- Plot a graph of force on the x-axis and acceleration on the y-axis using the Excel Spreadsheet program.

Pre- and post-test of physics concepts on forces and motion, pre- and post-interest survey questionnaires, and programming worksheets (**Appendix A**, **Appendix B**, and **Appendix C**) were given to participants to complete as data collection instruments. The procedure was based on a curricular subject and topic; high school physical sciences- forces and interactions (as outlined in the next generation science standards) (NGSS Lead States, 2013). In the entirety of this study, the implementation of best practices demonstrated in the literature by various educational robotics researchers involved one robot kit for a small team of participants were adhered to (Ferrarelli & Iocchi, 2021).

The questions used for the pre- and post-test were sourced from the literature on Newtonian physics-related research. Austin (2021), in a study done during an introductory physics course, had the students perform a simple in-class acceleration measurement to investigate the accuracy of Newton's second law of motion. Participating in students' measured quantities and calculations guided the framing of questions 2, 3, 4, 5, 7, and 8 in the pre- and post-test. In their research study aimed at making an alternative design for a physics lesson about Newton's second law using understanding by design (UbD), Setyanto et al. (2018) found that UbD can be used as an alternative design to teach Newton's second law. The questions used in their research informed the framing of the test questions. The interest questionnaire, which consists of nine-item statements, was adapted from Jaipal-Jamani and Angeli's (2017) research and modified to suit the purpose of this research study. The first author created the programming worksheet (**Appendix C**). The programming worksheet comprises four programming subtasks that measure participants' computational skills. The design of the worksheets was based on instructional design principles about how to teach complex technical skills, which describes methods and techniques for analyzing knowledge that is helpful to the performance of non-recurrent complex cognitive skills (van Merriënboer, 1997). **Figure 1** shows participants' engagements in learning activity.

Data Collection and Analysis

Data was collected using one-group 10 pre- and post-test questions (**Appendix A**) to measure participants' understanding of Newtonian physics concepts. The pre- and post-interest questionnaires (**Appendix B**) were designed to elicit from participants how studying a science concept influences their interest in learning with robotic devices. To measure participants' interest pre- and post-lesson, a Likert scale ranging from strongly agree to strongly disagree was used to gauge participants' computational thinking skills; a worksheet of four tasks on programming a LEGO EV3 robot was given to participants to complete during the research activity (**Appendix C**). The combination of diverse data collection instruments (questionnaires, pre- and post-tests, and worksheets) facilitated the collection of relevant data to assist in answering the research questions. The varied data collection instruments also

Figure 1. Participants engaged in learning activity (Source: Authors' own elaboration)

Table 1. Descriptive statistics of electrostatics knowledge from pre- & post-test scores

Variable	n	Mean	Standard deviation	Variance	Skewness
Pre-test	74	5.26	1.21	1.45	.45
Post-test	74	8.73	1.13	1.27	-1.16

Table 2. Paired samples test

	t	df	p (one-sided)	p (two-sided)	Cohen's d
Pre-/post-test	-19.22	73	<.001	<.001	1.55

eliminated the prospect of mono-method bias, which can threaten the validity, such as in research that employs a single data collection method (Field, 2018; Nelson & Cohn, 2015).

The pre- and post-test data, interest questionnaires, and programming worksheets were all coded in an Excel Spreadsheet. The first author graded the pre- and post-tests out of a total score of 10. The scores from the tests, Likert scale scores, and grading of the programming worksheet were imported into SPSS statistical software (version 28) for quantitative analysis. Test scores were evaluated using a paired-sample t-test to check the statistical significance between the pre- and post-test means. A paired sample test was run on the interest questionnaire items, and the test statistics and effect sizes were recorded. A repeated measures ANOVA (Johnson & Christensen, 2016) was performed to compare the effect of the programming tasks on computational thinking.

The objective to comprehensively answer research question one led the authors to use a repeated measures design to test the following hypotheses:

Hypothesis 1 (H1). Programming tasks do not affect computational thinking.

Hypothesis 2 (H2). Programming tasks affect computational thinking.

The statistical tests provided data on mean, standard deviation, t-statistic, p-value, and Cohen's d effect size.

RESULTS

The researchers found that LEGO EV3 robots positively affected participants' understanding of Newton's second law of motion and their interest in pursuing STEM education and careers. Also, the results revealed that participants were more confident and willing to learn with robotic devices after the activity than prior to engaging in LEGO EV3 robotics activity. The repeated measures ANOVA analysis showed that the scaffolded programming tasks affected participants' computational thinking skills.

A paired samples test (Field, 2018) was conducted to compare pre- and post-test scores on participants' understanding of Newtonian physics concepts. **Table 1** provides the means and standard deviations and shows growth in Newtonian physics knowledge from the pre-test to the post-test. Results indicated a statistically significant difference between pre-test scores (mean [M]=5.26, standard deviation [SD]=1.21) and post-test scores (M=8.73, SD=1.13).

From **Table 2**, the paired samples statistics show $t(73)=-19.22$, $p<0.001$. Cohen's d effect size was 1.55; a large effect size between the pre- and post-test scores shows how noticeably different the results are for the pre- and post-tests.

Figure 2 depicts boxplot of pre- and post-test means.

The statistics of the interest questionnaire administered pre- and post-instruction are displayed in **Figure 3** and **Figure 4**. In general, the results from the stacked bar graphs show participants responded in large percentages that they agreed and strongly agreed on post-questionnaire items as opposed to the pre-questionnaire survey.

Paired sample statistics were carried out for the interest questionnaire items.

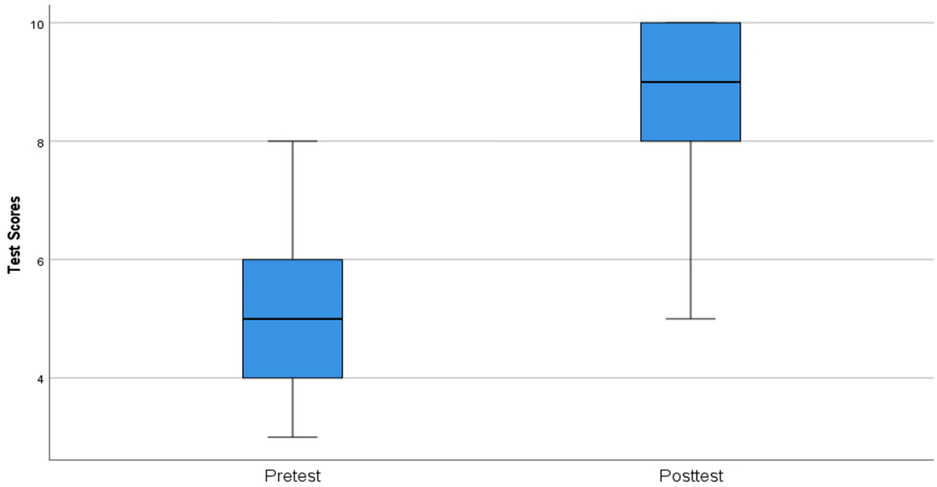

Figure 2. Boxplot of pre- & post-test means (Source: Authors' own elaboration)

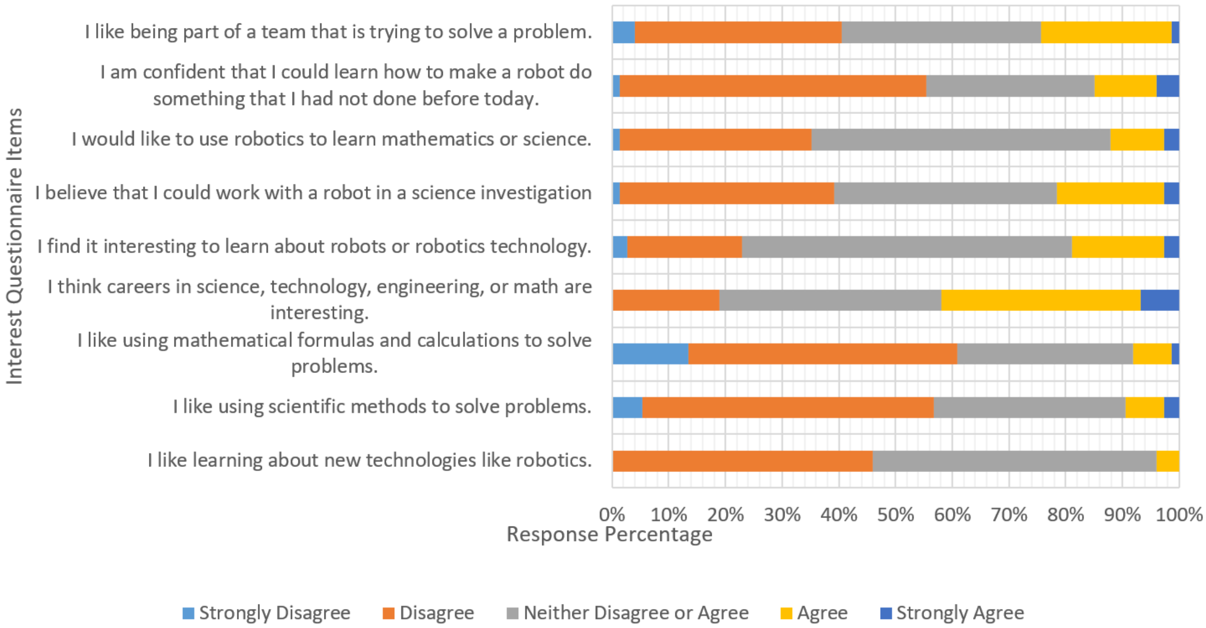

Figure 3. Bar chart of pre-interest items (Source: Authors' own elaboration)

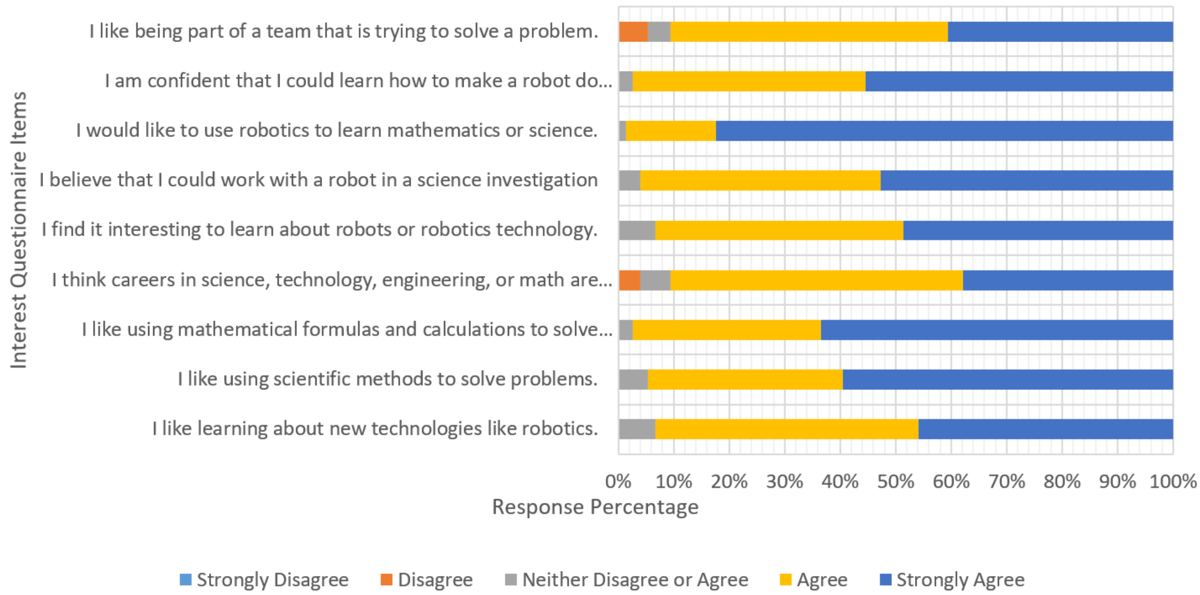

Figure 4. Bar chart of post-interest items (Source: Authors' own elaboration)

Table 3. Paired sample statistics for the interest questionnaire items

Questionnaire items	n	t-test	df	p	Cohen's d
I like learning about new technologies like robotics.	74	-17.89	73	<.001	.871
I like using scientific methods to solve problems.	74	-18.91	73	<.001	.928
I like using mathematical formulas and calculations to solve problems.	74	-18.25	73	<.001	1.057
I think careers in science, technology, engineering, or math are interesting.	74	-7.51	73	<.001	1.084
I find it interesting to learn about robots or robotics technology.	74	-13.61	73	<.001	.940
I believe that I could work with a robot in a science investigation	74	-17.38	73	<.001	.829
I would like to use robotics to learn mathematics or science	74	-23.00	73	<.001	.758
I am confident I could learn how to make a robot do something I had not done before.	74	-15.25	73	<.001	1.075
I like being part of a team that is trying to solve a problem.	74	-10.83	73	<.001	1.148

Table 4. Repeated measures ANOVA

Source of variation	Sum of squares	df	Mean square	F	p
Between-subjects	22,300.113	1	22,300.113	4,157.557	<.001*
Within-subjects	12,639.414	2	6,319.707	1,432.909	<.001*
Error	391.554	73	5.364		

Note. *Significant at p<0.05

Table 5. Mauchly's test of sphericity

Within-subjects effect	Mauchly's W	Approximated Chi-square	df	p	Epsilon	
					Greenhouse Geisser	Huynh-Feldt
Computational thinking	.817	14.58	2	<.001	.845	.863

Table 3 shows the results of the statistical analysis's substantive significance (effect size) and statistical significance (p-value).

The significant effect sizes showed evidence of the absence of type II or β error, which is the probability of concluding there is no effect when one exists (Shreffler & Huecker, 2022). Thus, to a particular degree of certainty, it can be surmised that this study has sufficient power to support or refute null hypothesis: programming tasks do not affect computational thinking.

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A repeated measures ANOVA was performed to compare the effect of programming tasks on computational thinking (**Table 4**).

Mauchly's test indicated that the assumption had been violated for the main effects of computational thinking, $\chi^2(2)=14.58$, $p<.001$ (**Table 5**). Therefore, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity, $\varepsilon=.85$. From **Table 5**, it can be seen that there was a statistically significant difference in computational thinking between at least two intervals, $F(1, 2)=4157.56$, $p=<.001$.

DISCUSSION

The findings from this study are analyzed and discussed in relation to the distinctive circumstances of this LEGO robot-based integrated STEM study, and its implications for secondary science education are also pointed out. The results show how a LEGO EV3 robotic device affects the teaching and learning of Newton's second law of motion. From the paired samples test on the pre- and post-tests, the authors infer that the learning with EV3 robots affected the participants' understanding of the Newtonian physics concepts tested. Participants' average test scores improved with a positive mean difference of 3.47. The paired samples t-test results also confirm that the participants' knowledge of Newton's second law increased from pre to post-test. An increase in Newtonian second law knowledge surmises a promotion of participants' conceptual understanding of the topic. This finding agrees with other findings in the literature (Athanasiou et al., 2019; Badeleh, 2021; Benitti, 2012; Ferrarelli & Iocchi, 2021), which is that robotics-based instruction promotes conceptual understanding of science concepts; in this case, Newtonian second law of motion concepts.

In addition to investigating the participants' conceptual understanding of Newtonian second law concepts, this research also looked at the effect of the pedagogical approach of using simple programming tasks to build computational thinking skills. Putting participants in a situation, where they had to write new programs in Scratch, test them, debug them, and rewrite them over to make sure they worked, a process repeated a number of times, helped them hone the skills needed to develop computational thinking skills such as problem formulation, abstraction, problem reformulation and decomposition (Palts & Pedaste, 2020). In answering the first research question, repeated measure ANOVA analysis indicated that scaffolded programming tasks affected participants' computational thinking skills. Therefore, the null hypothesis (*programming tasks do not affect computational thinking*) is rejected because participants' computational thinking was affected by their usage of Scratch Programming software in manipulating LEGO EV3 devices.

In investigating the effect of EV3 robots on participants' interest in learning physical science concepts, the descriptive statistics from the pre- and post-interest questionnaire showed a shift in perception after the activity. The Newtonian physics learning activity took place with minor instructions from the lead author as the instructor. This approach gave the participating students the freedom to construct a qualitative understanding of the relationship between the forces acting on an object and its motion and form their own opinions about the effect of the robotic device on their learning. The hands-on nature of the research setup and the cognitive undertaking that participants were charged with in building a LEGO EV3 robot from multiple parts was not just for establishing an in-depth conceptual understanding of the second law but also to make them think about how the robotics activity impacted their learning decisions.

Consistent with findings in the literature (Badeleh, 2021; Chen & Chang, 2018; Jaipal-Jamani & Angeli, 2017), the results of this research also showed that interest in learning with robotic technologies, the pursuit of STEM careers and confidence in solving mathematics and science problems do increase after engagement in a robotics learning activity.

The research literature on teaching physics concepts with robotics has primarily focused on formal school settings (Afari & Khine, 2017; Austin, 2021; Badeleh, 2021; Benitti, 2012; Ferrarelli & Iocchi, 2021; Ntemngwa & Oliver, 2018) and students enrolled in STEM disciplines (Rocker Yoel et al., 2020; Sullivan & Heffernan, 2016). The results of this research extend the literature on using robotics in teaching physics concepts by providing empirical data on teenagers' learning forces and motion in an after-school learning program. This research extends the study done by Jaipal-Jamani and Angeli (2017), though they investigated computational thinking skills and the effect of robotics on content knowledge, their research was limited to learning gear concepts.

CONCLUSIONS

The authors posit that teaching Newton's second law of motion using LEGO EV3 robots positively impacted participants' conceptual understanding, computational thinking skills, and desire to pursue STEM careers. This research study investigated the effect of robotics-based learning activity on understanding Newton's second law of motion. The objective was to find the connection between learning with a LEGO EV3 robot and the conceptual understanding of Newtonian physics. Data was collected through a ten-question pre- and post-test to assess participants' understanding of basic concepts in Newtonian physics. A pre- and post-interest questionnaire was used to gather information on how studying a science concept with a robotic device affected interest in pursuing STEM education and careers. To measure participants' computational thinking skills, a worksheet on programming tasks was given to participants to complete. The multiple data collection instruments (questionnaires, pre- and post-tests, and worksheet) played a significant role in answering the research questions effectively.

The data revealed that LEGO EV3 robots positively affected participants' interest in learning Newton's second law of motion. In addition, the descriptive analyses from the pre- and post-interest questionnaire revealed that participants were more confident and willing to learn robotics after the activity than prior to it. This study's findings support prior research on learning with robotics (Afari & Khine, 2017; Benitti, 2012; Ferrarelli & Iocchi, 2021). This research study moves STEM and robotics-based education fields forward by providing more evidence on the effect of teaching and learning with robotic devices as far as after-school learning programs are concerned.

One potential limitation of this study is the one-group pre- and post-test design, which makes it difficult to infer any causal relationship between the robotics-based instruction and participants' increased understanding of Newton's second law of motion. Also, the lack of a validated survey instrument and the approach to scoring the test (done solely by the lead author) may raise issues of reliability and internal validity regarding the findings.

Future research should explore the effect of LEGO EV3 robots on learning other science concepts, such as the Doppler effect, energy transfer, and inertia, through the construction and programming of robots.

This research study showed that when teenagers in high school were taught Newton's second law of motion with a LEGO EV3 robot, their conceptual understanding, computational skills, and interest in pursuing STEM education and careers.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: PRE- & POST-INTEREST QUESTIONNAIRE

Identification Code: ………………………………………….. Date: …………………………………………..

The statements below are designed to elicit information about your interest in learning with robotic devices. Please read the following statements and make an "**X**" mark under the column which best describes your opinion (SD: Strongly disagree; D: Disagree; NAD: Neither agree nor disagree; A: Agree; & SA: Strongly agree).

Table A1.

Statement	SD	D	NAD	A	SA
I like learning about new technologies like robotics.					
I like using scientific methods to solve problems.					
I like using mathematical formulas and calculations to solve problems.					
I think careers in science, technology, engineering, or math are interesting.					
I find it interesting to learn about robots or robotics technology.					
I believe that I could work with a robot in a science investigation					
I would like to use robotics to learn mathematics or science.					
I am confident I could learn how to make a robot do something I had not done before.					
I like being part of a team that is trying to solve a problem.					

Note. Adapted from Jaipal-Jamani and Angeli (2017) & modified to suit purpose of this research study

APPENDIX B: PRE- & POST-TEST QUESTIONS

Guided by NGSS performance expectations: HS-PS2-1, HS-PS2.A.1, HS-PS2.A, & HS-PS2 (NGSS Lead States, 2013). Modified questions from force concept inventory test.

Identification Code: ………………………………………….. Date: …………………………………………..

Instructions

Answer all questions in the spaces provided in the question paper. Read the questions carefully and answer according to the given instructions.

1. **QUESTION 1:** Newton's second law of motion gives
   A. magnitude of force
   B. velocity of the object
   C. concept of inertia
   D. all the above

2. **QUESTION 2:** Newton's second law gives a measure of
   A. acceleration
   B. force
   C. momentum
   D. angular momentum

3. **QUESTION 3:** Which of the following mathematically represents Newton's second law of motion?
   A. v=u+at
   B. F=ma
   C. F=m/a
   D. $S=ut+(1/2)at^2$

4. **QUESTION 4:** The incorrect statement about Newton's second law of motion is that
   A. it provides a measure of inertia.
   B. it provides a measure of force.
   C. it relates to force and acceleration.
   D. it relates momentum and force.

5. **QUESTION 5:** One Newton is equivalent to which of the following?
   A. $kg \times m/s^2$
   B. N/kg
   C. m/s/s
   D. kg×m/s

6. **QUESTION 6:** Determine the accelerations that result when a 12-N net force is applied to a 3-kg object.
   A. 6 m/s^2
   B. 4.5 m/s
   C. 4 m/s^2
   D. 36 m/s^2

7. **QUESTION 7:** Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is halved, then what is the new acceleration of the sled?
   A. 30 m/s^2
   B. 12 m/s^2
   C. 6 m/s^2
   D. 18 m/s^2

8. **QUESTION 8:** Which of the following statements best describes Newton's second law of motion?
   A. Whenever one object exerts a force on another object, the second object exerts an equal and opposite force on the first.
   B. An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.
   C. An object in motion is experiencing equal forces and will accelerate in the direction of these forces.
   D. The acceleration of an object depends on the mass of the object and the amount of force applied.

9. **QUESTION 9:** A toy car pushes a stationary golf ball with F Newtons of force. What other information do we need to find the golf ball's acceleration?
   A. Work of pushing the box
   B. Acceleration
   C. Velocity
   D. Mass

10. **QUESTION 10:** If the same force is applied to a 3 kg mass and a 15 kg mass, which of the following will happen?
   A. Both masses will accelerate at the same rate.
   B. The 3 kg mass will accelerate 5 times faster than the 15 kg mass.
   C. The 15 kg mass will accelerate 5 times faster than the 3 kg mass.
   D. None of the above will happen.

APPENDIX C: PROGRAMMING WORKSHEET

Identification Code: ………………………………………….. Date: …………………………………………..

1. Generate a program using LEGO MINDSTORMS education EV3 classroom application. The program must make your EV3 robot move forward by 5 wheel turns, turn right, move by 3 wheel turns, and then stop. Take a screenshot of your program and paste it below.

2. Generate a program using LEGO MINDSTORMS education EV3 classroom application. The program must make your EV3 robot navigate a square movement of 3 wheel turns each, then stop. Take a screenshot/print screen of your program and paste it below.

3. Generate a program using LEGO MINDSTORMS education EV3 classroom application. The program must make your EV3 robot move in a straight line using the gyro sensor for 5 wheel turns and then stop. Take a screenshot/print screen of your program and paste it below.

4. Generate a program using LEGO MINDSTORMS education EV3 classroom application. The program must make your EV3 robot follow a color line/tape using the color sensor for 3 wheel turns, then stop. Take a screenshot/print screen of your program and paste it below.