

The Effect of Employing Instructional Robots in Acquiring of Scientific Concepts in Physics for Tenth Grade Students in Jordan

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Abstract:

This study aimed at investigating the effect of employing instructional robots (IR) in acquiring of scientific concepts in Physics topic for tenth grade students, the study followed the quasi-experimental design where the study sample encompassed (40) students studying in a private school in Amman. The sample was randomly divided into two groups; control group (n=20) who studied using conventional method, and experimental group of (n=20) who studied using the instructional robot. The researchers developed a paradigm, which included several activities that employed IR to assist instructors while teaching Physics in international programs. Moreover, the researchers developed an instrument to measure the acquiring of the scientific concepts. The results of the study showed that there were statistically significant differences in the mean performance between the two groups in favor of the experimental group. The study recommended the need to use IR in teaching scientific concepts in Physics topic.

Keywords: instructional robots, scientific concepts, tenth grade students, Physics topic.

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أثر توظيف الروبوتات التعليمية في اكتساب المفاهيم العلمية في مادة الفيزياء لدى طلبة الصف العاشر في الأردن

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ملخص:

هدفت هذه الدراسة إلى استقصاء أثر توظيف الروبوتات التعليمية في اكتساب المفاهيم العلمية في مادة الفيزياء لدى طلبة الصف العاشر، واستخدمت الدراسة المنهج شبه التجريبي، إذ تكونت عينة الدراسة من (40) طالبا وطالبة يدرسون في إحدى المدارس الخاصة في عمان. تم تقسيم العينة بشكل عشوائي إلى مجموعتين: إحداها ضابطة، وتكونت من (20) طالبا وطالبة درسوا بالطريقة الاعتيادية، والأخرى تجريبية وتكونت من (20) طالبا وطالبة درسوا باستخدام الروبوت التعليمي. طور الباحثان أنموذجا يوظف الروبوتات التعليمية لمساعدة المعلمين في أثناء تدريس الفيزياء، التي تدرس ضمن أقسام البرامج الدولية. كما قام الباحثان بتطوير أداة لقياس مدى اكتساب الطلبة للمفاهيم العلمية. وقد أظهرت نتائج الدراسة وجود فروق ذات دلالة إحصائية في متوسط الأداء بين مجموعتي الدراسة ولصالح المجموعة التجريبية، و أوصت الدراسة بضرورة استخدام الروبوتات التعليمية في تدريس المفاهيم العلمية في مادة الفيزياء. **الكلمات المفتاحية:** الروبوتات التعليمية، المفاهيم العلمية، طلبة الصف العاشر الأساسي، مادة الفيزياء.

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Introduction

The technology use is overriding in this era and in all aspects of life. The exponential growth in this technology drives societies to strive to keep pace with it for the sake of being vying and successful. Education, as well as its practices are the heart of this concern, therefore countries are prioritizing developing their educational systems and practices constantly to prepare learners to a new world of unexpected levels of tech-related conditions and issues. Moreover, there have been a loud and wide call among various educational bodies regarding the importance of developing today's learners to become Science Technology Engineering and Math (STEM)-capable workforce of tomorrow for the sake of competitiveness and prosperity (Kapila and You, 2017).

From the early constructivist learning theories of Piaget, in the sixties of the last century, to the constructionism theories of Papert in the eighties, to today's multitude of robotics advancements, there have been a plethora of educational didactics proposed and proved to enhance students' learning through the use of IR (Altin and Pedaste, 2013). IR are electronic devices used within instruction to help learners build knowledge in design, programing, and understand STEM disciplines.

IR has been captivating attention since the eighties owing to its high potentials examined in many subjects generally and in STEM disciplines particularly (Uslu, et al., 2022). IR are strongly believed to ignite learners' interest, motivation, and attitudes toward STEM disciplines and proved to enhance their thinking skills such as computational thinking (Bedar & Al-Shboul, 2020; Ioannou, Makridou, 2018; Altin & Pedaste, 2013; Barker, et al. 2015). Besides, many studies have shown that IR use had positive effect on learning experiences, cognitive skills such as visual-spatial working memory, and cooperative learning (D'Amico and Guastella, 2020). Moreover, many pedagogical approaches that promote collaborative learning and learner-centered instruction such as: discovery learning, project-based learning, problem-based learning, learning by design, and hands-on learning can be applied with the aid of IR (Kapila and you, 2017; Alimisis and Boulougaris, 2014; Altin and Pedaste, 2013).

According to (Ferrarelli & Iocchi, 2021), IR has been applied to improve student's learning abilities in different disciplines including Physics, because it allows learners to design, implement, and visualize Physics concepts, thus using the robot as a cognitive tool or mindtool. Within this context, IR is an educational tool used to reorganize the mental representations among learners rather than increasing their efficiency in

achieving a task. Also, this tool can help learners to perform tasks at a higher level of cognition. On the other hand, the pioneer of educational technology as cognitive tool, (Jonassen, 1996), concluded that cognitive tools showed the potential to open a path to constructivist learning and transferable knowledge in educational systems dominated by routinized practice and reproduction of given information.

Physics is the study of matter and natural events, and is based mostly on empirical observations and quantitative measurements. The knowledge of Physics is needed in the fields of STEM, medicine, nursing, pharmacy, agriculture, engineering and related disciplines. It is the topic that requires the processes of science to understand the theoretical concepts and their applications in solving practical problems encountered in everyday life (Ehinder, et al., 2014). The attainment of scientific concepts is not easy, especially in Physics topic. Many students find this branch of science difficult and hard to understand in many of its subtopics. This would cause low motivation levels, negative attitudes towards Physics learning, and poorer achievement, especially, when the conventional method of teaching and routinized practices are employed in the classroom (Ariswan and Ngadas, 2019).

Hence, this study intended to examine and measure the effect of using IR as cognitive tool in enhancing students' asquiring of scientific concepts in Physics course. Since the desired educative effects of cognitive tools cannot be expected automatically (Ferrarelli & Iocchi, 2021), the researchers attempted to design the desired educative effects in the cognitive tool (IR) and in suitable context. Below is a brief presentation of related literature in which robotics effect on learners understanding, skills acquisition and achievement were examined.

Igel, et al. (2012) conducted a study that examined students' conceptual understanding using robotics activities in schools at Central Brooklyn in the United States. They assessed the effectiveness of an after-school program in implementing hands-on robotics activities. The researchers considered robotics as a tool for facilitating one group of (44) Tenth grade learners in understanding math concepts outside of a conventional classroom setting. They designed three interactive, team-based LEGO activities. Based on data collected in pre- and post-evaluation surveys, the findings demonstrated that learners improved their conceptual understanding of the content after participating in the activity.

Alimisis and Boulougaris (2014) conducted a study in Greece that

investigated the effect of using of IR (NXT type) on graphing skills and interpretation among high school students' one group of (20) individuals who were taught using conventional method prior to treatment. They used a special pencil and paper exam to test students' understanding of position-time graph from graphs developed by the IR device. Their results showed that there was a positive learning impact on learners regarding graphing skills and interpretation which in turn is expected to foster better learning of related Physics concepts

Abdullah and Hamdi (2018) conducted a research study in Jordan to investigate the effect of IR (called EV3 type) on enhancing achievement and interaction of learners (8th grade) in information technology topic. The study was conducted in a private school in Amman. The sample consisted of (44) students who were divided into two groups. The experimental group of (22) learners learned using IR kit and the control group of (22) learners learned using conventional method. The researchers used achievement test and note card to record reactions and interactions of students during the treatment. Their results showed statistically significant differences in the development of classroom interaction and in the achievement in information technology topic.

D'Amico and Guastella (2020) conducted a research in Italy that aimed at evaluating the effectiveness of the IR in learning concepts related to Geography and Physics. They focused on Motion topics in Physics and issues related to Geography for high school students. The control group (13 student) studied without robots and the experimental group (12 students) studies with the cooperative aid of robots in a high school in Italy. They used written assignment as Physics test tool written by teachers and a questionnaire set by them. As expected, the results indicated that students in the experimental group had a far better understanding of concepts and higher participation to the activities than students in the control groups.

Al-Ali (2020) conducted a study to find the effect of using IR on the achievement of 9th grade students in a school in Irbid. The sample contained (66 girls). The experimental group (33) were taught using IR while the other (33) were taught conventionally. They were interested in Mechanics topic in Physics and the achievement test was put by one of the researchers with the aid of the official Physics book from the Ministry of Education in Jordan and teacher guide. The results indicated a significant difference between the two groups and in favor of the experimental group.

All studies showed evidence for the general benefits of IR as being

effective in providing impactful learning experiences. However, there appears to be a need to determine the specific benefits which have been achieved through robotics implementation in K–12 formal and informal learning settings. Thus, this study tried to highlight these specific benefits by focusing on several outcomes in the IGCSE Physics syllabus that were not investigated previously such as moment and kinetic model of matter. Moreover, this study suggests a set of activities designed in easy-to-follow way to examine the degree to which we can benefit from integrating IR in our classrooms in a specific manner. Besides, it was observed that most studies were interested in topics in ICT, mechanical skills and information technology topic. Thus, this study tried to give more comprehensive look into the possibilities that we can achieve from integrating IR in many topics in Physics other than mechanics or graphing skills.

Statement of the Problem

The integration of IR within educational practices in Physics topic in high schools is still in its infancy. Previous systematic review studies have reported the potential contribution of educational robots in schools. However, there is a growing criticism from the robotics community in recent years over the lack of empirical research on how robotics can be employed to improve student academic performance (Wang, et al., 2023). In addition, for some fields of science education such as astronomy, biochemistry and physics, robots were seldom adopted in the research design and its use as a cognitive tool or mind tool was not found (Chiu, et al., 2022).

On the other hand, constructing concepts and notions in Physics have been always a concern for teachers and educationalists. When it comes to the micro-level learning, teachers' mission tends to be even harder to tackle, and tracking student's learning pathways to ensure notion construction is a difficult target to achieve. Employment of IR can serve various purposes in enhancing learning experiences by promoting active engagement, problem-solving, and collaboration among students as active learning tools (Sisman, et al., 2022).

There are different strategies to help teachers integrate IR with solid STEM content knowledge (Doshi, et al., 2015). One of these includes supplying teachers with clear set of activities on how to integrate IR within their Physics classes. This can save their time and effort in planning and give them the chance to focus more on procedures and content delivery (Al-Ali, 2020; Al_Masaed 2020).

Despite the serious work of (D'Amico and Guastella, 2020) in teaching Physics using IR, some gaps were observed in their work. For example, IR were used to teach motion topic in Physics most of the times. In addition, their work did not state any clear paradigm or guidance for teachers to follow when they are expected to function independently.

Purpose of the Study

This study aims to develop an IR paradigm that can be used to aid teachers while delivering and teaching Physics concepts and examine the effectiveness of the suggested paradigm on the attainment of the scientific concepts among students in tenth grade.

Significance of the Study

Theoretical importance

This study may provide feedback on the effect of using IR in developing and constructing scientific concepts in Physics among high school students. Also, it adds to the endeavors made to develop a paradigm that can efficiently assist in constructing scientific concepts in Physics.

Practical importance

This study can be considered as a meaningful addition to the current suggested paradigms that can be used and employed by teachers in classrooms. The content of the activities is built to align with the learning outcomes stated in the IGCSE Physics curriculum and can also be used with other curricula such as Advanced Placement (AP) curriculum. This study uses IR to cover many of the essential Physics concepts such as momentum and thermal Physics topics. This allows teachers to utilize time and effort efficiently since all activities are outlined with high degree of clarity, and minimum skills level in ICT. This paradigm is hoped to be adopted in the future by the ministry of education or private schools in Jordan or in the Arab countries or foreign educational bodies, such Cambridge International Examination (CIE) in UK given most of the Physics concepts in the Arab and foreign curricula are similar.

Questions of the Study

This study tries to answer the following question:

Are there any significant differences at ($\alpha=0.05$) between the performance means of the experimental group and the control group of 10th grade students in the scientific concepts attainment test (SCAT) in Physics due to the teaching methods (conventional method or using the suggested IR paradigm)?

Operational Definitions of Terms

The Proposed Paradigm

The proposed paradigm is a set of activities aligned with the outcomes stated in the Physics textbooks that are taught in international schools in Jordan, covering mainly the International General Certificate of Secondary Education (IGCSE) Physics curricula. In the paradigm there would be a clear set of steps and procedures that enable general science teacher to follow with least amount of programming skills required. In each activity there would be a direct refer to the outcome it is covering, as well as, the Math requirement and the ICT opportunity that appears in the activity.

Instructional Robotics

They are defined as learning tools or entities that can be designed, built, and programmed by individuals using very simple programming language (Alimisis and Sapounidis, 2021). Such programming language uses an array of drag and drop blocks that are uploaded to the entity; thus, it can move and perform tasks based on those set of instructions (blocks). Operationally, IR is defined as a tool used in the learning environment to aid in co-constructing scientific concepts for learners in high school.

Scientific Concepts

Chu, et al. (2020) proposed a framework for defining scientific concepts within five common features that teachers need to consider during instruction. Those features of definitions are Object/system, nature/characteristics, cause/effect, mathematical expression/equation, and condition/reference of frame. Operationally, scientific concepts are defined as the concepts mentioned explicitly in the IGCSE physics syllabus such as: vectors and scalars, dot and cross product, vector addition, speed, evaporation, kinetic model of matter, balance, ultrasound, echolocation, and atom. According to the syllabus, scientific concepts are required to be defined usually by using one, two or three features only. For example, in defining weight the syllabus focuses on as cause/effect and nature/characteristic. Thus, weight is defined as the pull of gravity and is calculated using $W=mg$.

Limitations and Delimitations of the Study

- Spatial limits: This study was limited to a private school in Amman and among 10th grade students.
- Time limits: This study was conducted in the second semester of the school year 2022/2023

- Human Determinant: This study was limited to students of age (15-16) years in an international department in a private school in Amman.
- Results are determined by the extent of the psychometric properties of the study measuring tool.

Methods and Procedures

Design of the Study and Sampling

The study followed the quasi-experimental methodology to examine the effect of IR on the attainment of scientific concepts in Physics. The participants of the study were (40) students aged (15-16) at the international sections in private schools in Jordan who study the (IGCSE) Physics curriculum. There participants were randomly distributed into two groups; control and experimental. The control group consisted of (20) students who were taught using conventional method of teaching, while the experimental group consisted of (20) students who were taught using IR paradigm.

Instruments of the study

First: Scientific Concepts Attainment Test (SCAT) instrument

The researchers developed this instrument which was used as a pre-and post-test to measure the level of the attainment of the scientific concepts of interest. It was a multiple-choice test, with a total of (30) items derived from the IGCSE Physics syllabus. A table of specifications was prepared for this test. The test duration was (30) minutes.

Second: IR paradigm

This included a set of activities that are designed, prepared and developed by the researcher. These are strongly related and rooted from the IGCSE Physics syllabus in different sub-topics such as: general measurements, motion, moments, momentum, kinetic model of matter, atomic structure, waves. The researcher will focus on two units: moment and kinetic model of matter. The robot used belongs to LEGO Mindstorms group, which includes: hub, two motors, wires, and 3rd generation (advanced) LEGO bricks such as axles, connectors, pins, beams and others.

Validity of the SCAT Instrument

- Content Validity

At first, the researcher built the SCAT based on the relevant literature. Then, it was validated by (7) experts in curriculum and instruction as well as educational technology and psychology faculty members (content

validity). Also, experts in IR were consulted. They were asked to verify the consistency, comprehensiveness accuracy and appropriateness of the items in the test. The IR paradigm was also assessed by the same panel of referees. All notes by the panel were taken under consideration. All instruments were implemented after the referees' agreement. It is worth mentioning that the SCAT instrument was derived from the previously-developed question bank which is prepared by the Cambridge International Examination board in United Kingdom.

- **Table of Specifications**

Teachers are likely unable to measure every topic or objective or ask every question they might wish to ask, so, a table of specifications allows teachers to construct a test which focuses on the key areas and weights those different areas based on their importance and provides the teacher with evidence that it has content validity (Chase,1999).

Reliability of the SCAT Instrument

The researcher applied the test-retest reliability method to the test where Pearson correlation coefficient was calculated between the scores achieved for the sample of (20) students in a two application times. The calculated Pearson correlation coefficient was (0.97).

Variables of the Study

- 1. The independent variable:** the teaching method (conventional method and using IR paradigm)
- 2. The dependent variables:** the attainment of scientific concepts.

The Instructional Methods of the Study

1. The conventional method

This method focused mainly on the use of the textbook Physics. It used to teacher-lead instruction with question-answer based method. Students interacted with the textbook, notebooks, calculators and among themselves, as well as with the teacher. This method was used with the control group. The e-textbook was used during instruction.

2. The IR paradigm method

This method used the proposed IR paradigm developed by the researcher. In the paradigm a set of activities were conducted. The activities fully covered the lessons in the unit titled "Turning effects of forces", and partially covered the unit titled "The kinetic model of matter". Students used LEGO bricks such as connectors, beams, angular beams, bush, and axles to build their own models by following building

instructions prepared and developed by the researcher. In each activity, there were several explorative questions and calculations the student needs to answer and calculate based on interacting with the model they built. In some parts the students are asked to modify their LEGO models based on certain requirements.

Statistical Analysis and Study Design

To answer the question of the study, the Statistical Package for the Social Sciences (SPSS) was used to analyze the data collected. Means, standard deviation, as well as, one-way Analysis of Covariance (ANCOVA) were calculated.

Results Concerning Study Question and its Discussion

Are there any significant differences at ($\alpha=0.05$) between the performance means of the experimental group and the control group of 10th grade students in the scientific concepts attainment test (SCAT) in Physics due to the teaching method variable (conventional method or using the suggested IR paradigm)?

To answer this question, means and standard deviations of the students' SCAT results were calculated. Table (1) below shows the results.

Table (1): Arithmetic Means and Standard Deviations of the Students Responses in the Pre-test and Post-test of SCAT Instrument

Group	Pre-Test		Post-Test		N
	Mean	Std. Deviation	Mean	Std. Deviation	
Experimental	16.1	5.7	20.6	5.5	20
Control	12.1	5.5	13.6	5.8	20
Total	14.1	5.9	17.1	6.6	40

Table (1) above showed that there were deceptive differences in the means and standard deviations between the two groups of the study on the pre and posttest of the SCAT instrument. The table above also shows that the means for the experimental group students who studied using the IR were higher and equal to (20.6), while the arithmetic means for the control group students who studied using the conventional method were lower and equal to (13.6).

To decide whether these differences were statistically significant or not at a level of ($\alpha=0.05$), the one-way ANCOVA analysis was performed as shown in Table (2) below:

Table (2): One-Way ANCOVA Analysis on the post-test of SCAT Instrument

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
SCAT-Pre test	408.9	1	408.9	18.5	0.00	0.33
Group	190.4	1	190.4	8.6	0.01	0.19
Error	816.7	37	22.1			
Corrected Total	1715.6	39				

($\alpha=0.05$)

Table (2) above shows that the value of “F” was (8.6) on the SCAT posttest and this value is related to significance level that equals (0.01) at ($\alpha \leq 0.05$), which means that there are statistically significant differences at the level of significance ($\alpha = 0.05$) in the attainment of the scientific concepts in Physics among students aged (15-16) according to the teaching method (teaching using the conventional method vs teaching using IR method).

In order to find out in favor of who the difference was, the adjusted arithmetic mean of the performance of the two study groups were extracted on the post-test of the SCAT instrument. The results are shown in Table (3) below.

Table (3): The adjusted arithmetic means and standard deviations of the performance of the two study groups on the SCAT post-test according to teaching method.

Group	Mean	Std. Error
Experimental	18.2	1.16
Control	15.0	1.16

Table (3) above showed that the adjusted arithmetic means for those in the experimental group were higher and was equal to (18.2) compared to the means for the control group which was (15.0). This implies that the difference was in favor of the experimental group who studies using IR with effect size of (19%). Thus, it can be inferred that there was a statistically significant effect of using IR on the attainment of science concepts among 10th grade students in private schools in Jordan.

Based on the results presented, our findings supports the fact that teaching using IR can lead to an increase in the level of interaction among the students in the experimental group, enhancing their learning process, and deepen their understanding of the learning content, which contributed to a significant increase in the attainment test (SCAT). Moreover, this method of teaching could have provided stimulating and motivating

elements for learning which amplified the learners' levels of motivation and as a result they were able to interact and understand scientific concepts way better than the learners in the control group.

Besides, teaching using IR a had positive effect on learning experiences, cognitive skills such as visual-spatial working memory, and cooperative learning (D'Amico and Guastella, 2020), this made the learners better attain Physics concepts which was observed in their performance during the activities in the clockwise and anticlockwise concepts in the moment lesson, and in the distinguishing properties of the states of matter lesson, as well as the diffusion (spread) of solid sugar crystal in liquid water example. Learners in the experimental group were better able to recall beam definition and pivot positioning as well as movement of the LEGO beam, this was demonstrated in their SCAT responses. We can conclude that IR use in teaching helps learners in enhancing their visual-spatial cognitive skills and visualize Physics concepts which leads to better learning.

Moreover, it was clearly noticeable that students in the experimental group attained the scientific concepts better and faster than those in the control group. This was demonstrated by their written responses in the activities in the summery part where they wrote their own definitions and conclusions using the correct scientific terms in an organized manner and they wrote fully linked sentences. The following are answers by students in the experimental group and control group for the question "why do different substances have different boiling points?"

Student E (experimental): "because each substance has different amount of bonding forces"

Student C (Control): "because different separation of particles results in higher levels of boiling points"

The answer of Student E is correct, short and comprehensive while the answer of Student C lacks accuracy and alignment.

On the other hand, some mathematical skills that are crucial to Physics such as proportionality were better understood and grasped by the students who studied with the use of IR. For example, the students were able to mathematically relate the amount of the load attached to the amount of the resulted moment. Some student noted that the LEGO beam tips down faster as load is increased, and these ideas are very crucial to comprehend the moment concept and factors affecting moment according to the Physics syllabus.

According to Dale's Cone of Experience (Davis & Summers, 2015),

the more concrete experience is linked to learner “doing”. This also may explain the higher scores the students gained, because using LEGO bricks in model building helped them in experiencing meaningful learning and retaining information. The results of this study agreed with many results such as (Igel, et al., 2012; Alimisis and Boulougaris, 2014; D’Amico and Guastella, 2020; Alali and Alhersh, 2020). Those studies showed that there was a positive effect of IR on students’ skills in mathematics, science, and physics.

Conclusions

There was a significant positive impact of using the proposed IR on the attainment of the scientific concepts in Physics, especially, in “Moment” unit and in “Kinetic Model of Matter” unit. The paradigm employed the advanced LEGO bricks in all of its activities. This conclusion is deduced from the results which showed that the experimental group individuals in 10th grade who studied using the IR scored (18.2) on average in the post-test SCAT which was higher than those in the control group who studied using conventional method and scored (15.0) on average.

Recommendations

In light of the study results and discussions, the researchers recommended the following:

1. Employing instructional robots in within teaching practices in a well-planned manner due to its positive effect on students’ attainment of scientific concepts.
2. Continues support and aid to teachers who are implementing such tools in sciences teaching practices.
3. Conducting other studies to evaluate the effect of IR on other science aspects such as electricity, magnetism, and waves to unfold the hidden possibilities of the IR on enhancing learning and teaching.

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