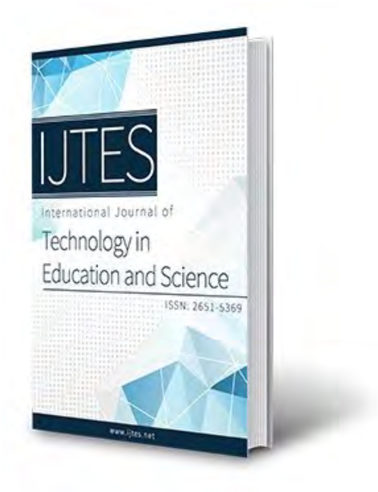

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The Effect of Educational Robotic Applications on Academic Achievement: A Meta-Analysis Study

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Abstract

In this study, it was aimed to investigate the experimental studies regarding the effect of educational robotic applications on academic achievement by the meta-analysis method. Within the scope of the research, the studies carried out on educational robotic applications were scanned from national and international databases and selected according to inclusion criteria. The sample of the study consisted of 2606 participants with 1300 in the experimental group and 1306 in the control group. In the study, the effect size values and combined effect size of each study included in the meta-analysis were calculated by using CMA. As a result of the study, it has been found that educational robotic applications have a positive and low level effect on academic achievement according to the random effects model. As a result of the analyzes conducted to reveal the publication bias status of the study, it has been found that there is no publication bias in the meta-analysis study. In addition, it has been found that the effect size of educational robotic applications on academic achievement does not change depending on the subject area and duration of application but changes depending on the sample size. In the other studies to be conducted, the effectiveness of the students in different variables such as computational thinking skills, problem solving skills, attitude, motivation, and anxiety levels can be examined in addition to the variables studied.

Introduction

Thanks to the fourth industrial revolution that emerged together with the rapid developments in the field of science and technology, it is now possible not only for computers but for all objects to communicate through the internet. With the trend of Industry 4.0, which has become the focus of attention in all areas such as production, medicine, entertainment, military, etc., cloud computing, artificial intelligence, cyber security and robotics topics have become the focus and investments and incentives aimed at these areas have been increased. The increase in the use of robots in industry and daily life has enabled the interest in the field of robotics to increase in recent years. Robots, which have recently taken their place in the field of education, are especially seen as indispensable parts of science, mathematics, engineering and science education processes. Therefore, among the studies that shape the technology of the future today, the importance and influence area of robotic coding studies have been increasing every passing day.

Briefly, it can be stated that the concept of robotics, which expresses the operation and use of robots, refers to all the processes related to the design, control, mechanical construction and programming of the robot (Kalelioglu & Keskinkilic, 2017). Robotics covers any programmable machine. As for robotic coding, it is the operation and control of robots with software created by using coding languages. In robotic coding, which basically takes engineering education as a model, mathematics, technology and science education are carried out together with engineering. Robotics coding is a program where even preschool children can design and manage a robot from start to finish. Robotics coding can be expressed as an integrated work platform that includes many disciplines such as IT, electricity, electronics, machinery, mechatronics, nanotechnology, software automation control systems, aerospace, bio-engineering, mathematics and science.

Robotics coding, which is among the requirements of the era and has developed at an extraordinary speed in the world, has become an area where students can easily learn at all levels of education from K-12 to higher education. Robotic coding training, which is effective in bringing in 21st century skills such as algorithmic thinking, critical thinking, computational thinking, communication, analysis and problem solving, has become the most popular educational trend of recent times (Korkmaz, Altun, Usta & Özkaya, 2014; Silik, 2016). Educational robotic applications enable more permanent and meaningful learning and the production of creative solutions to problems (Koc & Boyuk, 2013).

Today, there are many physically programmable robotic training sets such as LEGO Education Mindstorms (NXT, Ev3), Lego Wedo, Robbo, Ozobots, Bee-Bot, Cubelets, VEX IQ Platform Kits (Starter Kits) and Makeblock kits (mBot - STEM Educational Robot Kits) aimed at providing coding training to all age groups. These robotic sets have both text and block-based programming environments and application software. While C, Java and Python are text-based programming environments, Modkit, Enchanting, miniBlog, Robo Pro, Open Roberta, Arduino (S4A), Blocky and mBlock are block based environments (Costelha & Neves, 2018; Kalelioglu, Gulbahar, & Dogan, 2018). Many block-based programming environments are free and allow individuals to write programs without writing any code. With the development of these environments and the importance given to robotics education, many companies started to produce robotic education kits and sets.

It can be stated that educational robotics, whose basic theories are constructivism and structuralism, have three main objectives (Barak & Assal, 2018; Chaudhary, Agrawal, Sureka & Sureka, 2016; Ching et al., 2019; Ucgul & Cagiltay,2014; Yolcu, 2018):

- ✓ To bring in STEM skills.
- ✓ To develop broad learning skills such as engineering design, questioning, product-oriented thinking, analytical thinking, creative thinking, teamwork and being more willing to investigate and explore.
- ✓ To increase motivation to participate in science, mathematics and technology and to reduce psychological or cultural barriers about dealing with these fields.

There are many contributions to the inclusion of robotic coding, which has been associated with coding education in recent years in education programs. It can be said that robotic activities contribute to the development of many skills such as students' discovering their own talents, cooperative learning, learning by doing and living, developing cognitive and social skills (Costa & Fernandes, 2008; Kozima & Nakagawa, 2007). Together with the programming of the educational robot sets, they can help the concretization of abstract concepts and get an immediate output of the written program since students can directly see the effect of the robot on their actions (Ersoy, Madran & Gulbahar, 2011; Kazakoff & Bers, 2012; Ucgul, 2017). In this context, the robotic applications used in education can increase the motivation of students (Ribeiro, Costa & Rocha, 2008), contribute positively to their attitudes towards the course and programming (Kuzu & Turk, 2018) and contribute to the development of their ability to understand and solve problems with STEM skills (Ersoy, Madran & Gulbahar, 2011). Robotic activities encourage students to actively participate in the learning process by supporting their collaboration with team spirit (Chen, Quadir & Teng, 2011; Highfield, 2010).

On the other hand, while the widespread use of robotic applications and their use in education have provided many benefits in terms of the learning process and results, they also caused some problems. In particular, the fact that robotic applications are seen as a time-consuming process and that they do not have the necessary educational and technical equipment necessary in applications can be stated as the biggest obstacles in front of robotic activities. In addition, the fact that the equipment needed is costly and the pieces of the robotic training sets should be kept in the right places brings along some problems. Teachers experiencing problems in coping with the chaos occurring in the classroom environment can be stated as another problem in front of robotic applications (Alimisis, 2013; Yang, Zhao, Wu & Wang, 2008). However, when the proliferating contributions of educational robotic applications to STEM education and the experiences that the students will gain are considered, the uniqueness of educational robotic applications is understood once again.

The Purpose and Significance of the Study

Investigating the effectiveness of educational robotic applications in terms of some variables with meta-analytical effect size values may be leading in the planning and application of robotic supported education projects. Although there are many studies and applications on educational robotic applications in the literature, a meta-analysis study that allows large-scale generalizations on the subject and determines the general effect size has not been found. Therefore, it can be stated that the study to be conducted is significant in terms of combining the results of the study and revealing the overall effect size of educational robotic applications on academic achievement. It is considered that the holistic examination of the studies included in the research will make significant contributions to future researches about educational robotic applications, will provide a basis for the literature review, and will provide convenience as well as pointing the way for researchers and program developers who will conduct studies in the field. The main purpose of this study is to examine the experimental researches investigating the effect of educational robotic applications on academic achievement by using the meta-analysis method.

Method

In this study, the meta-analysis method, which is one of the research synthesis methods, was used. Meta-analysis comprises combining similar studies that are not related to each other in a particular subject or area within the scope of certain criteria and reanalyzing and reinterpreting conclusions (Lipsey & Wilson, 2001). Likewise, in this study, the meta-analysis method was used because of the intention to examine the effectiveness of educational robotic applications on academic achievement and the need to combine data obtained from numerous individual studies and make comments from a holistic perspective.

Data Collection

A detailed literature review was conducted about the topic to be able to find answers to the research questions within the scope of the study. Then, databases and search criteria were determined. International databases such as Web of Science, ERIC, SpringerLink, Science Direct, Wiley Online Library Full Collection, Google Scholar, Scopus, Taylor & Francis Online, ULAKBIM, ProQuest and the Higher Education Council National Thesis Center were utilized for access to studies. Database scanning was repeated at regular intervals to be able to reach the most up-to-date studies. The scanning process was terminated as of November 2020. Robotic terms and concepts related to achievement were used together as keywords in databases to be able to reach related researches. The PRISMA flow chart (Moher et al., 2009) showing the process of obtaining the studies included in the meta-analysis during the literature review stage is given in Figure 1.

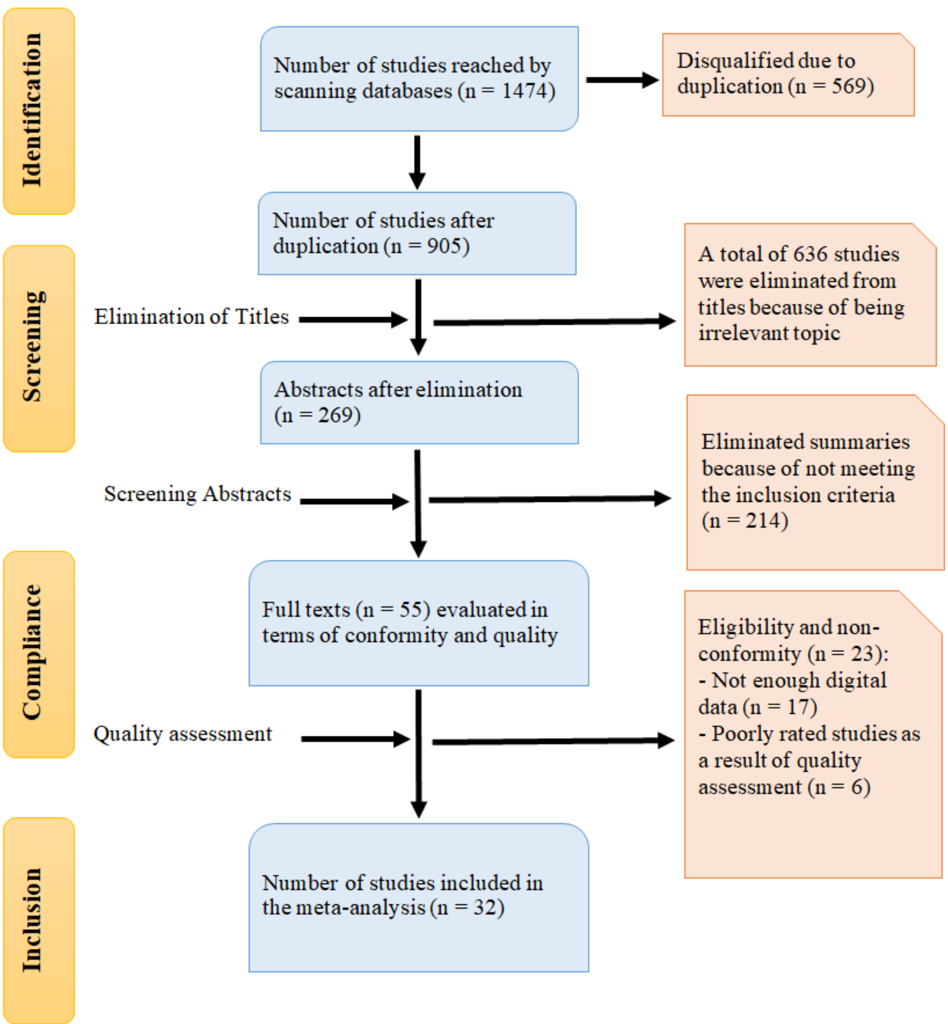

Figure 1. Flow Chart for Selection of Studies

When Figure 1 is examined, it is seen that a total of 1474 studies have been reached as a result of scanning the databases. The studies obtained as a result of detailed research were examined one by one and it was decided that 569 of the studies were duplicate and after the abstracts of 636 studies were read, they were excluded from the study because their title and content were irrelevant. 269 studies remained after this scanning. Later, after examining these studies in the context of inclusion criteria, 214 more were eliminated. When the remaining 55 studies were evaluated in terms of eligibility and quality, it was decided to exclude 23 studies that were not suitable for research. As a result, it was decided to include 32 studies meeting all criteria in meta-analysis. In addition, in some of the studies, it was seen that the academic achievement variable was included in more than one subject or different sample groups at the same time. Therefore, in accordance with the structure of the meta-analysis studies, the findings obtained in this study were analyzed and included in the study separately. In this context, 39 data obtained from 32 studies were included in the research. In all the following chapters of the research, the number of studies was expressed accordingly.

Inclusion Criteria

Determining the limits and criteria of the research is the most important and critical point of meta-analysis. In the research, the studies to be included in and excluded from the analysis are revealed within the scope of the determined criteria. The inclusion criteria of the researches to be used for the meta-analysis within the scope of the study are given in Table 1.

Table 1. Criteria for Inclusion in the Meta-analysis

Criteria	**Description**
Time interval	No time limit has been imposed since all studies related to the subject are aimed to be reached.
Suitability of the teaching method	Studies using experimental and/or quasi-experimental method models with pre-test and post-test control groups where educational robotic applications are used
Study resources	Articles published in academic journals, all published and unpublished master's and doctoral theses, books and conference proceedings
Statistical data	Numerical data required for the calculation of effect size (sample size, arithmetic mean, standard deviation)

In the studies that include the data of the academic achievement variable, data from a sample of 2606 participants, 1300 of which were in the experimental group and 1306 in the control group, were examined. The studies that will be excluded from the meta-analysis study are the theses that are not within the limits of the research, are not available due to lack of access permission, studies with qualitative data and all studies that do not contain sufficient data for analysis. In addition, since the studies of the same author and subject comprise both articles and a thesis, the thesis was included in the meta-analysis because it contains more detailed data. It was determined that some of the studies obtained from the scanning process are registered to more than one database and only the data in one database was used. In addition, experimental studies with no experimental part or with a single group are other reasons for excluding data.

Coding Method

The data in the studies were coded separately in order to compare the descriptive and numerical data of each study to be included in the meta-analysis research. In this context, after the criteria of the study were determined, a coding form was prepared in order to examine whether the studies were in accordance with the criteria for inclusion in the meta-analysis. The coding form in question was treated under three headings, being "the identity of the study", "contents of the study" and "the data of the study". The relevant data are presented in Table 2:

Table 2. Chapters of the Codification Form and its Content

The Identity of the Study	Contents of the Study	The Data of the Study
The Title of the Study	Teaching Level	Sample Size (N)
Author/Authors of the Study	Subject Area	Mean ($\overline{X}$)
Publication Year	Duration of Application	Standard deviation (sd)
Publication Type		
Publication Database		

The data of each study were coded by two instructors in the field of educational technologies at different times and free from the coding of the researcher in order to ensure the coding reliability, which constitutes the basic structure of the research. The accord between coders was determined as 93%. As a second method, the coding process was repeated several times at different times by the researcher and the consistency of the coding process was examined. The dependent variable of the meta-analysis studies is the effect size. The dependent variables of this study are the effectiveness of the educational robotic applications in the studies included within the scope of the research and the related effect sizes.

Data Analysis

The term constituting the nature of the meta-analysis is the effect size. Effect size, which is also reported in the literature as the effect coefficient, is used in a study to give information about how the independent variable affects the dependent variable positively or negatively (Dincer, 2014). For this purpose, Hedge's g coefficient was taken into consideration in the effect size calculation and the significance level of statistical analyzes was determined as 0.05.

Random effects model was used to calculate the overall effect size of the study. In addition, effect sizes were calculated for the fixed effects model and the resulting values were given in the findings. However, since the random effects model is the appropriate model of the study according to the results of the heterogeneity test, the comments were made accordingly.

In the study, the effect size classification developed by Thalheimer and Cook (2002) was taken into consideration in order to evaluate the effect size level based on arithmetic means and the findings were interpreted based on this information. One of the most important factors that should be considered in order to ensure reliability in meta-analysis studies, which can affect the results, is the bias of publication (Dincer, 2014). In this study, publication bias was evaluated and reported in two ways. The first one is the method used with a funnel plot based on non-statistical visual interpretation. The other is the method known as "fail safe number", based on Rosenthal's "Classic Fail-Safe N" analysis. In the study, the free trial version of CMA (Comprehensive Meta-Analysis) statistical package program was utilized to calculate the publication bias, effect size and heterogeneity tests.

Results

In this part of the study, findings obtained from meta-analysis research are given. In this context, the effect size value of the studies included in the meta-analysis and their comments are explained. The effect size and moderator analyses of the studies related to academic achievement are presented as separate titles.

Findings of the Studies on Academic Achievement regarding Effect Size

The minimum and upper limits of the effect sizes of educational robotic applications on academic achievement according to the fixed and random effects model, regarding the mean effect size, standard error and 95% confidence interval are presented in Table 3.

Table 3. The Results of Studies' Effect Size based on FEM and REM

Model Type	**n**	**Z**	**p**	**Q**	**df**	**ES**	**SE**	**% 95 Confidence Interval**	
								Lower Limit	**Upper Limit**
FEM	39	7.702	0.000	211.049	38	0.307	0.040	0.229	0.385
REM	39	3.961	0.000	48.306	38	0.385	0.097	0.195	0.576

In Table 3, it is seen that the average effect size value of the studies examined within the scope of academic achievement variable was calculated as ES = 0.385 with 0.097 standard error, according to the random effects model. As a result of the analysis, the lower limit of the effect size was calculated as 0.195 and the upper limit as 0.576 in the 95% confidence interval. In addition, in terms of statistical significance Z test was found to be 3.961. Accordingly, it can be stated that the result was statistically significant ($p<.05$). A positive mean effect size value indicates that the effect is in favor of the experimental robotic applications, which is the experimental group. When the findings obtained are interpreted according to Thalheimer and Cook (2002), it can be stated that educational robotic applications are low level in terms of increasing academic achievement. In this context, it can be said that educational robotic applications are positively effective in the academic achievement of students.

In order to ensure reliability in meta-analysis studies, it was examined whether the studies included in the analysis were biased. Regarding the probability of publication bias, the results of the Funnel Plot graph are given in Figure 2.

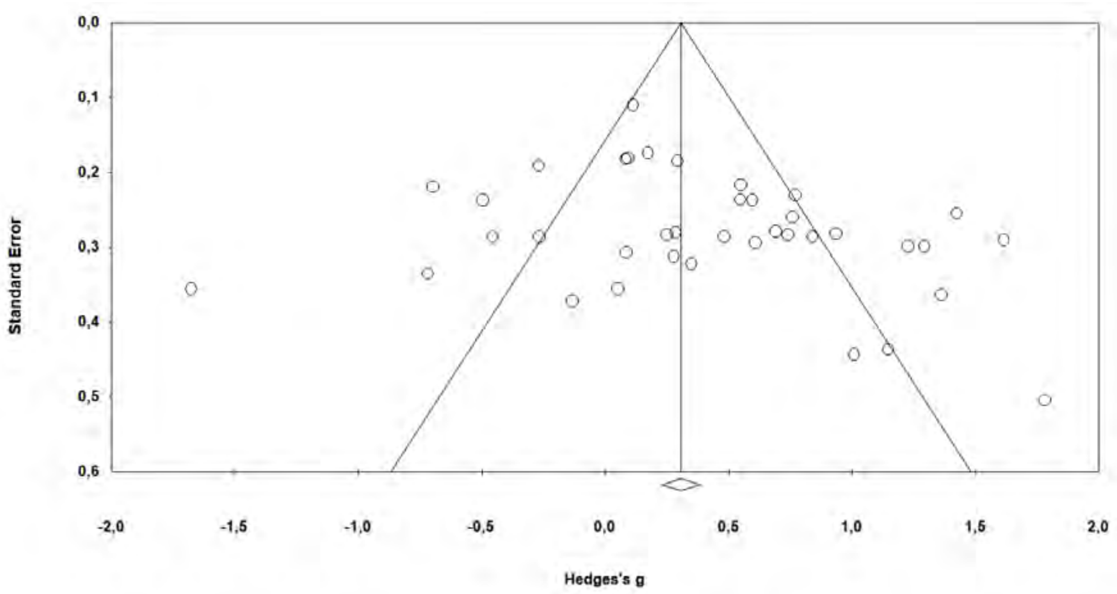

Figure 2. Funnel Plot of the Dissemination Bias Status of the Studies included in the Research

In the funnel graph, that the effect sizes are asymmetric indicates that there is publication bias and that they are symmetric indicates that there is no publication bias. In this context, when the funnel graph in Figure 2 is examined, it is seen that almost all of the studies are distributed symmetrically around the overall effect size, i.e. the distribution is not concentrated on one side. This situation can be interpreted as the sample of the study not being biased in favor of educational robotic applications and that this meta-analysis study is reliable. In addition to the funnel scatter plot, the value of Rosenthal was also calculated in the research. The findings obtained from this test are presented in Table 4.

Table 4. Rosenthal's FSN Calculations

Z-value for observed studies	8.53191
p-value for observed studies	0.00000*
Alpha	0.05000
Tails	2
Z for alpha	1.95996
Number of observed studies	39
Fail safe N	701

*$p<.05$

As a result of the analysis, the safe N number was calculated as N 701. In other words, it can be stated that when the research finding has a negative or neutral effect as much as the number in this value is added, the significant effect may decrease to zero. This value is well above the 5k+10 limit and is too high to be reached. This information was accepted as another indicator that there was no publication bias and that the results of the meta-analysis were reliable.

The Effect Sizes of Studies in Relation to Moderators

As a result of the examination, it was determined that the subject area, duration of application and sample numbers/sizes of the studies included in the research were different. For this reason, it was aimed to examine whether the effect size of educational robotic applications on academic achievement differs according to the subject area, duration of application and sample size. Table 5 presents the moderator analysis results of the studies included in the meta-analysis.

Table 5. The Effect Sizes of Studies on Different Dimensions in relation to Academic Achievement

	Variables	N	ES	95% CI		Q_B	Z	df	p
				Lower	Upper				
Subject Area	**Science**	14	0.339	-0.074	0.752	7.400	3.640	3	0.060
	Computer	13	0.536	0.230	0.841				
	Other	5	0.627	0.117	1.138				
	Maths	7	0.080	-0.150	0.310				
	Total	39	0.296	0.137	0.456				
Sample Size	**n≤50**	18	0.218	-0.107	0.542	11.360	3.106	2	0.003
	51≤n≤100	15	0.707	0.373	1.040				
	n≥101	6	0.094	-0.034	0.222				
	Total	39	0.178	0.066	0.290				
Duration of Application	**Sessions**	7	0.234	-0.412	0.880	1.854	3.891	5	0.869
	> 1, ≤ 5 weeks	10	0.631	0.177	1.085				
	> 6, ≤ 8 weeks	9	0.355	-0.062	0.772				
	> 9, ≤ 12 weeks	8	0.280	-0.047	0.607				
	> 12 weeks	2	0.287	-0.176	0.751				
	Unspecified	3	0.391	-0.154	0.937				
	Total	39	0.360	0.179	0.542				

According to Table 5, when the homogeneity test in between groups was examined in terms of the subject area, it was found as Q_B= 7.400. Based on the $\chi 2$ table, $\chi 2$ value was found to be 7.815 with 3 degrees of freedom at a 95% significance level. Since the homogeneity value between the groups was found to be less than the critical value, it can be said that the effect of educational robotic applications on academic achievement does not change depending on the subject area. When the homogeneity test in between groups was considered in terms of sample size, it was found in the value of Q_B=11.360 value. Based on the $\chi 2$ table, $\chi 2$ value was calculated as 5.991 with 2 degrees of freedom at a 95% significance level. Q_B statistical value was found to be greater than the value $\chi 2$, and it may be asserted that the distribution between effect sizes is heterogeneous. Accordingly, it was understood that the overall effect size was found to be ES=0.178 and that this value was at a low level according to Thalheimer and Cook (2002). On the other hand, it can be stated that the effect of educational robotic applications on academic achievement varies depending on the sample size.

According to Table 5, the homogeneity test value was found to be $Q_B = 1.854$ in terms of application time of the studies. From the $\chi2$ table, 5 degrees of freedom at 95% significance level was found to be 11.070. Therefore, since the Q_B statistic value is less than $\chi2$, there is a homogeneity between the effect sizes. In this case, it can be stated that the effect of educational robotics applications on academic achievement does not change according to the duration of the application ($p = 0.869$). In this case, it can be said that the level of academic achievement is independent of the application times in the courses in which educational robotics applications are used. On the other hand, it can be said that the general effect size value is ES = 0.360 and this has a low-level effect according to Thalheimer & Cook (2002). This finding can be interpreted as educational robotics applications positively affect academic achievement, albeit at a low level.

Conclusion

In this study, it was aimed to holistically examine the experimental studies, which discuss the effect of educational robotics applications that have become popular in recent years and constitute a new area of technology on academic achievement. In line with the purpose of the study, the studies examined according to inclusion criteria were combined with the meta-analytical method. In this context, a total of 32 studies were included in the meta-analysis. As a result of the meta-analysis, it was concluded that the effect of educational robotic applications on academic achievement was low level, therefore significant and effective. The fact that the average effect size value is positive shows that the effect of the process is in favor of the experimental group. Twelve studies published between 2006 and 2016 by Athanasiou, Mikropoulos and Mavridis (2019) were meta-analyzed. As a result of their research, it was determined that robotic applications generally had a positive effect on students' academic performance. Similarly, Talan (2020) examined 142 studies conducted between 2010-2019 for educational use of robotic applications in terms of different variables. In this study, it was seen that the use of robotics applications in education had positive effects on academic achievement (Talan, 2020). As a matter of fact, there are many studies showing that educational robotic applications have a positive effect on students' academic achievement in teaching mathematics, foreign language, engineering, science and technology in addition to computer science (Chin, Hong & Chen, 2014; Cinar & Tuzun, 2020; Hangun, 2019; Hong, Huang, Hsu & Shen, 2016; Huang, Yang & Cheng, 2013; Kert et al., 2020; Lu, Kang, Huang & Black, 2011; Ozdogru, 2013; Ozer, 2019; Usengul & Bahceci, 2020; Yolcu, 2018). In this case, it can be said that the result of the study is consistent with the relevant literature and the mentioned application increases the academic achievement of the students. In light of these results, it can be stated that educational robotic applications are more effective than traditional methods because they facilitate learning by concretizing the subjects, students play an active role in the learning process and they trigger interest, attention and motivation in students (Ersoy, Madran & Gulbahar, 2011; Witherspoon, 2018). In addition, it can be stated that students' hand skills increased, they rendered the course interesting by enabling the use of rich and accessible material and the students were able to learn having fun and thus increased their academic achievement (Ozdogru, 2013; Vollstedt, 2005). On the other hand, there are some studies indicating that there is no significant increase in terms of the academic achievement of educational robotic applications or where there are no significant differences when compared with other studies (Cakir, 2019; Chiazzese, Arrigo, Chifari, Lonati & Tosto, 2019; Jomento-Cruz, 2010; Li, Huang, Jiang & Chang, 2016). The reason for obtaining different results in these studies in the literature may be the application of courses in different ways, differences in the activities used during the course and the teacher's management of the process in a different way. In addition, students' adoption processes of the application, their attitudes and motivations towards the course can be effective in achieving different results. In this regard, it can be stated that the courses designed according to educational robotic applications should be well planned.

In terms of the subject area, the highest number of studies was conducted in the fields of Sciences with 14 studies and Computer Sciences with 13 studies. In addition, it was found that the researchers did not prefer the use of robotic activities in Mathematics. Therefore, it is necessary to obtain detailed information about the effectiveness of educational robotic applications in the mathematics course. On the other hand, it was also determined that small sample and medium sample were preferred in the studies and the number of studies with large sample size was low. The sample should be increased in order to reach the most accurate effect size. The probable reason for the low number of samples in applications may be that it is difficult, costly and inconvenient to use robotic activities in classes for crowded groups.

In addition, moderator analysis was conducted to determine whether the effectiveness of educational robotic applications on students' academic achievement changes according to the course/subject area, duration of application and sample size. When the related results are examined, it is seen that the effect of educational robotic applications on the academic achievement of the students changes according to the sample size and does not change according to the course/subject area and duration of application. It was concluded that the course, in which educational robotic applications are the most effective in terms of course/subject area is the field of computer sciences, and the field in which they are the least effective is mathematics.

As a result, it was found that educational robotic applications are generally effective in terms of the academic achievement scores of students. In this context, it can be stated that increasing the applications related to the use of robots in education and providing related trainings will positively affect students' academic achievement. In addition, the lack of quantitative data required to calculate the effect sizes in the studies makes the meta-analysis difficult, so it can be stated that the relevant data will be useful. In the other studies to be conducted, the effectiveness of the students in different variables such as computational thinking skills, problem solving skills, attitude, motivation and anxiety levels can be examined in addition to the variables studied.

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