BABES-BOLYAI UNIVERSITY

CLUJ-NAPOCA, ROMANIA

MODEL OF GUIDANCE FOR THE INSTRUCTION OF ROBOTICS BY THE PROJECT BASED LEARNING

ABSTRACT

In partial fulfillment of the requirements for the degree of

Doctor of Psychology

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Table of Contents

Chapter 1: Introduction

Many investigators and educators mention that some of the conditions under which people learn well, such as what they learn, is personally meaningful to them. What they learn is challenging and they accept the challenge; what they learn is appropriate for their developmental level; they can learn in their own way, have choices, and feel in control; they use what they already know as they construct new knowledge; they have opportunities for social interaction; and they receive helpful feedback. Projects in robotics could afford a good vehicle for implementing the concepts identified above. Indeed, an increasing quantity of literature has reported on the advantages of engaging students in robotics projects to foster their problem-solving, creativity and teamwork skills. Modern robotics construction kits, such as the Lego Mindstorm system, provide opportunities for pupils to design and build interactive artifacts using engineering-oriented instrumentation, including gears, motors and sensors, and to engage in active enquiry by creating playful experiences.

The robotics course was designed to explore pupils' intuitive learning and problem-solving methods in developing small robotics systems, the types of knowledge they use, and ways of enhancing their learning and problem-solving skills in the context of project-based learning in robotics.

This study presents a two-year study in which a robotics course for junior high school pupils was assessed, re-designed and followed-up very closely in its revised approach.

1.1 Goals

The main goals of the study were to examine the technological knowledge construction process by students, and their ability to design and implement solutions for technological problems. More specifically, this study examines the contribution of project-based-learning (PBL), as a pedagogical means for supporting the students' knowledge acquisition and problem-solving processes among junior high school pupils participating in robotics projects in the Lego Mindstorm environment.

1.2 Purposes of the study

The purposes of this study were to:

1. Assess how well students deal with problem-solving styles that would predict their individualized problem-solving performances

2. Determine the effect of technological problem-solving activity on student participants' problem-solving styles and performances over time.

1.3 Significance of, and need for, the study

The need for this study is supported by the increase in student participation since the inception of robotics and the lack of peer reviewed research on how participation in the robotics challenge affects student learning and their technological problem-solving abilities.

Chapter 2: Review of the Literature

A review of the relevant literature was conducted to develop the theoretical foundations related to technological problem-solving. Two fundamental themes, the theories of learning and problem-solving, build up to the principal element of how technological problem-solving styles and performance are affected by robotics and computer-control competition considered to be a technological problem-solving activity. Cognitive theory and the domains of knowledge were explored in general and as related to the cognitive nature of 9-14 year old children.

2.1 Learning theories

Dewey (1933) stated, "The major purpose of education is learning to think" (in Nummedal, 1987: 89). The basis for the conceptualization and development of models of learning, in which thinking processes are actualized, develops from cognitive theories. For example, Piaget's (1952) *Theory of Cognitive Development* focuses on the development of knowledge in children aged 0-18 years. His stages of development are called *sensory-motor* (0-2 years), *pre-operational* (2-7 years), concrete operational (7-11 years), and *formal operations* (11-18 years). The processes through which these stages are realized include schema, assimilation, accommodation, and equilibrium. Moreover, Brunner's (1964) *Theory of Cognitive Growth* observes more environmental and experiential components such as *curiosity* and *uncertainty, structure of knowledge, sequencing*, and *motivation*.

2.2 Constructivism

The theory of constructivism, whose source lies in the verb "to construct", is a learning theory dealing with the way in which people learn, the process in which they learn acquire and process knowledge (Bonk & Graham, 2004). Constructivism is a type of umbrella which unites under it modern learning approaches. The philosophy of constructivism started at the end of the 18th century by the philosopher Giambattista Viko, who believed that humans can understand only an item or knowledge which they constructed by themselves. The first who clearly implemented this theory to a class were Dewey (1933), and later Piaget (in Derry, 1996). Later the ideas of Vigotzky (1978) were also added and of theoreticians regarding the ways of representation (Bersin, 2004).

According to this theory, learning is not a passive process, but one in which the pupil's contributions are no less than those of the teacher (Barnes, 2002). The learning is executed by way of the structuring of knowledge and responsibility for it, during activity (Mioduser, 1998). The process of learning is not an independent process in which the learner structures his personal knowledge by turning information into knowledge through personal experience. The learner builds by himself new understandings, new knowledge and new conceptions (Bonk & Graham, 2004). The learning capacities develop in parallel to the development of cognition and every stage is based on the stage which preceded it (Mioduser, 1998).

2.3 Problem-based learning

Problem-based learning (PBL) has been described as a learning process where students from elementary school through graduate programs are presented with a problem that challenges them to apply reasoning, questioning, research, and critical thought – both individually and within groups – in order to find the solution to the problem (Cho, 2006). Problem-based learning has also been described as a “cognitive apprenticeship” focusing on the knowledge of a particular topic through using a real case example and the application of problem-solving activities associated with the knowledge in that case (Savery & Duffy, 1995) - a kind of “ideology routed in the experiential tradition” (Savin-Baden, 2000: 17). This is a key difference between PBL and other problem-based approaches using cases as other approaches will use the case example to highlight critical knowledge and learning areas, thus emphasizing content (Savery & Duffy, 1995).

2.4 Problem-based learning in robotics

Devol, Jr. patented the first industrial robot in 1954. The first Unimation Robot was sold to General Motors in 1961. Its name, “Unimate,” meant universal automation. In the 1970s and early 1980s assembly line robots became commonplace. Post-secondary curriculum efforts first began to emphasize the need for robotics personnel in the workforce in the United States in the early 1980s. Not until the 1990s did endeavors to recognize the study of robotics technology ensue at the elementary and secondary levels. Even then it was more like playing with toys than an actual co-curricular activity.

Though the use of robotics in industry began in 1960, educational robotics platforms did not begin to surface until 1980. It was also around this time that robotics curriculum projects were undertaken albeit for students at the community college level. Currently, there are more than 26 experiential K-12 robotics programs throughout Israel. More of these exciting groups exist internationally. A few of these robotics platforms are designed for elementary school students, while most are for use in junior high school, high school, and college/university settings. Many companies have developed mobile units, but some are scale models of industrial systems. The primary goal of all these companies is to promote the use of robotics in education for developing interest in science, technology, engineering, and mathematics, and to motivate students to learn.

2.5 Robotics in the classroom

One new approach to improving engineering and technology (SET) education that is gaining popularity is the use of robots to teach the content. Advances in technology have lowered the cost of robots and made it easier to bring them into classrooms with tight budgets. Papert (1980) laid much of the groundwork for using robots in the classroom in the 1970s. Breaking with traditional computer-aided instruction models where computers essentially programmed children, Papert (1980) attempted to create an environment where children programmed computers and robots. In doing so, the children could gain a sense of power over technology. He believed that children could identify with the robots because they are concrete, physical manifestations of the computer and the computer’s programs.

Papert (1980) found that robots were an excellent way to put constructivist theory into practice. The children learning with robots were able to imagine themselves in the place of the robot and understand how a computer program worked. The children were able to transfer their understanding of the real world into comprehension of logic and mathematical principles. He believed that what makes many concepts difficult for children to understand is a lack of real-world materials that demonstrate the concept. He asserted that programmable robots were flexible and powerful enough to be able to demonstrate ideas that previously had no easy real-world analogy.

Other researchers have also identified the concrete nature of robots as being one of their important advantages. By testing scientific and mechanical principles with the robots, students can understand abstract concepts and gain a more functional level of understanding (Nourbakhsh, Crowley, Bhave, Hamner, Hsium, Perez-Bergquist, Richards, & Wilkinson, 2005). Students can also learn that in the real world there is not necessarily only one correct answer to every question (Beer, Chiel, & Drushel, 1999). Beer et al. (1999) felt that it was more important for their students to propose creative solutions to problems than it was to recite answers they learned in class by rote.

The case studies which exist in the literature positively document the use of robotics to teach a variety of subjects to a wide array of age groups. They illustrate the potential effectiveness of robotics to positively impact both learning and motivation (Fagin & Merkle, 2003). Studies show that robotics generates a high degree of student interest and engagement, and promotes interest in math and science careers (Barnes, 2002; Robinson, 2005; Rogers & Portsmore, 2004).

In the classroom, some educators have used robots as a tool to assist in the teaching of actually programming languages (Barnes, 2002; Fagin & Merkle, 2003). For example, Rogers and Portsmore (2004) taught young students using robots. They designed a curriculum using LEGO robots that teaches kindergarten through 5th grade students about engineering.

Chapter 3: Methodology

The focus of this study is on technological problem-solving styles and student performance during a robotics course. The research spanned a period of two years (2009 and 2010), as shown in table 1 and employed several research tools - pre- and post-questionnaires, interviews and observations of the students. The questionnaire was administered to those students and to two other students of the same level during the first week and the last week of the semester.

Table 1: Instructional sequence and research structure

2009					
	Pre-test	Course	Number of participants (N)	Post-test	Activity
Group A	+	Robotics	16	+	Observations and interviews
Group B	+	Science	22	+	
2010					
	Pre-test	Course	Number of participants (N)	Post-test	Activity
Group A	+	Robotics	47	+	Observations and interviews
Group B	+	Science	41	+	
Group C	+	Social science (other)	42	+	

During the first semester of 2009, 38 pupils (16 of them female) participated, as described in table 1 A pilot study was conducted at a local junior high school. Administrative approval was obtained before securing parental permission and photocopies of release forms for each student participant.

3.1 The research questions

The research was guided by the following questions:

1) Are there differences in the students' attitudes towards problem-solving prior to, and following, the robotics course?

2) Do pupils suggest innovative solutions to problems in the context of active learning?
3) How does the social aspect support project-based learning?
4) Do students implement informal instruction of creative problem-solving within a project-based program?

3.2 The population and sample

The research population was 130 7th-8th grade junior high school students. The school is located in central Israel with student profiles similar to those in the Tel Aviv area. In the second year, 2010, 130 pupils (59 of them females) participated in the research,

3.3 Method

The research adopted a quantitative and qualitative methodology in order to expose as many aspects of the learning process as possible, mainly pupils' feelings, thoughts and actions as they related broadly to their project work (Guba & Lincoln, 1994; Silverman, 1997).

3.4 Quantitative research tools

This research takes the experimental designs to be the most rigorous of all research designs. True experimental design is regarded as the most accurate form of experimental research, in that it tries to prove or disprove assumptions with statistical analysis.

The students answered the same questionnaires at the end of the experiment pertaining to the test group (robotics) as did the control groups (social science and science) pertaining to random students, while the control groups performed the traditional study at school. The significance of the average difference in the two groups was examined, and differential analysis was performed with repeated measurements.

For this study the research employed a 5-point Lickert scale, wherein 1 = fully agree, 2 = mostly agree, 3 = disagree somewhat, 4 = mostly disagree, 5 = fully disagree. The questionnaire contains an equal number of expressions regarding problem-solving, social aspects, creativity, confidence and active learning. A reliability analysis (Cronbach's Alpha) was conducted to measure the internal consistency of the questionnaire on the 20-item scale (Heppner, 1988).

3.5 Study reliability

Reliability tests were performed to examine the different variables explored in the research, as shown in table 2.

Table 2: Study reliability

	Problem solving	Active learner	Creativity	Social aspect	Total
Items	5, 7, 12, 13, 20	1, 2, 8, 14,15	6, 10,11,17,19	3, 4, 9, 16, 18	
Cronbach's Alpha	0.914	0.917	0.922	0.917	0.917

During the study a comparison was made between the parameters using the averages. The higher the score, the more representative were the study's variables - problem solving, active learner, creativity and social aspects.

3.6 Procedure

The robotics course lasted 15 weeks. During this period of time, student participants completed the technological version of Heppner's (1988) self-reporting instrument, the assignment being a problem-solving inventory. It was administered during the weeks beginning September 20th, October 25th, and November 15th, 2009.

Raters directly observed and used the final revision of the student individualized performance rubric (Custer, Valesey & Burke, 2001) to determine student performance.

3.7 Data collection methods

This study focuses primarily on pupils' work processes, the artifacts they constructed, and their reflections on the course. The data collection aimed at following up on the pupils' activities in the class, their individual and team work approaches, the processes they used in completing the tasks they tackled, and the content of the presentations they prepared and presented to the class.

3.8 Data analysis

At the first stage, the data were entered into excel computer software. At the second stage all statistical data were transferred to analyses conducted using the SPSS computer software. Correlations were run to determine the relationships between age groups on PSI-TECH scores, and statistical analyses were performed for frequencies in distributions, averages (compared means) and standard deviation to test the dimensions of the scattered center of data.

3.9 Qualitative analysis

The research adopted qualitative methodology in order to expose as many aspects of the learning process as possible, mainly pupils' feelings, thoughts and actions as they related broadly to their project work (Guba and Lincoln, 1994; Silverman, 1997). Data collection aimed at following up on pupils' activities in the class, their individual and team work approaches, the processes they used in completing the tasks they tackled, and the content of the presentations they prepared and presented to the class. Data were gathered by preparing a detailed journal of each class meeting.

Chapter 4: The Research Findings

4.1 Characteristics of student participants

A survey was conducted at the beginning of the semester in order to achieve better understanding of students' previous experiences related to the robotics course,. The study sample for 2009 included 20 students, 61% male and 39% female. 90% of all participants had no previous experience in robotics, while 20% had one year of previous experience.

4.2 Quantitative aspect

The questionnaire was administered twice over a fifteen-week period (semester). Means, standard deviations, and the standard error for each component of the instrument and the overall total were calculated and reported by gender in table 3. Student participants included 71 males and 59 females (54.6% males and 45.5% females). The means and standard deviations were very similar for both genders.

Table 3: Number of items, mean, and SD of measurement for pre- test study scores

Gender		Active learner	Problem solving	Social aspect	Creativity
Female	Mean	2.01	2.007	2.014	2.064
N=59	Std. D	0.367	0.453	0.395	0.387
Male	Mean	2.037	1.986	1.941	1.98
N=71	Std. D	0.325	0.507	0.35	0.38
Total	Mean	2.025	1.995	1.974	2.018
N =130	Std. D	0.343	0.482	0.371	0.384

4.3 Research question 1

The students were first asked whether there are differences in their attitudes towards problem-solving prior to, and following, the robotics course?

The assumption was that there is a difference in the level of students' problem-solving in the context of a project-based learning course in robotics. A T-test was conducted in order to examine this hypothesis.

A T-test for independent samples (paired samples T-test) indicates that there is a significant difference (t(129)=-8.45, p<.001) between the research group and the control group. Table 4 presents the sample T-test, means and standard deviations.

Table 4: Problem solving-level differences before and after the intervention for all populations

		Mean	N	S.D	t	df	Sig. (2-tailed)
Pair 1	Problem-solving pre	1.958	130	0.357	-8.459	129	0.000
	Problem-solving post	2.831	130	1.152			

According to the hypothesis the mean level of problem-solving after the intervention (M=2.83, Std. D=1.15) was found to be significantly higher than before the intervention (M=1.95, Std. D=0.37).

The next step was a simple one-way analysis of variance conducted to determine the overall effectiveness of the intervention. Pre-test and post-test scores between the control and the experimental group using one-way ANOVA were compared.

A one-way independent ANOVA was conducted for each of the four MSLQ dimensions to see if there were differences in each of the group's means as they relate to each MSLQ dimension from the first administration.

However, significant differences were detected on the pre-test mean scores (F(2,129)=0.31, p>0.05) indicating that the variance of the pre-test was not equal between the control group and experimental group. Table 5 depicts the means and standard deviations.

Table 5: Differences between the levels of problem-solving

		N	**Mean**	**S. D**	**F**	**Sig**
Problem-solving pre	Social science	42	1.995	0.338	0.310	0.734
	Robotics	47	1.987	0.328		
	Science	41	1.926	0.363		

Further analysis of the source of the differences between the groups was tested using the Scheffe Test. No difference was found between the robotics group (M=1.98, Std. D=0.32), the social science group (M=1.99, Std. D=0.33), and the science group (M=1.92, Std. D=0.36) before intervention.

In order to examine the differences between the three groups of study after the intervention, relevant differences were located. A significant difference was found in the robotics group and the science group using the Post Hoc test (sig=0.000) (F(2,127) = 566.93, p<0.001), as well as between the robotics group and the social science group (sig=0.000).

However, there was no marked difference between the science group and the social science group (sig=0.918). As shown in tables 6 and 7 there was a significant difference between the robotics group and the other groups.

Table 6*:* Differences in problem-solving between the three study groups after the intervention

		N	Mean	Std. D	F	Sig
Problem-solving post	Social science	42	2.03	0.34	566.593	0.000
	Robotics	47	4.28	0.36		
	Science	41	2.00	0.40		

Table 7: Multiple comparisons (Scheffe test)

Dependent variable	(I) No_class	(J) No_class	Mean difference (I-J)	Sig.
Problem solving post	Social science	Robotics	-2.248	0.000
		Science	0.033	0.918
	Robotics	Social science	2.248	0.000
		Science	2.281	0.000
	Science	Social science	-0.033	0.918
		Robotics	-2.281	0.000

In addition, discrepancies tested before and after each group showed significant improvement, with those for robotics being greater in relation to both other groups, as shown in table 8.

Table 8: ANOVA differences between the three groups

		N	Mean	Std. D	F	Sig
Problem solving	Social science	42	0.071	0.463	307.767	0.000
	Robotics	47	2.289	0.466		
	Science	41	0.068	0.541		

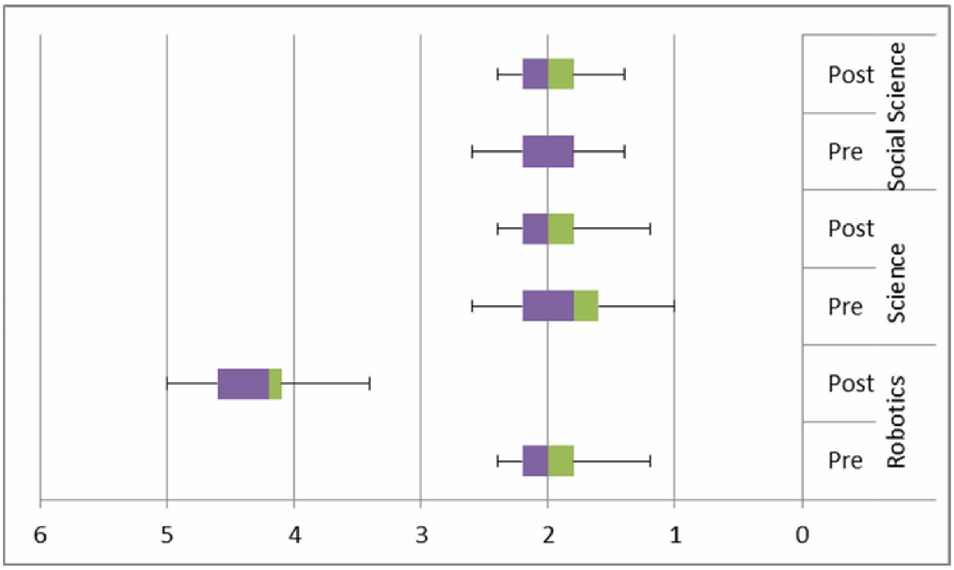


Figure 1: Graphic description of differences in problem-solving between the three groups, before and after the intervention

These findings confirm research hypothesis 1 according to which there is a difference between the research group and the control groups, with the attitudes of the students in the research group being more positive regarding problem-solving.

4.4 Research question 2

Do pupils suggest innovative solutions to problems in the context of active learning?

There is a difference in active learning and project-based learning before and after the intervention. The assumption was the level of active learning would be higher following the intervention.

In order to examine the differences between the three study groups after the intervention, relevant differences were found. A Post Hoc test found significant differences (sig=0.000) between the robotics group and the science group (F(2,129)=521.7, p<0.001), as well as between the robotics group and the social science group (sig=0.000). However, there was no marked difference between the science group and the social science group (sig=0.93). As shown in table 9 the significant difference was between the robotic group and the other groups.

Table 9*:* Differences in problem-solving between the three study groups after the intervention

		N	Mean	Std. D	F	Sig
Active learning post	Social science	42	2.071	0.350	521.701	0.000
	Robotics	47	4.357	0.382		
	Science	41	2.039	0.436		

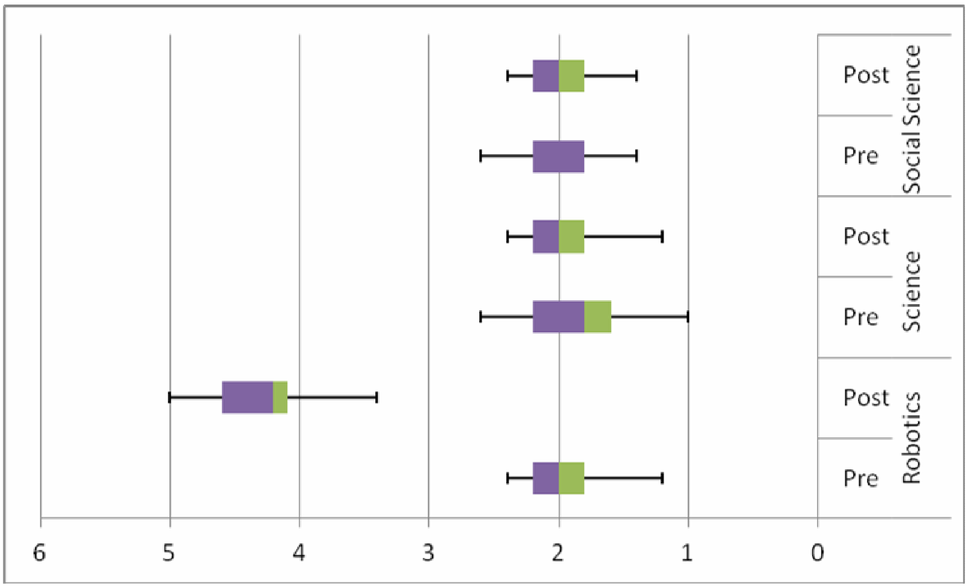


Figure 2: Graphic description of the differences in active learning between the three groups, before and after the intervention

4.5 Research question 3

How does the social aspect support project-based learning?

The first stage was tested using independent samples T-test (Paired Samples T-test) and significant differences were found, with the active learning after the intervention significantly higher than before the intervention (t(129)=-8.04, p<.001). Table 10 presents the sample T-test, means and standard deviations.

Table 10*:* Social aspect differences before and after the intervention for all populations

		Mean	N	Std. D	T	df	Sig. (2-tailed)
Pair 1	Social aspect Pre	1.97	130	0.37	-8.044	129	0.000
	Social aspect Post	2.85	130	1.18			

The level mean of the social aspect after the intervention was found to be (M=2.85, Std. D=1.18), significantly higher than measured before the intervention (M=1.97, Std. D=0.37).

A simple one-way analysis of variance was conducted to determine whether there were differences in the social aspect amongst the study groups. Examination of the differences between the groups before the intervention using one-way ANOVA found no difference between the groups' level of problem-solving (F(2,129)=0.136, p>0.05). Table 11 presents the means and standard deviations.

Table 11: Difference between the levels of social aspect of the study groups

		N	Mean	Std. D	F	Sig
Social aspect pre	Social science	42	1.95	0.409	0.136	0.873
	Robotics	47	1.98	0.369		
	Science	41	1.92	0.370		

The Schleffe test was used to test the source of the differences between the groups for further analysis (table 11). The results show that that there is no difference between the robotics group (M=1.98, Std. D=0.37), the social science group (M=1.95, Std. D=0.41), and the science group (M=1.92, Std. D=0.37) before intervention.

In order to achieve the differences between the three study groups after the intervention, relevant differences were found. The Post Hoc test for significant differences (sig=0.000) found robotics course (F (2,129) =732.4, p<0.001). A significant difference was also found between the robotics group and the social science group (sig=0.000). However, there was no marked difference between the science group and the social science group (sig=0.97). As shown in Table 13 the significant difference was between the robotic groups to the other groups.

Table 12: Differences in problem-solving between the three study groups after the intervention

		N	Mean	Std. D	F	Sig
Social aspect post	Social science	42	2.00	0.35	732.395	0.000
	Robotics	47	4.36	0.35		
	Science	41	2.01	0.30		

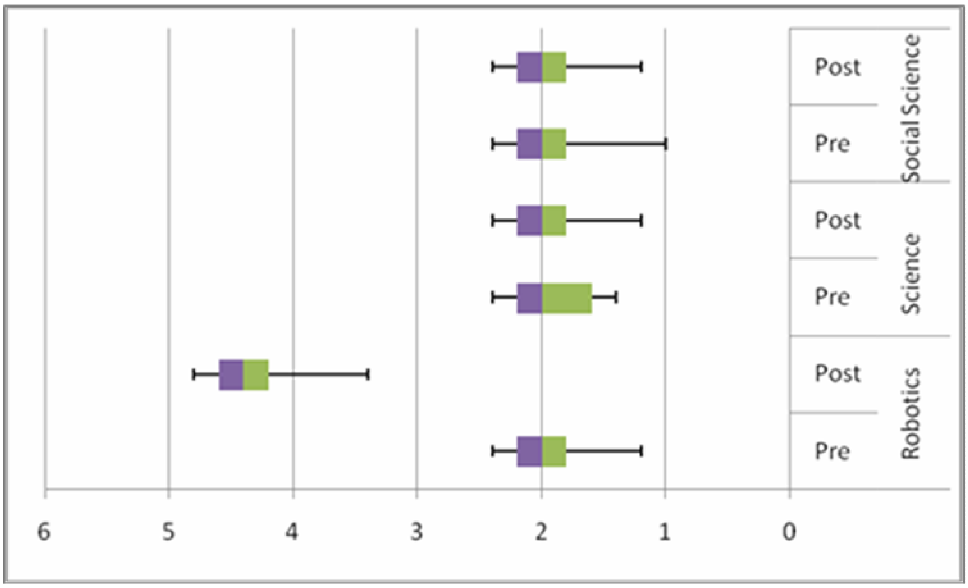


Figure 3: Graphic description of differences in the social aspect between the three groups, before and after the intervention

4.6 Research question 4

Do students implement informal instruction of creative problem-solving within a project-based program?

In order to examine whether there are differences in the level of creativity in project-based learning before and after the robotics course, an independent T-test for paired samples was performed. The results show a significant difference (t (129)=-7.35, p<.001). Table 13 presents the sample T-test, means and standard deviations.

Table 13: Differences in creativity before and after the intervention for all populations

		Mean	N	Std. D	t	df	Sig. (2-tailed)
Pair 4	Creativity pre	2.02	130	0.38	-7.35	129	0.000
	Creativity post	2.80	130	1.18			

Thus according to the hypothesis, the mean of creativity after the intervention (M=2.8, Std. D=1.18) was found to be significantly higher than that measured before the intervention (M=2.02, Std. D=0.38).

The next step was a simple one-way analysis of variance conducted to determine whether there was a difference between the levels of creativity among the study groups. Examination of the differences between the groups prior to the intervention using one-way ANOVA found no difference between the groups' level of creativity (F(2,129)=0.29, p>0.05). Table 15 presents the means and standard deviations.

Table 14: Difference between the levels of creativity amongst the study groups

		N	Mean	Std. D	F	Sig
Creativity pre	Social science	42	1.99	0.39	0.29	0.750
	Robotics	47	2.05	0.41		
	Science	41	2.01	0.36		

The Schleffe test was employed to further analyze the source of the differences between the groups (table 14). The results of the examination show there is no difference between the robotics group (M=2.05, Std. D=0.41), the social science group (M=1.99, Std. D=0.33), and the science group (M=2.01, Std. D=0.36) before intervention.

Relevant differences were found in order to examine the differences between the three study groups after the intervention, . The Post Hoc test found significant differences (sig=0.000) for the robotics group and the science group

(F(2,127)=732.395, p<0.001), as well as between the robotics group and the social science group (sig=0.000).

However, there was no marked difference between the science group and the social science group (sig=0.832). As shown in table 15 the significant difference was between the robotics group and the other groups.

Table 16: Differences in creativity between the three study groups after the intervention

		N	Mean	Std. D	F	Sig
Creativity post	**Social science**	**42**	**2.00**	**0.35**	**732.395**	**0.000**
	Robotics	**47**	**4.36**	**0.35**		
	Science	**41**	**2.01**	**0.30**		

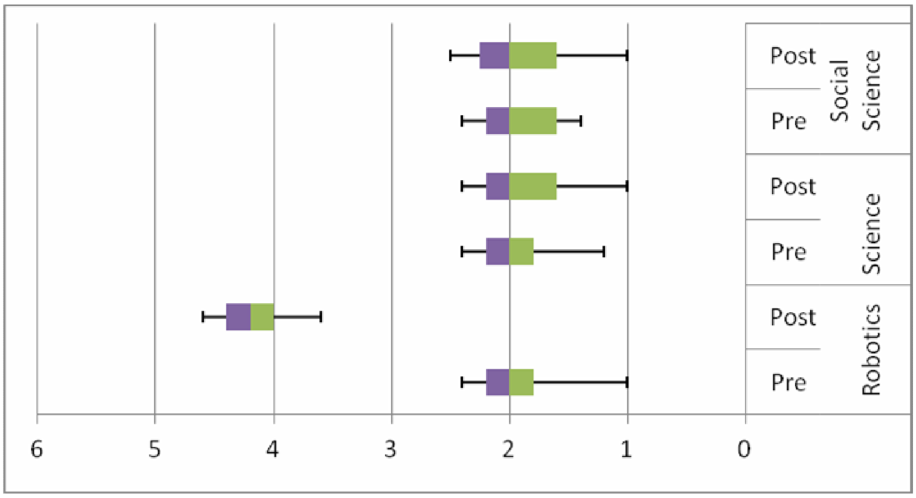


Figure 4: Graphic description of differences in creativity between the three groups, before and after the intervention

4.7 Gender differences

Another aspect explored in this study was differences between the genders in the method employed for project-based learning. The assumption was that there are gender differences in approaches to learning-based projects in the variables of problem-solving, active learning, social aspects and creativity investigated in this study.

This hypothesis was tested by a T- test for paired samples, which did not find any differences regarding gender before and after the intervention. presents the number of items, mean, and standard error for the original questionnaire.

4.8 Qualitative finding

The research adopted a qualitative methodology in order to expose as many aspects of the process as possible, mainly pupils' feelings, thoughts and actions as they related broadly to their project work (Guba & Lincoln, 1994; Silverman, 1997). Data collection aimed at following up on pupils' activities in the class, their individual and team work approaches, the processes they used in completing the tasks they tackled, and the content of the presentations they prepared and presented to the class.

Data were gathered by preparing a detailed journal of each class meeting; documenting spontaneous conversations with the pupils and unique events in the class; keeping records of pupils' computer files, such as programs and electronic presentations; photographing the systems constructed by the pupils; videotaping selected lessons; and holding discussions with parents, school teachers and principals regarding their points of view about the course. This study focuses primarily on pupils' work processes, the artifacts they constructed, and their reflections on the course.

4.8.1 The first year: The content-oriented course

The beginners' course observed at the beginning of this study concentrated primarily on teaching pupils a diversity of principles considered useful for the construction of small robots. The lessons were on subjects such as types of mechanical structures or gearboxes. The pupils constructed small robotics systems using Lego blocks and explored their properties. They learned, for example, how to describe a gearbox quantitatively using a formula and graph, as is common in science. An attempt was made to teach a combination of qualitative and procedural knowledge, as previously mentioned. Although the course was presented to the pupils as a preparatory stage in building sophisticated robots, in the subsequent advanced course discussions with the pupils and observations made in the class revealed that the pupils regarded the course as any other school subject. For example, they frequently came late to class, and attendance was about 80%, similar to the rest of the school. Not all the pupils made serious efforts to complete the tasks presented to them, and they seldom prepared their homework assignments or studied for tests.

4.8.2 Strong motivation among pupils who participated in a robotics contest

In contrast to the picture described above, very strong motivation was found among ten pupils from one class who developed an original robot to compete in an annual nation-wide robotics contest. In this class:

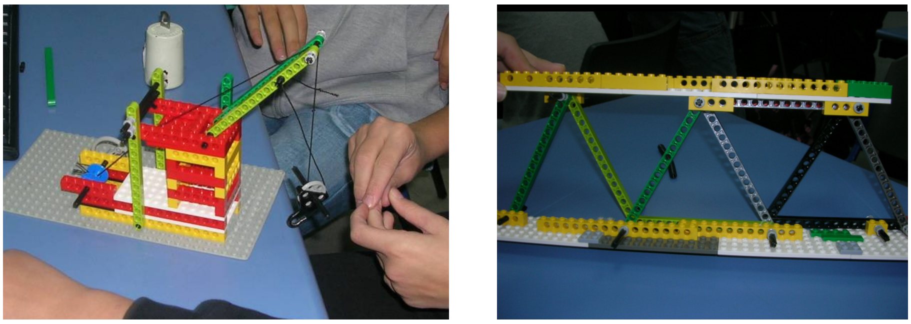
- The pupils worked independently, with minimal teacher intervention. For example, they split into three teams - the investigation team, the construction team and the programming team.
- The pupils often remained in the laboratory until very late in the afternoon or came to the laboratory over the weekend to work on their project.
- The entire group met at the home of one of the pupils at least once a week.

The strong motivation of pupils on this team in comparison to pupils who attended the basic robotics course indicated the necessity to revise the robotics program, as described in the following section.

4.8.3 The second year: The project-based learning course

To increase pupil motivation and foster learning in the class, the robotics course was redesigned in the second year to meet the following guidelines:

1. The learning would be project-based. The pupils start out with relatively simple tasks, such as constructing the longest and strongest fishing rod possible using Lego blocks. The projects' complexity gradually increased, whereby at the end of the semester, the pupils deal with tasks such as designing a computer-controlled car. Figure 5 shows two examples of pupils' projects.
2. The teaching of subject matter to the entire class is minimal; the teacher just explains specific points to the pupils in the context of the projects on which they are working.
3. The pupils are encouraged to document all their work on the projects by using a digital stills/video camera that is readily available in the class.
4. At the end of every project, each group prepares a presentation about its work and presents it to the class.
5. Pupils' pictures, videos and presentations are uploaded to the course's website shortly after the lesson.



Crane Bridge

Figure 5: Examples of pupils' projects.

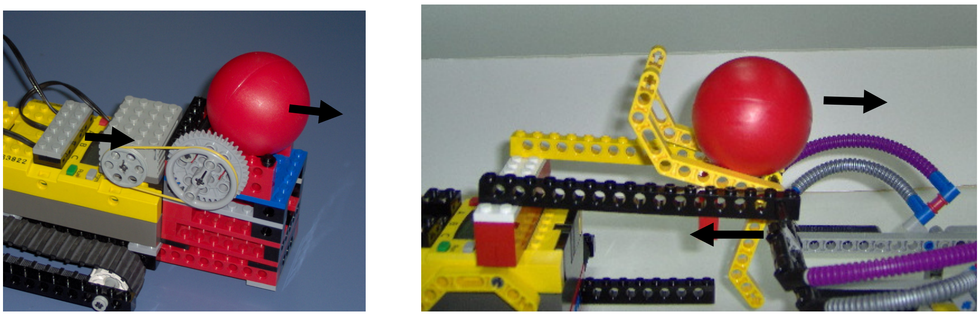
As previously noted, the new course described above was given in the second year of the current study, and involved the participation of 76 pupils (four groups of 16-20 pupils each). Basing the course on project work resulted in a considerable change in pupils' motivation, as described below:

- Pupils often arrived at the laboratory before the lessons formally commenced and remained there during the breaks or after the lessons to continue working on their projects.
- One pupil reported that she worked with her father on his laptop to improve her presentation to the class and they watched videos together about class discussions they retrieved from the course website.
- One schoolteacher, having no background in technology or science, sent some material on bridges she had found on the Internet to the robotics course instructor. She noted that she had become interested in bridges after "*the pupils did not stop talking about what they were doing in the robotics course*".

The change in motivation amongst pupils' on the course characterized the vast majority of the pupils in the four groups that attended the class, although they came from two different schools and were varied in their scholastic achievements and socio-economic backgrounds.

Developing the program around a series of increasingly complex projects enabled close observation of the ways pupils worked on their projects, with special focus on issues relating to scientific-technological knowledge and problem-solving.

One of the most challenging tasks addressed by the pupils in the advanced group was building a robot that would throw a ball quickly into a basket. All the groups constructed a motor-driven mechanism that thrust the ball forward into the basket, as seen in figure 6a. The problem was that this method was too slow. One of the groups dismantled their first construction and came up with the solution shown in figure 6b, whereby the ball is thrown into the basket by a simple arm.



a. The ball is moved forward by a motor-driven tray.

b. The ball is thrown into the basket by an arm activated when the robot reaches the target.

Figure 6: Two different mechanisms for throwing a ball into a basket.

One of the pupils in the group who built the simple mechanism seen in Figure 6b said,

”We wanted to use the car’s acceleration to throw the ball”.

Yet, the pupils reported that they had not ‘designed’ the bent rod; rather, they had looked through all of the Lego block components until they found something that they thought could be useful. When they found the bent rod, they thought it would work “like an arm” throwing a ball, and consequently arrived at the structure seen in figure 6b. What can we learn from this example about problem solving? We will return to this point in the discussion.

When the students were asked to write their views of the course on cards, the teacher suggested that they relate to questions such as, What did you like or dislike about working on the car project? What would you advise a friend who is going to start the robotics program? The following quotes from pupils’ answers show what they had learned from the above-mentioned abstracts on problem solving:

One pupil wrote: *“Although we did not welcome difficulties and problems, they are essential parts of the learning process. Through them, it is possible to learn how to avoid making mistakes in the future and how to solve problems. Despite their negative effect, we overcame them, understood how to achieve our goal, and finally constructed an excellent model”.*

Another pupil wrote,*"If a friend of mine would have started a task similar to ours, I would have suggested three things to her: first, work in teams all the time, because only thus can the goal can be achieved; second, write down all ideas proposed by the group members, and if possible, combine several of them so that no- one in the group is offended and the model will be original; and third, not to be ashamed to ask for help from a friend or from the teacher".*

A third pupil wrote,*"Open up your minds! Start out by assuming that in order to suggest a specific idea there is a need for knowledge and experience on this subject! Think about other subjects, make a connection between them and your task, and draw conclusions!"*

Although it is difficult to highlight a specific event or point in time when the pupils stopped working and spent time on defining a problem or holding a brainstorming session, the above examples from pupils' reflections on the course demonstrate how they regarded the questions: "What is a problem?" or "What is brainstorming?"

Chapter 5: Conclusions

This study aimed to investigate whether project-based learning influenced 8th grade students in their problem-solving, social aspect, and creativity. This chapter discusses the findings by relating to the four research questions and the theoretical framework presented previously.

5.1 Research question one

The first research question we raised in this study was, are there differences in the students' attitudes towards problem-solving prior to, and following, the robotics course?

Previous research indicates that more experienced problem-solvers reach greater levels of problem-solving performance than do those who are inexperienced with problem clarification procedures (Bjorklund et al., 1990). Years of experience have also been found to be effective predictors of near transfer problem solving skills (MacPherson, 1998). It was expected in this study that more student participants would have a superior problem-solving style. Because there was virtually no variance in the experience levels of student participants in this study, significant differences were found for test scores, hence these findings are sample specific.

5.2 Research question two

Do pupils suggest innovative solutions to problems in the context of active learning?

Social aspects accounted for only 2% of the variance in performance scores for this study. This finding supports MacPherson's (1998) indication that social aspects were the more important indicators of problem-solving skills. More research is needed to better determine the relationship between style and performance. Revisions in how social aspect is measured should be evaluated. Since the questionnaire is a self-reporting instrument and scores are observed, gaps in the relationship exist.

Robotics, with its characteristic identity and legitimacy, is preferably taught in a problem-based setting. The use of a theme, which can be divided into a large number of learning objects, or active learning, can be seen as a bridge between disciplines and departments, and therefore facilitates the establishment of robotics as a discipline.

5.3 Research question three

How does the social aspect support project-based learning?

The results indicate that while the social aspect may be complex, it is reasonable to suggest that social aspect activities, such as the robotics course, facilitate children's implementation of the social aspect. Student participants showed significant increases in social aspects and in confidence.

There was a significant time effect for social aspects. This may indicate that in order for children to fully comprehend and transfer problem-solving skills and social aspects, formal training or coursework is needed, although the social aspects of the student's problem-solving styles were high, as seen in the performance case summaries.

5.4 Research question four

Do students implement informal instruction of creative problem-solving within a project-based program?

Throughout the cognitive science literature, there is a recurring theme pertaining to the progression of hierarchical domains of creativity and knowledge leading to higher order thinking. Many theorists believe creative problem-solving to be the pinnacle. Jonassen (2004) specifies creative problem-solving as the most difficult to learn.

The research has considered what makes robotics creative and motivating to children, including those who are not considered 'technically oriented'. It has described learning that has emerged from children's experiences in building and programming robots, including examples of children learning subjects that they previously considered difficult and inaccessible, in order to solve problems in robotics. It has described examples of creative children independently identifying and understanding principles and concepts. It has described further how students working in teams learned that this programming and engineering knowledge has a social context.

5.5 Gender differences

Gender alone did not show any significant differences for scores. Overall, females scored no differently than did males in problem-solving performance, meaning that during this particular problem-solving activity girls were as equally engaged as boys. Research designed to compare teams of females with teams of males and with mixed gender teams would provide greater insight on this relationship.

5.6 Exit interviews

The results of the exit interviews support the idea that technological problem-solving is a non-linear process. Student participants recognized that there are steps to solving problems; however, the order in which they actually solved their problems was not sequential throughout the activity. Tangible results helped them realize the success of a problem solution, or whether troubleshooting and redesign might be necessary. Since LEGO is a modeling tool, the needs for sketching design ideas in this type of technological activity were reduced. However, several student participants found that using drawings was an effective method of communicating and sharing ideas with teammates.

Many student participants spoke of the value of teamwork in problem-solving, which supports the idea that there is a social component to learning. They seemed to think that this type of technological problem-solving activity helps them develop different perspectives on learning. However, no-one discussed developing respect for the perspectives and ideas of others. Few students realized that this type of technological problem-solving activity would help them in school. This indicates the lack of transfer of knowledge in this type of extramural school activity, which suggests a more formal approach be taken.

5.7 Observations

Observations during the first and the second years of the current study indicate that, in the first projects, the pupils often started to construct the system they were working on immediately and progressed through cycles of trial and error. As the pupils gained more experience, they paid greater attention to considering different solutions to the task they were tackling. In their third or fourth project, the pupils raised original ideas according to what Hayes (1978) terms ‘heuristic searches,’ namely the process in which the problem-solver uses knowledge about the problem to identify promising paths in seeking a solution.

5.7.1 The role of qualitative knowledge in robotics projects

In the literature review, we distinguished between three types of knowledge (Rittle-Johnson & Alibali, 1999; McCormick, 1997, 2004): procedural knowledge, which is the ability to answer questions or solve problems by manipulating particular rules, algorithms and procedures; conceptual knowledge, pertaining to understanding broad concepts and recognizing their application in various situations; and qualitative knowledge, which accounts for the ability to understand or evaluate a specific phenomenon in a system without relying necessarily on formal terms or mathematical formulae.

In the current study, the initial ‘content-oriented’ course (first year), focused primarily on procedural knowledge, with the notion of preparing the pupils to handle sophisticated assignments in robotics later in the more advanced course. The teacher taught basic concepts in robotics, such as types of mechanical structures or gearboxes, and the pupils built given robotic models and examined their properties through scientific-type experiments. Although the course was based on sophisticated Lego-robotics instrumentation, the pupils regarded it as just another school subject and were rarely highly motivated in completing the class assignments. Actually, this course exposed the disadvantages of traditional teacher-instructed schooling aimed at teaching pupils formal content for future use.

In the second year we adopted the project method. The pupils worked on three or four projects of increasing complexity, and prepared a summative presentation for each project. In this course, pupils’ motivation and interest in learning was much greater, but their lack of knowledge of scientific-technological concepts relating to robotics, such as force or friction, frequently limited their ability to design efficient robotics machines or understand the disadvantages of the system on which they were working.

In summary, these findings emphasize the need to integrate elements of instruction into the project-based course. The course was further developed by preparing a range of abstracts as PowerPoint presentations on subjects such as “What is force?” or

"What is a problem?" The teachers presented these materials to the pupils in the context of their projects, in an unconstrained manner, and the pupils could decide whether or how to use them. The pupils very quickly started using terms or concepts presented in these abstracts, such as force, friction, torque or center of gravity, in their discussions with their friends or in their summative reflections on each project.

Overall, the findings of this research support the use of the PBL method in a robotics course, concepts in an external school program, and that the evaluation instrument developed to test the concepts is reliable and valid.

Robotics is not an answer for every one or every problem, but does provide some insight into how the 'right' technology, in the context of problem-based learning, can draw children into learning underlying principles. And it has shown how context, need, and the desire to 'make it work' draw children to that learning so naturally that they hardly notice the intellectual strides they are making.

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Keywords: Problem solving, Problem-based learning (PBL), Problem solving ability, Problem solving performance, Heuristics, Cognition.

Problem solving – the lager problem process that includes problem finding where problem is defined as a state of desire for the reaching of a definite goal from a present condition that either is not directly moving toward the goal, is far from it or needs more complex logic for finding a missing description of conditions or steps toward the goal.

Problem-based learning (PBL) - is a student-centered pedagogy in which students learn about a subject in the context of complex, multifaceted, and realistic problems. The goals of PBL are to help the students develop flexible knowledge, effective problem solving skills, self-directed learning, effective collaboration skills and intrinsic motivation.

Problem solving ability - The competence exhibited during performance of a task, whether by natural aptitude or acquired proficiency.

Problem solving performance - Levels of behavior exhibited during a technological problem solving activity. Performance levels encompass the following progressions: Novice; Beginner; Competent; Proficient; Expert.

Heuristics - Heuristics indicate likely directions to pursue or approaches to follow

Constructivism - concerns the world of constructivist psychologies. Many schools of psychotherapy self-define themselves as “constructivist”. Although extraordinarily different in their therapeutic techniques, they are all connected by a common critique to previous standard approaches and by shared assumptions about the constructive nature of knowledge.

Cognition - refers mental processes. These processes include attention, remembering producing and understanding language, solving problems, and making decisions. Cognition is studied in various disciplines such as psychology, philosophy, linguistics, science and computer science.