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Effects of Innovative Project Based Learning Model on Students' Knowledge Acquisition, Cognitive Abilities, and Personal Competences

Hava E. Vidergor (Gordon Academic College of Education, Israel)

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ABSTRACT

The current study addresses the limited research on knowledge acquisition in Project-Based Learning (PjBL) and assesses its development using a Multidimensional Curriculum Model (MdCM) among 563 elementary and secondary school students in Israel. The mixed-method approach involves a quantitative pre-post design, comparing intervention groups who are studying modules based on MdCM to control groups using traditional PjBL. The knowledge measured comprises three dimensions: declarative, procedural, and conditional. Qualitative measures, including semi-structured interviews and reflective diaries, added information on student learning. Main findings indicated an effect of MdCM as a form of PjBL which showed significant differences between intervention and control groups in terms of total knowledge acquisition, particularly in procedural and conditional knowledge. Interviews and reflective diaries elaborated on the significant link between thinking processes and knowledge acquisition, indicating that students perceived development of their cognitive abilities and personal competencies. In this study, implications for teaching using MdCM as a novel PjBL approach are discussed.

Keywords: Project-Based Learning; Multidimensional Curriculum Model; knowledge acquisition; cognitive abilities; personal competences

Introduction

Knowledge acquisition is one aim of the teaching-learning process. Lately, this goal has been somewhat abandoned, with the increased focus on skills students need to acquire in the 21st century (Care et al., 2018). Researched-based evidence suggests that Project-Based Learning (PjBL) promotes these required skills; therefore, it is a highly regarded teaching-learning strategy currently offered to teachers. (Culclasure et al., 2019). Limited empirical research has addressed the acquisition of student knowledge among school children studying via forms of PjBL. For example, Aydinyer (2010) found that PjBL increased procedural and conditional knowledge acquisition in math. In contrast with previous studies, a recent study by Culclasure et al. (2019) found no significant differences in academic and behavioral outcomes when comparing PjBL and non-PjBL classes, and they recommended that schools move into deeper and more sophisticated PjBL implementation.

The current study employed a Multidimensional Curriculum Model (MdCM) (Author, 2015, 2018a, 2018b; Authors, 2019) that offered an innovative approach to PjBL to investigate the development of students' knowledge acquisition, cognitive abilities, and personal competences by way of an intervention unit. The application of MdCM may be a possible solution for enhancing the acquisition of knowledge and development of cognitive abilities and personal competences through the addition of PjBL, PBL, and thinking tools across multiple academic subjects

Knowledge acquisition was divided into three levels: declarative, procedural, and conditional/situational, and was enhanced by students' personal perceptions indicating their development of abilities and competences related to knowledge. This study may add to the understanding of the contribution of the innovative MdCM approach to PjBL regarding the acquisition of knowledge and the development of cognitive and personal competences, as well as, shed light on its general application.

Project-Based Learning knowledge acquisition and personal competences

Project-Based Learning (PjBL) is defined by Bell (2010) as "a key strategy for creating independent thinkers and learners. Children solve real-world problems by designing their own inquiries, planning their learning, organizing their research, and implementing a multitude of learning strategies" (p. 39). The steps in PjBL include (1) finding an idea for a project, (2) planning and designing a project, (3) fine-tuning, (4) implementation, and (5) presentation in a final event (Patton, 2012). According to Thomas (2000), PjBL is characterized by projects that are central to curriculum; focused on questions and problems; involving constructive investigation; student-driven; and realistic. The MdCM model follows the basic steps of PjBL and elaborates on them by adding perspectives and thinking tools that will be further explained in the section relating to the model.

Several studies indicated that using a PjBL approach led to significant increases in all achievement areas (Boaler, 1999; Thomas, 2000). Gultekin (2005) noted that evidence exists in support of developing research, problem solving, and higher-order thinking skills. Hung et al. (2012) used a digital storytelling approach to PjBL and found it improved the learning motivation, problem-solving competency, and learning achievement of students. Neo and Neo (2009) stated that working via PjBL enhanced students' interest, as well as their critical thinking, presentation and communication skills, and their ability to work effectively in a team.

Limited empirical research has addressed student knowledge acquisition among school children studying via forms of PjBL, let alone according to its three types (declarative, procedural, and conditional/conceptual). Boaler (1998) found that students at the project-based school performed similarly to the traditional school on the procedural questions and much better on the conceptual questions (p. 135). In an additional study, Boaler (1999) indicated that students studying via the Problem-Based Learning (PBL) approach (considered part of PjBL) were equally able to answer procedural questions that used formulas, but they were superior in answering applied and conceptual problems. Therefore, the researchers concluded the students had acquired a different kind of knowledge (Boaler, 1999, as cited in Bell, 2010). Grant and Branch (2005) found that the products of eighth-grade students' learning in a PjBL environment represented the learners' knowledge in the three areas of system knowledge, domain knowledge, and metacognitive knowledge. Kapur (2015) studied problem solving (i.e., generating solutions to a novel problem) and problem posing (i.e., generating problems and associating them with solutions) as preparatory instruction. Findings suggest that both processes are important for conceptual understanding and transfer.

The multidimensional curriculum model

Culclasure et al. (2019) mentioned a need to move into "deeper and more sophisticated PjBL implementation" (p.11), meaning that educators must take into account the challenges and opportunities of implementing PjBL in schools. Educators must also design tools for measurement and provide information about the PjBL implementation.

The model developed by Author (2015, 2018a, 2018b) illustrates an innovative way of applying PjBL to improve learning and instruction. This method is based on the premise that learners who actively construct knowledge will develop a lifelong skill that not only helps them use critical thinking to process information but also helps them predict and interpret experiences (Seimears et al., 2012). The unique characteristic of the model is that it adds different perspectives to the PBL and PjBL. It also focuses on thinking processes and thinking strategies through the application of various thinking tools.

The model is comprised of six dimensions: three interconnected basic curriculum dimensions (content, process, and product) and three additional key dimensions that orbit around, interconnect and focus on three different perspectives (personal, global, and time). Figure 1 illustrates the components of the model.

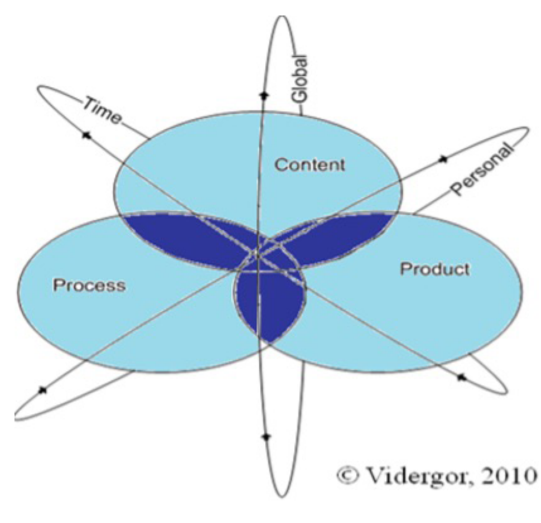

Figure 1. The Multidimensional Curriculum Model (MdCM)

The content dimension is comprised of themes, issues, and concepts preferably relating to large multidisciplinary or transdisciplinary concepts. The process dimension consists of working on more than one perspective using different teaching strategies and thinking tools in a blended learning environment. The product dimension should be multi-categorical and should reflect the new knowledge or skill gained while researching the concept or issue using the selected perspectives.

The personal perspective stresses students' personal involvement and self-awareness and creates interest and intrinsic motivation. The global perspective challenges students to look at an issue from the macro point of view—to analyze events and concepts by examining similarities and differences that involve different aspects influencing global events and trends. The time perspective prepares students to predict and cope with future changes more effectively based on past and present knowledge through the use of certain tools which help them analyze and think about possible personal or global consequences.

Developing higher order thinking and future thinking

The three thinking processes developed by MdCM are scientific thinking-inquiry; creative thinking/problem solving and inventive thinking; and future thinking.

Scientific thinking-inquiry. Scientific thinking is the examination of questions regarding certain content by performing scientific experiments (Hativa, 2003) It also includes defining the problem, formulating hypotheses, planning an experiment, analyzing experiment results, and drawing conclusions (Zohar, 1996).

Creative thinking/problem solving and inventive thinking. De Bono (1970; 2006) explained that divergent and convergent thinking processes are the basics of the creative thinking process and problem solving. Problem-solving skills, as described in the Future Problem-Solving Program Coach's Handbook (FPSP, 2001), are comprised of six steps: finding the problem, defining the problem, generating solutions, suggesting criteria, selecting the best solution, and writing an action plan. Eberle (1996) proposed the inventive thinking; Substitute, Combine, Adjust, Modify, Put to other use, Eliminate, Reverse (S.C.A.M.P.E.R.) tool for meliorating and creating new products.

Future thinking. Passig (2013) explained that future thinking is based on personal experience (or perspective) and gradually develops till the age of twenty-four. He added that taking into consideration the collective wisdom (global perspective) of the present and looking at the past offers endless opportunities to predict the future more accurately than ever. Passig (2004) further determined that awareness of Future Time Span (time perspective) can be developed using a model comprising four strategies, four levels of awareness, and five time spans.

MdCM approach to PjBL

The learning process of applying conventional PjBL, as defined above by Patton (2012), was expanded by the MdCM approach through the following stages: (1) getting acquainted with the topic—applying the personal perspective via inquiry and thinking maps; (2) working on a selected subtopic—using the personal or global perspective, developing creative thinking via thinking hats and problem-solving stages (3) designing the product of the future—using the time perspective and developing future thinking by designing an innovative product and writing a group future scenario situated in the near or far future addressing accumulated knowledge; (4) presentation of product, action plan, and future scenario to authentic audiences; and (5) reflection on the learning process.

Content	Relevant multi/transdisciplinary content (concept, issue, phenomenon, product, object etc.)		
Thinking Process	Scientific Thinking Inquiry	Creative Thinking Problem Finding and Problem Solving	Future Thinking Construction and Analysis of Concept
Thinking Strategies	• Forming a research question • Proposing hypotheses • Collecting information • Organizing information • Using graphic presentation • Inferring/drawing conclusions	• Defining problem • Suggesting solutions • Finding criteria • Identifying perspectives • Selecting best solution • Encountering different angles • Empathizing (Being in someone's shoes)	• Defining & identifying components • Classifying & analyzing • Comparing • Identifying connections • Identifying processes • Organizing in sequence • Evaluating • Meliorating • Creating • Predicting development
Tools	• TASC thinking wheel • Inquiry stages	• Six thinking hats • Types of problems • Problem-solving stages	• Thinking maps • Future scenarios
		• S. C. A. M. P. E. R	
Assessment Tools	• Building criteria for product evaluation with students • Using formative and summative assessment • Incorporating self, peer and teacher evaluation		
Products	• Mini Research	• Problem solution • Action plan • Improved model	• Concept maps • Development model • Time line • Future model • Future scenario
	Multi categorical (combined) written, oral, creative, or other		
Reflection	Meta cognition/personal reflection on thinking process • General questions on learning process • Questions regarding thinking strategies		

Table 1. Components of the MdCM Model

Designing a unit based on MdCM (Author, 2018b) addresses many components such as (a) multidisciplinary/transdisciplinary content; (b) thinking processes (c) higher order thinking strategies; (d) thinking tools (d) assessment criteria suitable for each product; (e) multi-categorial products; and (f) meta-cognitive personal reflection on the thinking process. Further elaboration on MdCM can be found in Author (2018a; 2018b) and Authors (2019).

Assessing knowledge acquisition

Shavelson et al. (2005) defined three levels of knowledge. Declarative knowledge is defined as knowing domain specific content: facts, definitions and descriptions. Procedural and schematic knowledge is about knowing how (production rules/sequences) and also why (principles/schemes). Strategic/conditional knowledge is knowing when, where and how our knowledge applies (strategies/domain specific heuristics).

Sugrue (1993) argued that in problem solving, the understanding of concepts belongs to declarative knowledge, while the understanding of the principles and production rules or sequences of steps is considered procedural knowledge. Conditional knowledge is indicated by "the existence of an instance of a concept, and/or that a principle is operating or can be applied and/or that a particular procedure is appropriate" (Sugrue, 1993, p. 22).

Li and Shavelson (2001) suggested measuring the extent of declarative knowledge through multiple-choice and short-answer questions or concept/thinking maps. Procedural knowledge should be measured through the use of performance assessments (RuizPrimo & Shavelson, 1996). On the other hand, Sugrue (1995) suggested a model for the assessment of all three levels of knowledge in which each level is assessed by three components: selection (multiple choice), generation (open-ended question), and explanation (hands-on or performance based). The current study adopted the approach that knowledge consists of three basic levels (declarative, procedural, and conditional) which should be assessed by a variety of tools (multiple choice, performance tasks and situational scenarios).

To summarize, research on PjBL focuses on skills and learning achievements. As there is lack of information on the acquisition of knowledge using PjBL, MdCM offers an innovative approach. The use of MdCM provides indications of the enhancement of cognitive abilities in the form of higher-order and future thinking: students work in groups on an issue, apply the different perspectives and thinking tools to construct new knowledge and create an innovative product accompanied by a written future scenario. The assessment of knowledge acquisition at the declarative, procedural and conditional levels constitutes a validated measurement method.

Focus of study and main hypothesis

In light of the accumulating knowledge, the current study attempted to investigate the changes occurring in students who worked on a unit of study based on the MdCM and thus applying a novel approach to PjBL. These students were compared with students who applied the conventional PjBL method, and regarded knowledge acquisition according to their grade level (elementary and middle school) and gender (boys and girls) was considered. The main hypothesis was that differences would be found between the group receiving the MdCM intervention and the control group that did not receive the MdCM intervention, regarding general knowledge and its dimensions. More specifically, we examined the following hypothesis: Students in the intervention group would score higher than the control group in overall knowledge and its dimensions' main features after the intervention. We were also concerned with students' perceptions of the learning process using MdCM relating to knowledge, cognitive, and personal gains.

Method

The current study presents a mixed-methods approach (Creswell & Plano-Clark, 2017) comprising a quantitative quasi-experimental two-group design complimented by qualitative research using semi-structured interviews and students' reflective diaries to examine the development of knowledge following the application of MdCM to PjBL.

Participants

Participants (N=563) included two groups of students from matching grade levels and similar levels and socioeconomic status (SES).

(a) Intervention group – A total of 274 students participating in the intervention program studying a unit designed to implement the MdCM approach in PjBL. These students studied in five elementary schools, Grades 4-6 (n1=145) and five middle schools, Grades 7-9 (n2=139) in urban locations in the northern and Haifa region of Israel. The intervention group experienced PjBL involving PBL based on the MdCM model using the different thinking tools and perspectives.

(b) Control group – A total of 289 students studying in the same schools and grade levels as their peers from five elementary schools (n3=140) and five middle schools (n4=149). The control group experienced the basic stages of PjBL without PBL and without the perspectives (personal, global, time) and thinking tools of the MdCM.

Cluster grouping with randomization (Dreyhaupt et al., 2017) was used to control group representation, grade level, students' cognitive level, and gender. Within each school, the selection of classes (intervention and control) was carried out randomly at class level: one class was chosen randomly to receive intervention and another class in the same grade level was randomly chosen as the control group. The two classes were selected out of three or more classes in the same grade level possessing similar ability levels, social economic status level, and gender representation. The two classes in each grade level (intervention and control) were taught by the same teachers, once using MdCM and once using traditional PjBL teaching.

The study was conducted in 10 schools and 20 classes. In Israel, schools are divided into elementary (first-sixth grades) middle school (seventh-ninth grades) and high school (tenth-twelfth grades). In regular schools, special classes are in place for special needs students (7%) and excellent students (10%). Jewish (74%) and Arab students (26%) study in separate schools because the medium of instruction for Arab students is Arabic and not Hebrew (Weissblay & Winninger, 2015).

The average number of students in an Israeli class is between 26-30 (Vinninger, 2020), and the schools are almost equal in number of boys (n=290) and girls (n=273). The population of students was well represented in terms of culture. Two Arab schools (n=112, 19.9%) represent their approximate percentage in the population. As for students' cognitive level, most students studied in regular classes (n=458, 81.3%) except for two classes of weak students in elementary school (n=57, 10.1%) and two classes of excellent students (n=48, 8.5%), which is the approximate level of representation in general population of students.

To avoid bias, students in both the intervention and control groups received and experienced the same treatment conditions, apart from the new method being assessed.

(c) Representatives of the intervention group – A total of 60 students participating in the intervention program studied a unit designed to implement the MdCM approach in PjBL (six students per class). These students studied in the same elementary (n5=30) and middle schools (n6=30) in urban locations in the north and Haifa region of Israel. In total, half of the number of students were boys and half were girls. Students were selected based on verbal ability and interest (i.e., students who could express themselves clearly and who were interested in sharing their ideas regarding the learning experience).

Procedure

The study consisted of four parts.

Part 1: This part developed an intervention program consisting of 10 units of study in different subject areas: (a) math–wise consumerism (two units, elementary and middle school); (b) science–hearing; culture and tradition – the Druze; (c) my homeland – community settlements' ; (d) music education – ; (e) the Beatles; (f) the cell phone; (g) women's status; (h)leadership in the Bible, and (i)genetics. All units applying the MdCM within the framework of the PjBL were developed by teachers studying for their M.Ed. at a college of education in Israel under the supervision of the researcher. Each unit consisted of 12 to 15 lessons and was taught during the months of April-May 2018 and April-May 2019 by the developers.

All MdCM-based units included a group investigation of a subtopic of the larger issue or concept, referring to the personal perspective using thinking maps and thinking hats. Students then solved an identified problem and wrote and presented an action plan using the six steps of future problem solving.The students investigated the development of the issue over time and created a timeline. The final stage consisted of developing and presenting the new product and a written future scenario (i.e., imagining life in the future as related to the investigated topic, incorporating the knowledge acquired throughout the unit).

Prior to implementation, units were peer-assessed based on pre-determined criteria to indicate unit compliance with the model. Control classes were taught by the same teacher applying conventional PjBL.

Part 2: This phase involved examination of students' knowledge prior to intervention and after intervention. The participants of the two groups (pre-test n=563, post-test n=560) individually performed the pre-test (i.e., responding to a knowledge questionnaire in their original study groups.) The time estimated for the pre-test was approximately 20 minutes and for the post-test, 30 minutes. At the end of the intervention program, the entire procedure was repeated with same students (n=560). The questionnaire was collected by teachers onsite.

Part 3: Intervention group students' reflective diaries were collected twice during the study period (in total, 540 entries).

Part 4: Semi-structured interviews were conducted with six selected students from 10 intervention classes (n=60). Students were interviewed by teachers after the intervention. Interviews were performed individually and lasted approximately 20 minutes each.

Parents' consent in writing was obtained for completing questionnaires related to knowledge and for the semi-structured interviews. Students were informed that the study was anonymous and that participation in the study was voluntary and did not impact student evaluation. Scores were not revealed to students and/or their teachers. Names of the schools remained confidential, and information gathered was used solely for the purpose of this study.

Measures

The tool especially developed for the current study addressed the acquisition of knowledge.

Knowledge Questionnaire. The questionnaire aimed to examine acquisition of knowledge and not skills. The questionnaire was also related to the specific topic studied in the unit and followed a specific design. The first four multiple choice questions related to declarative knowledge, asking "what" questions. The next four questions related to procedural knowledge and gave students small performance tasks, asking them to explain "how". The last part consisted of two situations relating to conditional or situational knowledge, and asked students to solve a problem by putting together the "what" and "how" in a given situation.

The questionnaire was administered to the intervention group and control group twice, before and after the intervention, to assess differences between two points of time in the same group, as well as differences between groups. The questionnaire was validated by two experts in the field of education and educational research for content validity. Reliability calculated for students' responses was .93. Factor analysis yielded three scales: (a) declarative knowledge (4 items, Cronbach's alpha = .91, total score 40 points; example question: "The sense of hearing works on deciphering: 1. Sound, 2. Sound waves, 3. Communication waves"); (b) procedural knowledge (4 items, Cronbach's alpha = .90, total score 40 points; example question: "How can we identify where the sound comes from?"); and (c) conditional/situational knowledge (2 items, Cronbach's alpha = .86, total score 20 points; example question: "A man suffers from dizziness and imbalance. What can you, as his doctor, do to help him?"). The total score of the knowledge questionnaire was 100 points. In essence, students answered a questionnaire related to the specific studied content which followed the outline of types of questions described earlier. Table 2 shows factor analysis results.

Dimension	**Knowledge Acquisition**		
	Declarative Knowledge	**Procedural Knowledge**	**Conditional Knowledge**
Alpha (.93)	.91	.90	.86
Declarative Q3	.90		
Declarative Q2	.89		
Declarative Q4	.89		
Declarative Q1	.79		
Procedural Q2		.86	
Procedural Q1		.85	
Procedural Q3		.85	
Procedural Q4		.65	
Conditional Q1			.76
Conditional Q2			.76
Explained Variance	1414.93	1227.28	290.96
Mean Score	31.42/40	24.42/40	9.1/20
(SD)	(37.61)	(37.41)	(17.05)

Table 2. Results of factor analysis

Reflective Diaries. For the reflective diaries, students were asked to write in free-form about any knowledge and/or insights acquired in relation to the unit of study.

Semi-Structured Interview. The semi-structured interviews in the current study relate to the learning experience as perceived by students from the intervention group. Students were asked, "What have you learned in this unit?" Additional questions were added for elaboration as the interview progressed. Examples include, "How can you use what you have learned?" and "What have you gained from the learning experience?" Other questions relating to different areas are not reported here.

Analysis

To ensure trustworthiness of the data and findings (Santiago-Delefosse et al., 2016), multiple sources of data collection (i.e., questionnaire, indicators, and individual interview) were used to help triangulate the data and confirm the findings and interpretations.

Pearson correlations were performed to establish connections between knowledge and thinking dimensions. The sum of scores was calculated for knowledge in general, and scores were calculated separately for each dimension. Paired sample tests were performed to examine differences between intervention groups and control groups according to time (pre-and-post). Repeated measures analysis was used to examine differences in variables according to group (intervention and control), grade level (elementary and middle school) gender (boys and girls) and time (pre-post)—in general and for separate dimensions, while calculating sums.

Student scores for the second and third parts of the knowledge questionnaire (procedural and conditional knowledge) were calculated via an indicator based on the scales and items drawn by factor analysis, with a single item scoring between 0 and 10 points and all 10 questionnaire items scoring a maximum of 100 points. Development of the indicator applied an inter-coder agreement procedure (Keeves, 1998).

Level I Codes **Original Responses from Students**	**Level II Codes** **Categories Generated from Level I Codes**	**Level III Codes** **Consistent Themes Created from Level II Codes**
"I learned the subject of consumerism in depth" "I found out how severe the problem of hearing was in the past"	Learning about the Subject (Declarative)	Knowledge Acquisition
"The thinking map enabled me to classify the musical instruments according to similarities and differences". "I learned how to find the best solution to a problem in hearing"	Leaning How to Use Knowledge via Thinking Tools (Procedural)	
"I can apply many things in real life situations like: convincing other people, or how to solve a problem, or make the right decision to buy something". "Whenever I have a dilemma and need to decide to buy or not to buy something, I try to use the six thinking hats"	Application of knowledge in Everyday Life Situations (Conditional)	
"I learned that I can think differently" "I learned that I like creativity and thinking out of the box" "I learned to believe in myself and my abilities"	Learning About Myself	

Table 3. Three levels of analysis of students' replies

Definitions of problematic statements were refined, and an additional random sample of that content was categorized to obtain 85% reliability.

Qualitative analysis of the semi-structured interviews and reflective diaries employed Creswell and Poth's (2016) thematic content analysis focusing on key issues or emerging themes. An initial reading of all data was conducted, and notes were taken to identify emerging categories and themes. During second and third readings, a coding scheme began to emerge and was later refined. Relationships among categories and subcategories were identified and clarified. Emerging core categories consisted of learning about the subject, learning how to use knowledge via thinking tools, application of knowledge in everyday life situations, and learning about myself. Table 3 presents three levels of analysis of students' replies relating to knowledge acquisition.

A reliability of 87% was calculated for the analyzed content, performed by two independent coders who were experts in teacher education, following a standard intercoder reliability process (Miles & Huberman, 1994).

Results

Knowledge acquisition differences between groups

General knowledge acquisition. Our main hypothesis that differences would be found between the intervention and control groups in mean scores of knowledge acquisition and its dimensions in general after the intervention program was confirmed. Table 4 presents differences between the intervention and control groups according to mean differences, T, F and effect size values.

The difference between the two groups is significant and shows medium to large effect size. No differences were detected between the intervention and control groups in pre-test in total knowledge acquisition and its three dimensions, which indicates that differences lie in the post-test. Knowledge scores in post-test show 14.34% or points difference between the intervention and control groups in the sum of their knowledge acquisition.

Knowledge dimensions. Knowledge dimensions investigated in current study were declarative, procedural, and conditional knowledge. Table 5 presents differences in knowledge acquisition and dimensions between pre-test and-post-test scores of intervention and control groups according to T, F and Effect Size values.

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The dimension showing the highest level of improvement was conditional knowledge. The percentage of knowledge acquisition generally dropped, while level of knowledge acquisition rose in both groups. The intervention group

	Pre-Test Mean (SD)	Post-Test Mean (SD)	MD	T	F (df= 1,560)	Effect Size
Intervention Group (n=274)	47.89 (8.80)	81.87 (6.09)	-33.98	-27.83***	300.54***	0.681
Control Group (n=289)	48.99 (7.53)	68.63 (7.83)	-19.64	-5.55***		

Table 4. Differences in knowledge acquisition between intervention and control groups according to T, F and Effect Size values.

	Intervention Group			Control Group				
	Mean (SD)		MD	Mean (SD)		MD	F	Effect Size
	Pre-Test	Post-Test		Pre-Test	Post-Test		(df=3)	
	(N=274)	(N=272)		(N=289)	(N=288)			
Declarative Knowledge (40 p.)	25.40	36.51	-11.11	25.42	33	-7.58	52.73**	.353
	(9.92)	(6.42)		(9.13)	(7.06)			
Procedural Knowledge (40 p.)	17.17	32.05	-14.33	18.28	25.61	-7.20	178.12**	.547
	(9.05)	(8.68)		(9.49)	(8.26)			
Conditional Knowledge (20 p.)	5.32	13.86	-8.54	5.29	10.02	-5.29	47.89**	.329
	(6.75)	(6.93)		(6.45)	(6.93)			
** p<0.001								

Table 5. Differences in knowledge acquisition and dimensions between pre-and-post test scores of intervention and control group according to T, F and Effect Size values.

mastered 69.3% of the application of conditional knowledge (13.86 points out of 20) while the control group mastered 50.01% (10.02), which is a 19.29% difference. In procedural knowledge, the intervention group mastered 80% (32.05), while the control group mastered only 64% (25.61), which is a difference of 16%. In declarative knowledge, the difference between the intervention and control groups was only 9%, which was the lowest of all dimensions.

Knowledge acquisition differences within groups

We further sought to examine differences in knowledge acquisition in general and its three dimensions within the two groups. Table 6 shows differences in knowledge acquisition and dimensions between pre-and-post test scores within the intervention and control groups according to T, F and effect size values.

General knowledge acquisition. A main effect was detected for both groups, with the intervention group showing a higher level of difference between pre-test and post-test (F[6,1112]=359.874, p <.001, ES= .771) compared to the control group (F[6,1120]=281.283, p <.001, ES= .720). The intervention group improved knowledge by almost 32 points/percent, while the control group improved by approximately 20 points/percent.

Knowledge dimensions. A main effect was detected in all three dimensions in the intervention group. Effects for pre-post intervention declarative knowledge (F[10,1002]=176.777, p <.001, ES= .735), procedural knowledge (F[8,1004]=49.303, p <.001, ES= .651), and conditional knowledge (F[6,1112]=86.64, p <.001, ES= .446) indicated there was a significant improvement in all dimensions after the intervention. The intervention group mastered 91.3% of declarative knowledwge, 80% of procedural knowledge, and 69.3% of conditional knowledge. The most improved type of knowledge in the intervention group was procedural (17.17 pre and 32.05 post, 14.33 improvement out of 40 points/36%).

Knowledge acquisition according to background variables

To further investigate differences within the intervention group, knowledge acquisition and its dimensions were examined by background variables such as grade level and gender.

Knowledge acquisition according to grade level. Table 7 shows differences in pre-and-post test scores of knowledge acquisition and dimensions within intervention group according to school in Mean, Mean Difference, F and Effect Size values.

		Pre-Test Mean (SD)	Post-Test Mean (SD)	MD	T	F (df=3)	Effect Size
Declarative Knowledge	Intervention	25.40 (9.92)	36.51 (6.42)	-11.11	-10.53**	110.78**	.25
	Control	25.42 (9.13)	33 (7.06)	-7.58	-6.68**	44.19**	.12
Procedural Knowledge	Intervention	17.17 (6.75)	32.05 (6.93)	-14.33	-12.19**	168.74**	.44
	Control	18.28 (9.49)	25.61 (8.26)	-7.20	-6.63 **	43.08**	.11
Conditional Knowledge	Intervention	5.32 (6.75)	13.86 (6.93)	-8.54	-10.70**	113.76**	.27
	Control	5.29 (6.45)	10.02 (6.93)	-5.29	-6.25**	39.02**	.11
Total Knowledge Acquisition	Intervention	47.89 (8.80)	81.87 (6.09)	-33.98	-18.42**	279.67**	.51
	Control	48.99 (7.53)	68.63 (7.83)	-19.64	-9.50**	90.0 8**	.20
**p<0.001							

Table 6. Differences in knowledge acquisition and dimensions between pre-and-post test scores within intervention and control groups according to T, F and Effect Size values.

	Intervention Group: Elementary School			Intervention Group: Middle School				
	Mean (SD)		MD	Mean (SD)		MD	F	Effect Size
	Pre-Test (N=145)	Post-Test (N=142)		Pre-Test (N=139)	Post-Test (N=138)		(df=3)	
Declarative Knowledge	26.63 (10.32)	34.69 (6.87)	-8.06	24.35 (9.39)	38.05 (6.18)	-13.70	40.42**	.27
Procedural Knowledge	17.83 (10.37)	28.38 (9.21)	-10.55	16.94 (9.16)	32.24 (7.97)	-15.30	51.38**	.34
Conditional Knowledge	4.82 (7.39)	12.96 (7.17)	-8.14	6.15 (6.81)	15.07 (6.53)	-8.92	39.58**	.27
Total Knowledge Acquisition	49.28 (11.68)	76.03 (6.97)	-26.75	47.54 (7.55)	85.36 (7.17)	-37.82	97.01**	.47
** p<0.001								

Table 7. Differences in pre-and-post test scores of knowledge acquisition and dimensions within intervention group according to school in Mean, Mean Difference, F and Effect Size values.

General knowledge acquisition. A main effect was found for pre-post intervention according to school (F[3,1110]=3.122, p <.05, ES= .028), showing a mean difference of 10 points improvement between elementary school (MD= -26.75, p <.001) and middle school (MD=-37.82, p <.001) and a difference of 9.33 points in the mean score in post-test (76.03 [6.97] <85.36 [7.17]), respectively. Findings show that in the intervention group, the elementary school starting point of knowledge was a little higher, but students showed less improvement compared to middle school, and in post-test they reached a lower level of knowledge acquisition.

Knowledge dimensions. Main effects in all three knowledge dimensions were found in the intervention group. Findings regarding declarative knowledge indicate that elementary school students' starting point was a little higher (26.63) compared to middle school students (24.35), but middle school students improved significantly (13.70 out of 40 points which is 34.25%) compared to elementary school students (8.06 out of 40 points which is 20%). In both elementary and middle school, the procedural and conditional knowledge starting points were similar, but middle school students showed a higher level of improvement. Middle school students scored higher in procedural knowledge post intervention (32.24/80.6%) as compared to elementary school students (28.38/71%), improving by 15.30 points/38% and 10.55 /26.4% respectfully. In conditional knowledge, middle school students scored higher, post intervention (15.07/75%), as compared to elementary school students (12.96/64.8%).

Students' perceptions of knowledge acquisition

Students' perceptions of knowledge acquisition were measured via a semi-structured interview conducted post intervention, in which they were asked what they had learned in the unit. Analysis of the interviews yielded four subcategories: learning about the subject, learning how to use knowledge via thinking tools, application of knowledge in everyday life situations, and learning about myself.

Learning about the subject (declarative knowledge). Students related to the different subjects to which they were exposed while learning a unit of study using MdCM-based PjBL. About the subject of consumerism, students said, "I learned the topic of consumerism in depth," and another student added, "I learned you need to treat people with respect and listen to what they want and need." About the topic of hearing, a female student said she "found out how severe the problem of hearing was in the past." A male student mentioned that he learned that "a major change occurred in hearing aids and procedures over the years." Students who learned about community settlements explained that they "learned many new things about types of settlements." Another student elaborated and related to the process of decision making on membership: "I learned that it does not matter if a person is different, in the end we are all equal." All statements relate to what the students perceived they had learned, or, in other words, what constitutes their declarative knowledge of the topic.

Learning how to use knowledge via thinking tools (procedural knowledge). Students reported that they learned how to use different thinking tools that helped them learn about the topic. Some students explained that "the use of thinking hats showed me how to organize the material about hearing logically." Another student added that thinking maps helped him perform the process of analysis and comparison, explaining that "the thinking maps enabled me to classify the musical instruments according to families, similarities and differences." Several students related to the thinking hats and the experience of putting themselves in the shoes of others—in learning how to empathize: "I learned how to use the thinking hats and put myself in the character's place to feel and understand and solve the dilemma of the Druze." Other students related to the problem-solving stages and process, indicating that "learning how to use the problem-solving stages helped me find the best solution to the problem of hearing." All statements relate to how the students perceived they had learned to use the different tools in context of the subject, or, in other words, what constitutes their procedural knowledge.

Application of knowledge in everyday life situations (conditional knowledge). Students reflected on their learning and suggested different ways of how to use their accumulated knowledge in real life situations in the different subjects they studied. Several students related to the thinking hats: "whenever I have a dilemma and need to decide whether to buy or not to buy something, I try to use the six thinking hats," and "the thinking hats will help me decide in (real) life situations between two options." Other students related to the future scenario explaining that "I use the future scenario to think what I would like to do in many years to come," and "the future scenario helps me to think about what I need to do to make my future better, safer, and more interesting." A student learning about consumerism commented that he could "apply many things in real life situations, like convincing other people, or how to solve a problem, or make the right decision to buy something." All statements relate to the students' perceptions of the application of what they have learned in real life situations—what constitutes their conditional knowledge.

Learning about myself. This last subcategory relates to students' insights about themselves from being exposed to the topics, tools and strategies of learning based on MdCM. In learning about their personal characteristics, students mentioned: "I understood that I am a good friend and help other people," and "I learned that I like changes." Another student shared her concern, expressing that "I learned that it is still very difficult for me to work with and accept children who are different than me." Additional insights relating to characteristics were shared by a boy stating "I realized that sometimes I am very impulsive and want things now," and a girl stating "I learned to believe in myself and my abilities."

Other students related to cognitive characteristics, reporting that "I learned that my thinking is greater than what I thought," and "I learned I am able to think like grownups." Several students added that "I discovered I could think differently," and "I learned about myself that I like creativity and thinking outside the box." All statements relate to how the students perceived themselves and their personal gains from studying the topics.

To summarize, quantitative findings indicate that compared to the control group, the intervention group students significantly improved their knowledge acquisition and all its dimensions (declarative, procedural, and conditional). Qualitative findings provide an insight into what they learned, how they learned to use the knowledge via thinking tools, and in what future situations they suggest this knowledge could be applied. They also showed awareness and learning about their personal and cognitive characteristics from studying an McDM-based unit of PjBL.

Discussion and conclusions

Knowledge acquisition and its dimensions

The current study established a correlation between knowledge acquisition and types/processes of thinking—scientific, creative and future thinking. Anderson and Krathwohl (2001) support this conclusion and explain that new knowledge is created using problem solving, critical thinking, and creative thinking. Moreover, Perkins et al. (2000) indicates that control of knowledge in a specific domain develops thinking in that domain. The current study did not focus on thinking skills, but a clear connection exists between acquisition of higher-order thinking and new knowledge construction.

General knowledge acquisition. Findings regarding the total sum of knowledge acquired by students studying a unit of MdCM-based PjBL indicated that there were no prior differences between the control group and the intervention group, in that the starting point was similar, although higher than anticipated in both groups. Post-tests showed a significant difference between the intervention and control groups of approximately 14%, and general control of more than 80% of the knowledge. This difference may have occurred as a result of employing different types of thinking processes and tools (Author, 2018a). These processes and tools may have increased students' interest and engagement in the subject; therefore, they created better construction of new knowledge. Within the intervention group, we found 33% improvement between the pre-test and post-test, which may indicate that teaching-learning that applies the MdCM in PjBL may offer greater potential for knowledge acquisition.

Dimensions of knowledge acquisition. Examination between groups detected significant differences. Improvement in conceptual knowledge between the pre-test and post-test in the intervention group doubled, compared to the control group. The assumption is that this kind of improvement may occur due to the incorporation of thinking maps, which help students analyze, synthesize and conceptualize issues or ideas using visual and figurative representation, and allow for better understanding and memorization (Hyerle & Alper, 2011).

Regarding conditional knowledge, a 20% difference was detected between the intervention and control groups, in favor of the former. Conditional knowledge as described by Shavelson et al. (2005) is knowing when, where and how our knowledge applies. Sugru (1993) explained that conditional knowledge is indicated by "the existence of an instance of a concept, and/or that a principle is operating or can be applied and/or that a particular procedure is appropriate" (p. 22). This difference may occur as a result of using the problem-solving stages, as well as dealing with authentic issues that are relevant to students' lives, connecting them to their personal perspective and practicing the use of accumulated knowledge for predicting future actions (Authors, 2019).

Within the intervention group, procedural knowledge showed the highest level of improvement, mastering 70% of knowledge in that area. Li and Shavelson (2001) define procedural and schematic knowledge as knowing "how" (production rules/sequences) and also "why" (principles/schemes). This improvement may have been caused by the use of thinking maps, which help organize the material, analyze concepts, and recognize sequence, similarities, differences, and connections (Hyerle & Alper, 2011). Also, as McNeil et al. (2012) explains, the development of procedural knowledge might affect and be affected by the development of conditional knowledge and vice versa, as the bi-directional view. According to the iterative view of knowledge development (Schneider et al., 2011), types of knowledge are connected. When one type of thinking is not fully developed, another type could emerge because one type of knowledge clearly influences the development of the other.

Conditional knowledge was found as the hardest to develop and showed lower level of mastery when compared to the declarative and procedural knowledge developed in the intervention group. This result may be caused by the nature of conditional knowledge—applying the solution of ill-structured problems in real-life situations (Walker & Leary, 2009; Savery, 2015). As conditional knowledge is the most difficult to build, using different models of problem-solving (FPSP, 2001; Isaksen et al., 2010; Hesse et al., 2015) on a regular basis in simulations of real-life situations will most likely contribute to its development.

Significant differences between elementary and middle school students are related to age difference and precocity to acquire knowledge in general and on a higher level. No differences were detected between boys and girls, which is an indication of their equal ability to acquire and apply knowledge at all three levels.

Students' perceptions of knowledge acquisition and development of personal competences. In the semi-structured interviews and reflective diaries, students indicated what they had learned in the unit using MdCM-based PjBL. Students' perceptions confirmed the strong connection between knowledge acquisition and thinking tools detected earlier, especially in procedural knowledge, explaining they have learned how to use the tools in the context of learning. Regarding conditional knowledge, students focused on real-life situations in which they could use the acquired knowledge aided by the group future scenario. They explained when, where and how the subject evolves in the future, based on their learning about its past and present (Author, 2015, 2018a; Authors, 2019).

Students' awareness of personal characteristics was divided into cognitive gains, such as thinking and creativity, followed by their self-awareness. They also reported awareness of personal characteristics, or gains such as accepting others, being flexible and showing leadership as a result of experiencing learning through PjBL and PBL based on MdCM. The awareness of their abilities and personal traits may be enhanced by the personal perspective of MdCM, which challenges students to look at the topic and investigate it from their own point of view. Students are also challenged to extend leadership skills, asking themselves who they need to be or become to take control of the addressed issue (Author, 2018a; 2018b).

Limitations

The study was conducted with a small sample of students from elementary and middle school in Israel. The study sample should be enlarged to include other countries in Europe and the USA, which could broaden our understanding of the contribution of MdCM to the acquisition of knowledge and personal competences. The study examined the knowledge acquisition among mainstream elementary and middle school students. Further research might investigate the benefits of using MdCM for the acquisition of knowledge and cognitive and personal competences among gifted and special needs students. Finally, the study examined the acquisition of knowledge, and cognitive and personal competences applying MdCM, therefore further research might investigate its contribution to the development of intrinsic motivation and learning strategies.

Conclusions and recommendations

The current study revealed the impact of the innovative approach MdCM offers PjBL implementation in terms of (a) enhancing different types of knowledge acquisition (i.e., declarative, procedural and conditional) in both elementary and secondary school students in different disciplines or topics; (b) establishing a close link between knowledge acquisition and scientific, creative and future processes of thinking, contributing to knowledge acquisition via thinking tools applied by MdCM; (c) raising students' awareness of the cognitive and personal gains of learning via MdCM.

Teachers could use the MdCM model to develop all types of thinking (especially higher-order thinking) among elementary and middle school students using PBL and PjBL as main strategies. To increase knowledge acquisition further alongside cognitive and personal competences, additional recommendations include (1) devoting more time to the development of procedural and conditional knowledge when implementing MdCM to incorporate all three processes of thinking—scientific, creative, and future thinking; (2) developing conditional knowledge by using PBL on different occasions and in different forms; (3) focusing on students' cognitive abilities and personal competencies developed during the construction of new knowledge; and (4) applying the different thinking tools and perspectives in the modules of study, as these constitute the basic tools for constructing new knowledge and developing students' cognitive and personal abilities.

To develop their competence in using the MdCM effectively, teachers should be offered professional development on the MdCM-based approach to PBL/PjBL, accompanied by training in the design of multidisciplinary content-based units. The professional development course should be accompanied by a follow-up on implementation to enhance the impact of the model and help students gain relevant procedural and conditional knowledge, as well as cognitive and personal competences.

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Dr. Hava Vidergor, PhD is a senior lecturer of curriculum and instruction. Her research interests center on curriculum planning and design, innovative teaching strategies, hybrid learning environments and gifted education.

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