

# Mathematical connection skills and their relationship with productive thinking among secondary school students

Lina Fouad Jawad

Computer Department, College of Education for Pure Sciences, Ibn Al-Haitham, University of Baghdad, Baghdad, Iraq

## ABSTRACT

In recent times, it has increasingly become imperative to demonstrate the function which mathematics plays in the different aspects of life in general, especially in terms of solving problems and decision-making. Mathematics is applied in solving different problems that individuals and society at large are faced with daily. Also, it plays a crucial role in the lives of students by enabling them to prepare for life challenges through the creation of positive interaction between the students and real-life situations, and the development of their mental capabilities in terms of problem-solving and creativity. It also helps them to be responsible and develop self-confidence. This research seeks to find out whether there is a correlation between the learners' ability to connect mathematics with its branches and other sciences, as well as to their daily lives and their ability to think productively. This is achieved using two statistical tests, whereby one of the tests is used in determining the mathematical connection skills possessed by the learners, while the other is employed to measure productive thinking among learners. A sample of 300 students in fourth-grade science from Baghdad was used for the study. The results of the analyses revealed that mathematical connection skill is positively correlated with productive thinking.

**Keywords:** Mathematical connection, Mathematical connection skills, productive thinking.

### *Corresponding Author:*

Lina Fouad Jawad

Computer Department, College of Education for Pure Sciences / Ibn Al-Haytham

University of Baghdad

Baghdad, Iraq

E-mail: [lina.f.j@ihcoedu.uobaghdad.edu.iq](mailto:lina.f.j@ihcoedu.uobaghdad.edu.iq)

## 1. Introduction

Generally, mathematics is a field that is representative of a system of interwoven correlations that are combined as one curriculum. Mathematics is underpinned by the constructivist theory which shows that any information that has no relationship with the information needed by learners plays no clear role in their cognitive formation, given that learners are more interested in building and installing real knowledge in their brains [1]. Such knowledge is also acquired from information that has been previously acquired from different sources [2, 3]. As a result of the important role played by mathematics in the different aspects of life, the National Council of Teachers of Mathematics (NCTM) has shown interest in mathematical connections, and as such have set goals towards achieving the standard connection between mathematical concepts, branches of mathematics, and other subjects, as well as the relationship between mathematics and daily living [4-6]. To a large extent, the mastery of learning mathematics is associated with the learners. The mastery of learning mathematics is largely related to the student's intelligence and expressive ability, i.e. how well they can express ideas. The field of mathematics is known to be the most robust field of science that supports the development of different thinking modes, because of its nature which enables the analysis of ideas and efficient thinking. Productive thinking refers to a pattern of thinking that is related to mathematics and allows the learner to unleash the ideas in their minds for the production and generation of novel ideas [7-9]. One of the key goals of the present era is to teach productive thinking. In a report (titled "We are learning to be"), it was noted that the world is increasingly evolving as a result of economic and social factors, and as such it becomes imperative for humans to think and be a creative in a fashion that helps them to achieve their future aspirations [10-13].

### 1.1. Research questions

1. Do secondary school students possess mathematical connection skills?
2. Do secondary school students possess the skills of productive thinking?
3. Is there a correlation between mathematical connection skills and productive thinking among secondary school students?

### 1.2. Search terms

**Mathematical connection:** refers to the understanding of the overlap and synergy between mathematical concepts, the understanding of the interwoven correlations between the main concepts and sub-concepts, as well as the realization of mathematics as a large conceptual system [14-16].

**Mathematical connection skills:** refers to the process through which mathematics becomes of integrated relevance and a close texture (both connected and interconnected). It is also described as the skills possessed by students which make them be able to carry out investigations on the concepts of mathematics alongside their generalizations while allowing them to establish connections between mathematical knowledge and its real-life applications [17]. Within a procedural context, mathematical connection skills can be described as the students' ability to establish a connection between the different fields of mathematics with each other, and mathematics with real life and other areas of science. This is based on the degrees acquired by the sample of the study in terms of the mathematical connection skills test.

**Thinking:** Involves several invisible intellectual activities performed by the human brain when subjected to a stimulus that is received by one or more senses in search of meaning in a given circumstance or experience [18-21].

**Productive thinking:** this is a concept that is concerned with finding new correlations or novel ways. Achieving this requires a series of skills, and abilities, including originality, flexibility, fluency, imagination, and expansion. Within a procedural context, productive thinking is described as the ability of the study sample to obtain thinking skills that allow them to think critically and innovatively. Productive thinking can only be determined by the scores that have been obtained by the study sample in terms of the productive thinking test.

## 2. Theoretical background

### 2.1. Mathematical connection

Mathematical power is one of the critical areas of students' performance that must be subjected to evaluation as considered in the NCTM project, which encompasses Principles and Standards of School Mathematics. This mathematical power is one of the key factors that determine how mathematics is learned by students, i.e. there logical thinking, discovery, and connection abilities. Mathematics enables critical and creative thinking and can be used to find solutions to new and uncommon mathematical problems. Mathematical power refers to the maximum amount of mathematical knowledge which a student must possess to be able to communicate and reason within the context of mathematics and in life generally [5, 22]. Three major dimensions constitute mathematical power:

- The first dimension: this dimension is concerned with the contents of mathematics such as geometry, numbers, probability, spatial sense, numerical sense, numbers, measurement, algebraic thinking, and data processing.
- The second dimension: this dimension represents mathematical abilities like problem-solving, procedural and conceptual; knowledge.
- The third dimension: the third dimension denotes the patterns of the different processes, including, mathematical inference, mathematical interdependence, and Mathematical representations. One of the key elements of mathematical power is mathematical connections, which denotes one of the processes found in the third dimension, and this process of mathematical connection represents "the network of intellectual construction on which ideas are built and linked to each other by relationships and laws, not a separate group."

### 2.2. Mathematical connection skills

Mathematical progressions can only be achieved through mathematical connections, given the fact that it is often applied in different areas of science. Mathematical connections also help a learner to achieve meaningful and advanced learning by having a better and consistent insight into the interconnectedness between topics [23]. Based on the review of literature done in this work, different works in which mathematical connection skills have been classified, are presented in Table 1 below.

Table 1. classifications of mathematical connections skills

Author	Connection Skills			
[24]	Mathematical connection in problem-solving	Mathematical connection in procedural knowledge		Mathematical connection in conceptual knowledge
[25]	Connecting mathematics	Connecting mathematics to other sciences		Connecting mathematics to daily life
[26]	Recognize the correlation between mathematical ideas and how they are utilized.	Understand how mathematical ideas relate, and how they can be integrated, as well as how they can be built on each other.	Recognize and use mathematics in a context outside of mathematics	Understand the mathematics and its uses in other sciences
[27]	Internal Connections (Inside Mathematic)		External Connections (outside the context of mathematics)	
[28]	link the concepts in mathematics itself	to link, the concept of mathematics with concepts in other fields	to link the concepts of mathematics with everyday life.	
[29]	The connection between mathematical concepts	The connection between mathematics and other sciences	The connection between mathematics and everyday life	

### 2.3. The importance of mathematical connection in teaching and learning mathematics

1- Mathematical connection represents one of the most critical requirements for understanding what is taught. Teaching is an activity that is mainly aimed at developing the learner's understanding of things being taught, and the mathematical connections enable the learner to gain insight into learning experiences and mathematical ideas, it also entails the efforts put in by learners to understand themselves and others by connecting mathematical knowledge and organizing them. This way, the learner can solve mathematical problems using modeling. In other words, mathematical connection skills help a learner to model mathematical problems to provide a solution.

2- Mathematical connection is a means through which the relatedness of concepts is ascertained: within this context, the connection is regarded as a collection of multi-faceted ideas that can be used to demonstrate principles and correlations associated with mathematics. More these collections of ideas can be used to visualize the correlations between mathematical concepts and ideas, which cannot be used independently to represent something.

3- Mathematical connection is a tool that enables problem-solving: one of the goals of mathematical connections is to motivate the use of this interdependence for problem-solving; if a robust and flexible set of problem-solving tools are possessed by the learners, they will be able to apply and translate various representations of the same instance of a given problem. More so, mathematical connectedness can enable students to achieve mathematical harmony.

4- Mathematical connection as described by the NCTM (2000) is a process rather than a method, and through this process, mathematical ideas are built. In the NCTM document, it was noted that mathematical connection is not a learning method or theory. Conversely, it refers to the means and process through which mathematical ideas are built, and it can help students to represent their ideas in an organized way. Thus, one of the roles of

mathematical connection is to promote the increasing growth of students' understanding and ability to provide solutions to problems that they are faced with. Also, with mathematical connection tools, learners can construct and install models that support the acquisition of mathematical knowledge in a simplified manner [30].

#### **2.4. The role of the learner in developing mathematical connection skills**

Scientific thinking, problem-solving of the acquisition of new knowledge can only be achieved by a learner who acts positively towards the process of learning. In other words, having a positive attitude towards learning can help a learner to reap the benefits of efficient learning. Also, the learners must be proactive, otherwise, they cannot benefit from the process of learning. Apart from that, the active participation of learners in the learning process is crucial to the development of mathematical connections, while increasing the learning abilities which include the following:

1. Making sound judgments and meaningful decisions through the application of standard rules.
2. Understanding how to connect ideas sequentially.
3. Gaining the ability to connect mathematical ideas and experiences, and apply them in the correct way.
4. Gain insight into how others relate to their feelings and thoughts.
5. Helps learners to be committed to precision and accuracy [31].

#### **2.5. The teacher's role in developing students' mathematical connections**

- 1- Selection of mathematical problems including mathematical ideas in the topics under study.
- 2- Encourage the discovery of novel mathematical ideas through the use of past experiences.
- 3- Support students in establishing mathematical connections between the ideas that have been extracted from procedures, generalizations, and concepts, and then apply them to solve problems associated with mathematics.
- 4- Creating and defining sports situations that demonstrate how the topics of sport are connected to other topics, other subjects, and the lives of other students.
- 5- Establishing several interconnections between the branches of mathematics.

#### **2.6. Productive thinking**

The concept of productive thinking was first introduced by Frihtemer in his book which is focused on productive thinking. In this book, the use of different examples, ranging from simplified understanding to complex analysis of the process of thinking was employed, reaching the core of the problem. Productive thinking also helps the learner to gain insight into the structural composition of the situation and access to understanding to ensure the significance and meaningfulness of the issue [32, 33]. The application of productive thinking to the process of learning can help the learner to have a better understanding of knowledge content [34]. For one to be able to think in this manner, he/she must be able to create a picture of the situation through imagination and plan. More so, this kind of thinking also needs reasoning, problem-solving, decision-making, and judgments. It also involves the generation of ideas, rather than the mere analysis of arguments [35].

#### **2.7. Productive thinking requirements**

According to psychologists, productive thinking can only be achieved through two major requirements, which are creative thinking and critical thinking.

**Critical thinking:** this type of thinking is a thinking pattern used by individuals when there is a need for them to make a judgment or express an opinion regarding a topic or an issue.

**Creative thinking:** this is the kind of thinking that produces solutions or new ideas that are completely different from the usual ones. Through this kind of thinking new ideas emerge.

##### **2.7.1. Critical and creative thinking in mathematics**

Mathematics is not only concerned with information and facts in particular fields, it is also a way of thought and direction applied when solving a wide range of problems, and as such, mathematics teachers need to extend their teaching beyond just the dissemination of facts to students, and incorporate the building of skills that helps them to discover facts and obtains them. Mathematics teachers should also teach the students how the facts can be used and how they're related to other facts.

Mathematics is one of the most important fields of study that are based on different types of thinking and thinking patterns, and requires a lot of mind work, i.e. mapping ideas in mind and relating them to problems before producing results. One of the most effective ways of teaching mathematics as a subject is to use mathematics as a means of developing critical thinking among students and teach them about its relevance and the need to apply it in every area of life.

Even though mathematics is regarded as one of the most important subjects that helps in stimulating creativity and innovative thinking, creativity cannot be merely achieved, it only occurs when there is a challenging problem that needs to be solved. Therefore, the mind becomes actively engaged in searching for new ideas. Mathematics also helps in developing organizational skills, which allows an individual to organize content flexibly. More so, it is robust in terms of problem situations in which students need to find solutions according to the nature of each situation [36].

### **2.7.2. The relationship between critical thinking and creative thinking**

Even though creative thinking is informal, theoretical, productive, contemporary, and divergent, while critical thinking is deductive, right-wing, convergent, and requires testing of hypothesis, it cannot be concluded that they are independent of each other. This is due to the fact that creativity results from critical thinking; critical thinking must be applied to produce new ideas. This means that critical thinking is an evaluative approach that is applied by creative people when seeking optimal solutions. On the other hand, creative thinking is perceived on a generative basis. Regardless of their characteristics, and the role they play, they are not independent of each other, rather they are complementary, and in some cases share similar characteristics. Thus, it is not realistic to have a clear distinction between the two, given that they are characterized by novelty, qualitative evaluation, and production. The ideas generated through critical thinking are normally subjected to evaluation, which focuses on examining the validity of the ideas and how suitable they are for use in a given situation.

### **2.8. Productive thinking skills**

The role of productive thinking cannot be over-emphasized as it enables learners to broaden their horizons in terms of the way they perceive things and helps them to explore different possibilities. Through productive thinking, individuals can think creatively [37]. Productive thinking occurs when critical and creative thinking are combined, thereby resulting in the production of novel ideas [38, 25].

Thus, productive thinking is characterized by components that are similar to those of critical and creative thinking. Such components include flexibility, fluency, sensitivity to the problem, novelty, prediction of assumptions - conclusion - evaluation of arguments - interpretation).

1- Fluency: involves being able to produce a variety of ideas and alternatives.

2- Flexibility: refers to the skill possessed by an individual for generating novel work patterns, rather than being restricted to a given set of patterns. In other words, flexibility allows individuals to do things in different ways, rather than following some extant patterns or ways of doing things.

3- Originality: distinguishing between ideas and the ability to influence beyond the ordinary of ideas and generate authentic responses characterized by uniqueness and acceptance.

4- Sensitivity to the problem: described as the ability of an individual to perceive tools, objects, or ideas that others may not perceive.

5- Predict assumptions: It is the ability to distinguish between the degree of truthfulness of the information and its untruthfulness, and between the truth of an opinion and the purpose of the given information.

6- Conclusion: this involves being able to conclude from specific facts that are derived through assumption or observation.

7- Evaluating arguments: refers to being able to reject or accept an idea that is perceived, and being able to know the difference between primary and secondary sources, as well as strong arguments and weak arguments. It is also concerned with having the ability to make a judgment on the adequacy of the information.

8- Interpretation: involves the identification of problems, logical explanations, and then determining the acceptable generalizations.

#### **2.3.1. The teacher's role in developing the stages of productive thinking in the classroom**

1- Organize the class in a way that allows students to interact.

2- Encouraging students to ask many questions about the topic.

3- Encouraging students to give different answers.

4- Encouraging students to be original through questions.

- 5- Encouraging judgments and mastery by inviting students to add details.  
6- Assigning students to evaluate their best ideas.

Table 2. Related studies

Author & Year	Objective	Method	Sample	Tools	Results
[39]	describe student productive thinking in solving the problem	Descriptive	38 high school students	the questionnaire, a test, and interviews	thinking productively leads to identifying the problem, writing facts clearly, and making the calculation
[40]	analyzing and students' mathematical connection ability in the linear equation system	descriptive	30 of 11 <sup>th</sup> high school students	test for mathematical concepts	sample unable to connect mathematical concepts with other sciences.
[29]	describe students' mathematical connection skills in solving the problem	Descriptive	57 students	mathematical connection skills in the algebraic test	the sample is lowest in connecting mathematics with other sciences.
[41]	Knowing the Role of Mathematical Connections in Mathematical Problem Solving	Descriptive case study	2 of 8th-grade students	Tests of mathematical connection skills & problem-solving	The relationship is direct between mathematical connection skills and mathematical problem solving
[42]	investigate the relationship between productive and re-productive thinking with solve insight problems	Descriptive	-	(KAI) test and a battery of spatial insight problems	productive and re-productive thinking lead to predicting performance on spatial insight problems

### 3. Research methodology

In this study, the use of a descriptive approach was employed because of its importance to the nature of the research conducted. This research approach can be used in different kinds of studies including comparative and correlative studies. The research population consisted of a random sample of secondary schools, while the research sample consisted of (300) fourth-grade students, that were selected using a stratified sampling technique.

### 3.1. Mathematical connection skills test

A test was administered to the students to test their mathematical connection skills, and the test was made up of 20 paragraphs of objective items with multiple-choice responses. The questions consisted of four options, covering questions on skills related to connecting mathematics with other mathematical topics, connecting mathematics with other sciences, and connecting mathematics to life). The test was administered to an exploratory sample of 100 fourth-grade students to validate the statistical analyses. The instrument was presented to a group of experts to verify the validity, and consequently, the questions were approved. The validity of the construct was ensured by identifying the relationship between the degree of each paragraph with its skill degree, with correlation coefficients ranging between (0,370-0.644). Also, the correlation between the total degree of skill and the total score of the test was determined with the coefficients ranging from (0.843-0.894). The coefficients obtained from these tests reveal that the test construction is valid. Meanwhile, the reliability of the test was determined using the Cronbach's Alpha test, and a value of 88.0 was obtained, indicating the consistency of the test. The coefficients of difficulty, discrimination, and the effectiveness of the wrong alternatives for the test items were verified, and they were all effective and within the permissible values, as indicated by the statistics references. The final version of the test was made up of 20 items for each item and one grade for each item. The scores of the test were within the range of 0-20.

### 3.2. Productive thinking test

The Productive Thinking Test was adopted and adapted for the same study sample, and the psychometric properties were verified. The test instrument was made up of 26 items, which were both objective and essay. The total number of essay questions was 8, while the remaining 18 were multiple-choice items. The total score for the test was 44.

### 3.3. Final application

The two research instruments used were the Mathematical connection Skills Test and the Productive Thinking Test. The test was carried out in the 2020/2021 academic session, starting from 10<sup>th</sup> January 2021 to 13<sup>th</sup> January 2021.

## 4. Results and discussion

To answer the question which states "Do secondary school students possess mathematical connection skills?". A one-sample t-test was used to compare between the hypothetical mean of (10) and the arithmetic mean (15.51), with a standard deviation of (3.58). The results showed that there is a statistically significant difference, as the calculated T-value reached (3.63), which is greater than the tabular (2) at 0.05 level of significance, and a degree of freedom (299). This indicates that the sample possesses mathematical connection skills, as shown in Table 3.

Table 3. Arithmetic and hypothetical mean, standard deviation, degree of freedom, T-value, and significance level for students' scores in the Mathematical connection skills Test

Hypothesis mean	arithmetic mean	sample	standard deviation	Freedom Degree	value of T:		statistical significance
					Tabular	Calculation	
10	15.51	300	3,58	299	2	3.63	Function

These results can be attributed to the nature of mathematics, where the topics of mathematics are interconnected and overlap with each other, as well as the inclusion of mathematics books with issues related to daily life as well as other sciences.

Thus to answer the second question, which states "Do secondary school students possess the skills of productive thinking?". The t-test for one sample was used to compare the hypothetical mean of (22) and the arithmetic mean (25.34), with a standard deviation of (3.324). Table 3 shows the result at a significance level of (0.05)

with a degree of freedom (299). It was found that the sample possesses productive thinking skills as shown in Table 4.

Table 4. Arithmetic and hypothetical mean, standard deviation, degree of freedom, T-value, and significance level for students' scores in the Productive Thinking Test

Hypothesis mean	arithmetic mean	sample	standard deviation	Freedom Degree	value of T:		statistical significance
					Tabular	Calculation	
22	25.34	300	3,324	299	2	2.57	Function

The findings of this study are attributed to the nature of mathematics, which focuses on many skills, including feeling the problem, predicting assumptions, deduction, interpretation, and other skills that represent productive thinking skills.

To answer the last question "Is there a correlation between the mathematical connection skills and productive thinking among secondary school students?", the Pearson correlation coefficient was used, as the value of the correlation coefficient was (0.667) at the level of significance (0.05) ) as presented in Table 5.

Table 5. The correlation coefficient, its square, and the type of relationship among the students of the research sample

Test	Sample	Correlation Coefficient	Square Correlation Coefficient	Relationship Type
Mathematical connection Test	300	0.667	0.445	Medium
Productive Thinking Test				

According to Table 5, there is a moderately positive and statistically significant relationship between the mathematical connection skills and productive thinking among the students that participated in the research.

## 5. Conclusions and recommendations

Secondary school students possess mathematical connection skills and productive thinking skills, due to the nature of the content of mathematics curriculum in line with global trends that call for the necessity of connecting the branches of mathematics and demonstrating their connection with other sciences as well as to life. Also, the content of mathematics textbooks is based on inference, interpretation, sensitivity to problems, generating several ideas, predicting assumptions, evaluating arguments, and other skills.

With regards to the nature of the relationship between mathematical connection skills and productive thinking, there is a positive correlation between them. This is because being able to connect mathematical concepts, leads to mastering the learning of mathematics, which in turn is related to the student's thinking.

- 1) Enriching each subject of mathematics with a set of activities that help develop productive thinking skills.
- 2) Study of mathematical connection and productive thinking with other age groups.
- 3) Organizing training courses for male and female mathematics teachers on how to develop thinking in general, and productive thinking in particular, for the different school stages.

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