Universidad de las Américas Puebla

# Learning content in a second language:

# Advantageous for the brain?

## A comparison of monolingual and bilingual students' cognitive aptitudes in mathematics learning

Tesis sometida a la

Facultad del Departamento de Lenguas

Como Requisito Parcial para la Obtención del Grado

**Master's in Applied Linguistics**

por

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Primavera 2010

La Tesis ha Sido Leída por los Miembros del Comité de Tesis de

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Y Considerada como Requisito Parcial para Obtener el Grado de

**Master's in Applied Linguistics**

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Cholula, Puebla, México a 13 de mayo de 2010

**Acknowledgments**

This thesis would not have been accomplished if certain persons had not taken part in it. I would like to particularly thank my thesis director, Dr. Connie Johnson, for her support during the whole process of the realization of this thesis. I specially appreciate her assistance in writing reports, her suggestions and the materials she lent me. She shared her knowledge about the topic and always helped me to improve and what I know today about bilingual education is mostly due to her.

Also, a special thank goes to the other members of my committee, Dr. Brita Banitz and Dr. Lydia Giles. I appreciate their vast knowledge and skill in many areas and their assistance in writing reports. Dr. Banitz was also the professor of the thesis proposal course during which she helped and encouraged me a lot. She is the professor who helped me start and design the thesis.

I would like to express my gratitude to the bilingual institution which allowed me to perform all the tests and to all the pupils of the fifth and sixth grades who accepted to participate whether in the pilot or in the actual study.

Finally, I would like to thank Daniel Ramírez who contributed to the statistical analysis of the study and Julia Schmidbauer, the professional translator who translated the tests from English in the two languages needed for the study.

**Abstract**

This study investigated the relationship between bilingualism and cognitive skills. It shows how 10 to 12 year old bilingual learners apply cognitive aptitudes on mathematic tests compared to monolingual speakers. The study took place in Mexico and compared monolingual Spanish speakers with bilingual Spanish – German speakers regarding their cognitive aptitudes. The cognitive skills that were being investigated were velocity in spatial speed, short-term memory, logical thinking and abstract reasoning.

This study is especially addressed to teachers and parents because it shows the cognitive impact on a child who is learning content in a second language. The results demonstrate that bilingual education in the group tested increases the positive use of cognitive skills on tasks such as mathematics. The study also indicates a difference between gender in which boys outperformed girls in the tests.

Finally, this study has been conducted to encourage bilingual education in Mexico and to show parents that this kind of education does not overwhelm their children, on the contrary, it augments their ability to use their cognitive skills.

**Table of content**

**List of Tables**

**List of Figures**

# IINTRODUCTION

“Will my child not have disadvantages if he enters the bilingual group and have classes in German, his second language, instead of Spanish, his native language?” This question has been asked by many parents who have concerns about bilingual education. As a teacher, I have confronted this situation several times. Now, with this thesis, I do not only have an answer to this question but also evidence to support my beliefs about bilingual education.

Languages are keys that open the doors to the world, therefore speaking two languages is better than speaking only one. Being bilingual has become more and more common since today, people travel, learn languages, live abroad and frequently meet people from other countries speaking other languages. In the twenty-first century, going abroad is not as difficult as it was before. Universities organize exchange programs; firms send their workers to foreign countries; there are many opportunities to be in contact with other languages and cultures, which was not the fact some decades ago. The development of the lifestyle of the twenty-first century not only encourages people to learn a second language, it forces them to do it and most of the time, speaking two languages is not even sufficient. Nowadays, being multilingual is necessary; it already surpasses being “only” bilingual in many countries. In Mexico for example, speaking Spanish and English is required by some private schools, as well as by many firms. But speaking a third language such as German is a privilege and a further chance to find a job later.

Knowing more than one language is a privilege which is an opinion shared not only by linguists but today, according to my experiences, by the majority of people, including parents and teachers. Bilingual schools are increasing in many countries of the world for example, in Mexico, it is possible to find numerous schools in cities that offer English classes. Parents agree on the fact that learning a second language is positive and most of them give their children the opportunity to learn a second language from as early as the kindergarten or sometimes even before.

At this point, it is relevant to distinguish between terms so as not to get them mixed up. First, an important distinction has to be made between a second language and a foreign language. For the purpose of this thesis, the term *second language* will be used to define the fact that students are learning content (such as mathematics, biology, geography etc.) in a language not spoken at home. This means more specifically that the learner has a first language environment (home) and a second language environment, which is in this case, the school. A second language learner belongs to a community which the language is not only spoken but the culture is also shared. When speaking about a foreign language, this means that the language is learned in the first language environment, such as when children learn, for example, English at a school in Mexico. They do not have a direct contact with the English spoken community.

The second important distinction that has to be clearly understood is the difference between learning a second language and learning **in** a second language. Take for example German classes as a foreign language (grammar,

conversation, listening comprehension etc.) which is different from learning content in German (mathematics, biology, arts, etc.), when German is not the native language of the learners. The parents' opinion about learning content in a second language is controversial.

According to my own experiences as a teacher, I can say that parents are still sceptical about the consequences of learning content in a second language. Questions regarding the effectiveness of being able to learn using a language other than the native language are frequently asked. Parents tend to think that a child will learn a lot less if the content is taught in a second language than if it were in the child's first language. They are entitled to be sceptical since it concerns their child's education, yet they need to be informed in order to make the right decision. Is bilingual education a trend of today's life or is it a correct and well-considered choice? Should parents trust bilingual education?

The purpose of the investigation is to provide information that bilingual education is good and parents can make an informed decision. This thesis explains what they should know about bilingual education and answers their questions. Parents should understand why bilingual education is the best option for their children. The claim is to show that taking content classes in another language rather than the native language leads to many advantages and does not cause interference between the languages nor overwhelms the students.

The general area of the study is applied linguistics. The topics that will be investigated are bilingualism, language and cognition, and education. The study is

a quantitative study focused on bilingual education. The two languages involved in this study are Spanish, being the language of the monolingual students and the home language of the bilingual students, and German, which is the educational language of the bilingual students.

In my study, I worked with monolingual and bilingual learners. The bilingual students have German as a second language and not as a foreign language because they are learning the language within a German community and because they are using German in content classes, as well as in their community. If they only had German language classes, I would need to call them foreign language learners. The fact that they are second language learners, use German as the language of instruction for other subjects, and share a culture has contributed to their bilingualism. The participants of this bilingual group all speak Spanish at home and German at school, in the classes as well as in the school community. So, can it be said that taking content in a language other than the native language is the key to bilingualism?

The German native speakers of the school will not be taken into consideration for this study. The reason is that they are not all of them considered to be bilingual. Depending on when they arrived to Mexico, they speak more or less Spanish. Some of them are beginners, some of them advanced and some of them truly bilingual. Not all of them fit into one of the two groups. This has been the reason for not including these pupils, since the variables of language is controlled. The participants of the two groups formed for this study are either bilingual or monolingual.

A crucial aspect that should be taken into consideration is that many schools promote bilingual education without being actually a true bilingual education institution. Having some hours of English language during the week is definitely not bilingual education, but would be foreign language learning. In order to talk about bilingual education, content classes, such as mathematics, biology, arts, music etc. have to be taught in a foreign or second language. In this study, the term bilingual education refers to the fact that the second language is used as the tool to learn content, so the focus is first on the content, then on the language. In Mexican foreign language classes, the central point is the language. The doubts that parents have about bilingual education will hopefully be resolved in this study but a main problem may be that information concerning bilingual education is missing. How should parents know what is good for their children if they are not well informed? How can they know if taking content classes in a second language really leads to positive effects if schools do not explain this to them and why they should trust it? They have the right to be explicitly informed and exposed to the consequences of bilingual education.

The focal point of the study is to analyze the ability of pupils between 10 and 12 years old to deal with cognitive tasks. In order to analyze these abilities, participants will take a series of cognitive tests. For the study, two groups are required – one of monolingual learners (Spanish) and another of bilingual learners (Spanish and German) – which will take the same test, each group in its original language of instruction and the results of the tests should show differences between monolingual and bilingual participants. In order to show that bilingual

learners do not suffer from any disadvantages by learning content using a second language, it is important to have not only the bilingual pupils but also a control group made of Spanish monolingual students. The comparison of both groups will show whether bilinguals or monolinguals perform higher on cognitive tasks. The results will be explained and commented upon.

Monolingual and bilingual students will be tested in mathematic content classes since mathematics will be taken as the example of a content class for bilinguals taught in a language other than the one spoken at home. One of the reasons for choosing mathematics as the example for general content classes is because cognitive skills can be tested for mathematical cognitive tasks. The second reason is that mathematics is a content class that has been taught in the second language since the first grade at the institution where the study was conducted. The final reason for choosing mathematics is because I am a math teacher who teaches this class in German. The participants of the study are not my students; they come from other groups which I do not teach. Finding out which cognitive skill is the more developed by bilinguals can help me for my classes since I could focus the teaching on the pupils' strength. Knowing which one is the less developed will lead to a special training of this skill in mathematics in order to develop it more. In addition, mathematics is an exact science; the mathematics tests that have been used did not lead to complex answers of the questions asked and the participants did not have the possibility to give ambiguous answers which means that the answers could only be either right or wrong. This gave exact numbers for the results.

The choice of doing this study in Mexico has a coherent explanation. Bilingual schools are becoming more and more popular in the country, which causes parents to think about the positive and negative aspects of enrolling their children in one of these schools. The second reason is the fact that many schools that actually call themselves bilingual institutions are not. Parents should know the difference between learning a language and learning in a language, which is the key point in bilingual education. The cognitive aptitudes that will be tested and discussed in this study are related to bilingual education, and not to foreign language learning. The consequences in cognitive aptitudes that will be found cannot be automatically related to foreign language learning since this study only focuses on bilingual education, whereas the mathematic content is taught in a second language, German. The study does not assure that the results found can also be applied for foreign language learning. This is why the study makes the distinction between second language and foreign language, as explained previously. The third reason for having this study done in Mexico is that bilingual education is only accessible in private schools because public schools do not promote content classes in a second language. Starting with bilingual education also in public schools would be a very good initiative in Mexico. If at some point representatives of the public education in Mexico, as well as the parents, were convinced that bilingual education was beneficial, then it might also be made available to children in public schools.

My strongest motivation for doing this study is to encourage bilingual education and immersion instruction at schools in Mexico and demonstrate that

positive cognitive aptitudes are gained by learning content through a second language.

As mentioned previously, speaking two languages is better than only speaking one, but the languages themselves are not the only positive aspect. A bilingual learner has many more advantages than being able to speak in two languages; learners also acquire many cognitive aspects by speaking two languages. Bilingual speakers might forget one of the two languages they have learned or acquired if this language is not being used but they will probably not lose the skills they gain by being bilingual. A research conducted by Fiocco (2009) found out that aging does not necessarily imply a loss of cognitive function. Bilinguals will not only have better skills for language learning but they will also have a large number of further advantages beyond language. They will acquire various cognitive skills that they can apply in their everyday life, such as memory, logical thinking, velocity or abstract reasoning.

My intended contribution will be to help parents, teachers and schools directors to understand the positive attributions of bilingualism and to encourage this kind of education in Mexico.

Three hypotheses have been formulated since the study has been designed to find evidence to support these hypotheses. The evidence will be discussed in chapter 4, according to the results of the tests of each group. Each of the three hypotheses will be supported or rejected.

1. Speaking two languages does not cause any interference nor overwhelm the students in content classes. Bilingual education is not negative.

2. There is a difference in the use of cognitive skills depending on if a child is bilingual or monolingual.

3. Bilingual students have advantages over monolingual students in content classes such as in mathematics. Bilingual education is positive.

To summarize the three hypotheses, the main argument is that bilingual education has no negative effects on the brain; but instead has positive effects on the human brain.

In addition, there is a null hypothesis, which will be rejected or accepted according to the statistical analysis explained in chapter 4. The null hypothesis is the following: $H_0$= There is no difference between the monolingual and bilingual group results.

In case the null hypothesis turns out to be supported, the other three hypotheses mentioned previously will be rejected. In the case of at least one of the other three hypotheses turns out to be supported, the null hypothesis will be rejected.

These hypotheses led to five research questions which motivated the investigation and will be answered and discussed in chapter 4.

1. How do monolingual students between 10 and 12 years old score on cognitive and mathematic tests?

2. How do bilingual students between 10 and 12 years old score on cognitive and mathematic tests?

3. What similarities and differences can be found between the monolingual and bilingual students' results of the four cognitive tests? Are these results significant?

4. What similarities and differences can be found between the girls' and boys' results of the four cognitive tests?

5. Based on the results, what recommendations can be made regarding taking content classes in a language other than the one spoken at home?

Besides the five research questions that guided the study, the following assumptions were taken into consideration in this investigation. These assumptions built the basis for the study. They are stated and explained:

1. I assume that bilingual education has not only an impact on language learning but also on cognitive aptitudes. This is important because if this assumption turns to be true, bilingual education will lead to advantages in other areas than only languages. The consequences of choosing a bilingual institution will be vast, since human beings use cognitive skills every day, in most of their thoughts, decisions and learning processes. If this study can show that bilingualism increases the development of cognitive skills, it should not be a challenge for parents to choose between monolingual or bilingual education.

2. I assume that the cognitive aptitudes that bilingual students have come from their bilingualism. The two groups used for the investigation (the monolingual and the bilingual group) have the most important variable – language – as the main difference. Other variables (age, level, socio-cultural background, social class) are controlled. The mathematic programs both groups follow are the same (even if the content might not be taught at the same time, they are all taught during the first six years of primary education). Every student, coming from the monolingual or bilingual group, has to be at the same level of knowledge when starting secondary school; the participants are presently in their last or next to the last year of primary school and the age of the participants is the same in both groups. The participants come from the same socio-cultural background since they all go to the institution chosen for the study which is a private bilingual school. The fact that the mathematic teacher of the groups is not the same will not affect the results because teachers at the institution have to follow the same methodology, syllabus and lesson plans. In addition, the pupils have already had many different mathematic teachers until their present year of study, thus avoiding the implication that one group has had a better teacher than the other; they have all had between four and five different mathematics teachers. The differences in the results should be caused by bilingualism because language is the most important variable for the study and it is different for the two groups. Differences between the groups that would not be caused by bilingualism but by other variables (not controlled, such as time spent on the homework or mathematic aptitude) are not investigated in the study and so it cannot be assured if they influence the

results or not. But the most important variables are controlled, meaning they have no effect on the outcome.

3. I assume that cognitive aptitudes can be tested. It is possible, using a cognitive test, to find out how the participants score on each of the four cognitive skills chosen for this study.

4. I assume that cognitive aptitudes can be applied in any learning processes used in content classes, such as in mathematics. When they are in a learning process, pupils activate their cognitive skills whether they are in a math class or a literature class. For example, if they have acquired a well developed short-term memory skill, they will be able to take advantage of it in every subject.

This thesis is addressed to parents who might be interested in bilingual education program. It is meant as well for directors of any institution in order to support their own bilingual education or to encourage them to start such a program if they still have not. The last audience is the *SEP, the Secretaria de Educación Publica*, the public instruction in Mexico who should also start to think about bilingual education in the country, which would allow Mexico to forge ahead. What is more important than education? It is the seed that makes a person, a society or a whole country grow.

# II REVIEW OF LITERATURE

In this chapter, I discuss the main aspects of literature related to the study and I have divided them into eight subsections. I begin explaning the value of bilingualism in the sixties when linguists started to be interested in bilingual speakers and the impact that bilingualism had on them. Later, I discuss various definitions of bilingualism and I also propose my own definition. In a further section, I explain two important distinctions: additive and subtractive bilingualism, which need to be understood in order to distinguish the advantages and disadvantages of bilingualism.

In the next section, an important discussion on bilingualism and the brain is made to establish important bases for my study. I also explain how bilingualism is processed in the brain by mentioning different theories about it. Then, I relate bilingualism and education by providing linguists' opinions about learning in two languages. This section explains the difference between learning *a language* and learning *in a language*.

The next section has the focus on language and cognitive skills, which is also an important point for my study. I list, according to literature, diverse cognitive skills that bilingual learners have because of their bilingualism. I then relate bilingualism to mathematics, which is the subject I chose for the tests of my study. I discuss what has been said in literature about language competence and mathematics.

The last section is dedicated to gender[1] and language learning. In my study, I have separated the participants by gender to analyze their differences in learning. Also this section explains how boys and girls learn a language differently and its impact on learning content in a language.

### *2.1 View of bilingualism in the sixties*

Lust and Yang (2004) describe the view of bilingualism that people had some decades ago. Bilingualism was often regarded as atypical and even abnormal when compared to monolingualism, according to Lust & Yang. Bilingualism was not only the source of cognitive retardation but also the cause of detrimental effects on intelligence and language development. According to Baker (2006), bilingualism in the past was accused of being the cause of split personality, causing cerebral confusion, and spiritual deprivation. This is why, to this day, there exist all these negative preconceptions about bilingualism. One of the main goals of my thesis is to change the beliefs that people have had regarding bilingualism. I would like to not only show that bilingualism does not cause cerebral or spiritual damage, but to demonstrate that it is actually good for cerebral development. It is now time to change what people have believed about bilingualism. This thesis will help to modify their view of bilingualism if they still have not and let apart these incorrect preconceptions.

[1] In the study, the term *gender* refers to biological sex.

In 1962, Lambert and Peal (cited in Lust & Yang, 2004) found out that bilingualism did not provoke any cerebral damage nor was it negative for the individual. They stated that bilingualism had been studied before but that the researchers had commited errors in interpreting the results by not taking into account many variables. The first time that researchers actually stated positive aspects of bilingualism was in 1962. Lambert and Peal found that bilingual speakers had many different positive aptitudes in cognitive skills, such as intelligence, creativity, concept formation, classification, analogical reasoning, and visual-spatial skill. After 1962, bilingualism started to have a positive connotation but the process was slow. The view that people had regarding bilingual speakers would not change from one day to the other. Today, bilingualism has gained acceptance although it was not a shared opinion some decades ago.

The fact that researchers (Lambert & Peal, 1962, cited in Lust & Yang, 2004) found that bilingualism had no negative effects on the brain does not mean that the opinion people had about it changed right after the study was done. It takes a long time for people to change their minds.

### *2.2 Bilingualism: Definition*

One single definition of what exactly is understood by being bilingual does not exist. For some people being bilingual automatically means speaking the two languages perfectly, but can a language be spoken perfectly, even by native speakers? The term “perfectly” is inappropriate and this belief of speaking two languages perfectly when one is called bilingual should be avoided. It is

inappropriate because a speaker who is able to communicate orally, read, and write on a very high level of a second language still might make some mistakes or have some features of his native language. Even though this speaker might not achieve 100% competence in his second language, he is still considered a bilingual, according to my definition of bilingualism mentioned at the end of this subsection (see last paragraph of 2.2). It is better, at this point, to forget the idea that bilingual speakers always speak two languages “perfectly” since this is an illusion and does not occur very often. It would be wrong to expect a bilingual to speak his two languages without any features of a foreign accent, or without any grammatical, syntactic, morphologic or semantic mistakes. It also occurs to a native speaker who sometimes hesitate about a linguistic aspect of his own language.

Being bilingual does not especially mean that the person speaks two languages at the very same level. In order to be classified a bilingual, the speaker needs to have acquired knowledge in two languages and needs to be fluent in both languages as well. According to Hamers & Blanc (1993), bilingualism is a state of a linguistic community in which two languages are in contact with the result that two codes can be used in the same interaction and that a number of individuals are bilingual. And by being bilingual, Hamers & Blanc mention the state of an individual or a community characterized by the simultaneous presence of two languages.

In her article about using two languages in learning mathematics, Moschkovich (2007) confirms that bilingualism has more than one possible definition. She cites De Avila & Duncan (1981) and Valdés-Fallis (1978), linguists

who have defined bilingualism using different terms and explanations, sometimes with interesting and innovative ideas, such as in Valdés-Fallis, who in 1978 also considered being bilingual any individual belonging to a bilingual community.

> Definitions of bilingualism range from native-like fluency in two languages, to alternating use of two languages (De Avila & Duncan, 1981), to belonging to a bilingual community. (Valdés-Fallis, 1978, p. 124).

According to my opinion, belonging to a bilingual community is not sufficient to be called a bilingual speaker. On the other side, expecting from the bilingual to speak the two languages perfectly is also too exaggerated. Further on (p.18), I give my own definition of what is for this thesis considered a bilingual speaker.

Bialystok (2001) mentions two kinds of descriptions of bilingual speakers, the unrealistic and the realistic definition. Speakers who have full fluency in two languages is the unrealistic definition of being bilingual whereas a more realistic definition would define the bilingual speaker as someone who can function in each language according to given needs. She uses the term *unrealistic* because of the fact that bilingual speakers most of the time do not speak both language at a very same level. So it is unrealistic to think that they achieve full fluency in both languages. The term *unrealistic* used by Bialystok for the first definition is, according to my opinion, not totally appropriate because there are many speakers who are fully bilinguals and feel secure in both languages. These speakers are called balanced bilinguals because they have a high language competence in both

languages, most very close to native speakers (Hamers & Blanc, 1993). The other type of bilingualism is called the dominant speaker, which means that the individual has a higher competence in one of the two languages. According to Bialystok, most bilinguals are dominant in one language, a fact that leads to conclude that a balanced bilingualism is less probable, but which does not mean at all, according to me, *unrealistic*. This is why I do not appreciate her expression of *unrealistic*. I would rather say that bilinguals are more frequently dominant speakers and less frequently balanced speakers, but both do exist.

Valdés & Figueroa (1994) state that a bilingual person is an individual who achieves a high level of language proficiency in the two languages. The language proficiency they achieve is very close to the one of native speakers but they also mention that linguists do not always agree with this definition. Rickerson (2004) defines those persons as true bilinguals, people whose skills in both languages are very strong.

There is no perfect definition of bilingualism. As mentioned, authors have tried to define this term but the definitions given have an aspect that other authors disagree with and this is why new definitions have been proposed, adapted, changed etc. I would like to define *bilingualism* the way I perceive it and the way I think is the most appropriate.

Bilingualism is, according to me for this study, the fact that a person is able to speak fluently, understand and be understood in two languages or variants of languages. I do not agree with Rickerson (2004) saying that it is necessary to be a

*true* bilingual to be called a bilingual person. Someone who is able to communicate in two languages, even though not perfectly, is bilingual. By mentioning *not perfectly* I mean that the bilingual is allowed to make a mistake, have features of the native language in the pronunciation of the L2, or hesitate about the use of a word. If that occurs, the bilingual is still a bilingual speaker, as long as this person is able to speak fluently and being understood. Even if the performance is not always 100% native-like, the bilingual speaker has the language competence and is able to find another way of explaining if his statement has not been well understood. Also, the bilingual speaker does not need to be automatically bicultural (see figure 1). Most of them are although a bilingual speaker is still bilingual if he is not bicultural. This means that the amount of cultural aspects acquired by the speaker is not a requirement to become bilingual.

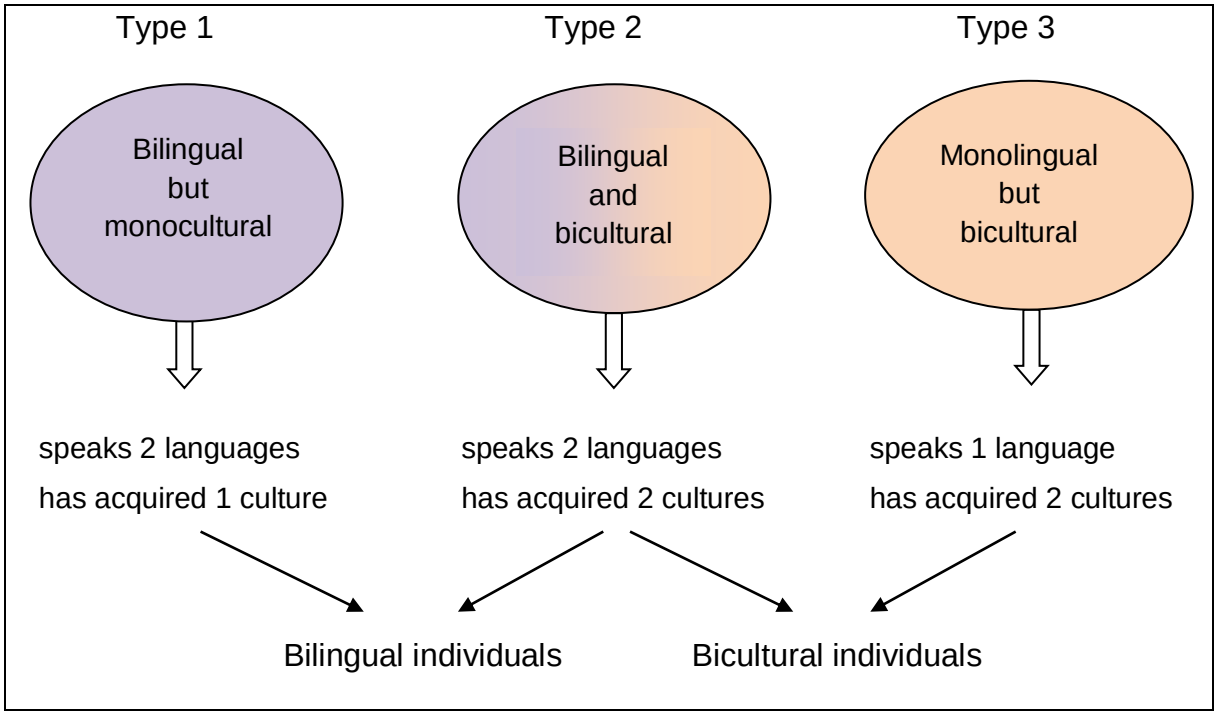


Figure 1: Types of situations in bilingualism and biculturalism

Figure 1, designed by myself, shows three different types of bilingualism and biculturalism. Type 1 indicates that the individual is bilingual but he has not acquired two cultures. This occurs when the bilingual has left his native country in an early age, has started to live in another country, speaks its language and has learned the culture of this new country without having forgotten his first language. This individual has two languages but one culture only. Type 2 shows an individual who is bilingual and bicultural. The speaker identifies himself with the two cultures of the two languages he speaks. This is the most common type. This would be for example a Spanish native speaker living in Mexico (language + culture) and speaking German and learning the German culture at the school environment (language 2 + culture 2). The last type would be an individual who has acquired two cultures but only speaks one language. This could occur when someone has emigrated to a new country, has acquired the culture of this country by living there but has not learned the language. For example, an Arab speaking woman lives in the United States, has acquired the culture of this country, and is part of an Arab speaking community in which all individuals share the Arab culture. If this woman has not learned English yet, she would be bicultural but not bilingual and would belong to type 3. To be called bicultural, the speaker needs to have acquired two cultures, most of the time this is only possible if the learner lives in a country where the culture of the language is transmitted directly. But in some cases, such as the one of the bilingual participants of the study, they have acquired their second culture at school. This is the environment where the German culture is shared. Monocultural, on the other hand, is an adjective that qualifies a person having acquired only one culture, such as the example for type 1 mentioned above.

For this study, the bilingual speakers are dominant and bicultural. They all belong to type 2. They all speak Spanish and German, are able to communicate orally and to write and read in both languages. They also are bicultural because they are in contact with both cultures in two different social environments, one at home and one at school. I am aware that the amount of cultural aspects of German is very limited, since the speakers do not live in a German speaking country. Culture is transmitted at school, being the only environment where the students are in contact with the German culture. Another possible term that can be used to describe the bilingual participants' setting would be *immersion*. This means that they are immerged in the second language during a part of the day.

### *2.3 Additive and subtractive bilingualism*

The advantages that a bilingual speaker has are very different according to whether the child is an additive or subtractive bilingual. According to Lambert (1974, 1977, cited in Hamers & Blanc, 1993), the additive type has a positive connotation whereas the subtractive approach has a negative one. The additive bilingualism and culture result in positive effects to the learner whereas a subtractive bilingualism develops when the two languages are competing rather than complementary. If children have a subtractive bilingualism, they probably will have more disadvantages than advantages, such as forgetting their native language and not acquiring a high proficiency in the L2.

The study designed by Clarkson (1992) can show that the additive type is related to positive effects whereas the subtractive approach to negative effects on the learners. Additive bilingualism occurs usually when the two languages

complement one another (or the speaker is a balanced/competent user of both). Subtractive bilingualism occurs when the two languages compete with each other. But there is another factor that has an effect on the type of bilingualism. For the additive type, Baker (2006) refers to languages that are prestigious and powerful. On the other hand, the subtractive type can come from two languages which are not highly valued by the dominate society (at least one of the two languages). This may lead to negative effects caused by a lack of motivation, a lack of possibilities to apply the language, a lack of knowledge of the language, the self-esteem of the speaker, the non-acceptance of the language by the society, the loss of the minority language and many other factors that devalue this language. Baker defines subtractive bilingualism saying that both languages are underdeveloped, maybe because of lacking prestige. It refers to the negative affective and cognitive effects of bilingualism. Additive and subtractive bilingualism are influenced by attitudes and the attitudes that people create about a language play a crucial role for the communities speaking this language. Having positive attitudes towards the language can lead to additive bilingualism, whereas having negative attitudes can lead to subtractive bilingualism. Attitudes do not cause one or the other type of bilingualism but they affect or influence it. What causes additive or subtractive bilingualism has to do with how speakers use the language and that use might be affected by their attitudes. In his study, Clarkson explains the results saying that the language proficiency level of the bilingual students who did poorly on the tests was very low in their L1 as well as in their L2. The language proficiency level of the students who perform better, on the other hand, was high in both languages. These results conclude that a high language competence is needed in both

languages in order to gain positive aspects of bilingualism. If one of the two languages is not valued and a high competence is not achieved, the speaker will definitely have negative effects. An example of a subtractive bilingualism that leads the individual to negative cognitive and affective effects could be a speaker of a minority language, not well accepted by the majority language, who does not achieve a high competence in the L1 and needs to learn an L2 without having the appropriate basis of the native language. In subtractive bilingualism, the native language is less robust; society assumes that it will be used only temporarily until replaced by the dominant language as the group assimilates. Most immigrants to the United States, Canada, and Australia experience subtractive bilingualism; their skills in their native languages erode over time, and English becomes their dominant language, according to August & Hakuta (1998). Ríordáin & O' Donoghue (2008) mention that competence in the language of communication/interaction is a prerequisite for engagement in the learning process when content in taught is another language than the first language.

In the present study, the bilingualism approach taken by the students is additive, and because of the requirements needed to enter the bilingual group, the participants have a high competency level in German. Cummins (1976, cited in Ríordáin & O' Donoghue, 2008) insists that the student needs to achieve a certain language level in L2 to be competent in the content class. The participants of the present study have a sufficient level of German in order to avoid disadvantages caused by the lack of language competence. The fact that they were accepted into the bilingual group already means that they achieved a high level of language

proficiency in German because they passed the language test that the school provides for children who have the desire to enter the bilingual group. The test has been designed by language teachers and revised by the coordinators of German teaching. If the children pass the test, they are accepted to the bilingual group under certain conditions. They have to fulfill the expectations (language level, attitude towards learning, motivation, progress within the group, etc.) in order to be able to stay in the group. If they do not achieve the language level expected or any of the conditions required, they can no longer stay in the bilingual group. The pupils of the bilingual groups for my study do not have to perform a language test again because the test they took has the level equivalent to a C1 language level[2] (on the Common European Framework), which means close to native-like competence. So they have an additive approach of bilingualism, which, according to the authors mentioned above, leads to positive cognitive and affective effects.

### *2.4 Bilingualism and brain functions*

Bialystok and Hakuta (1994) state that knowing two languages is much more than simply knowing two ways of speaking. They mention that the mind of a speaker who has learned two sets of linguistic aspects for a single conceptual representation has entertained possibilities that the monolingual speaker has not. Paradis (2000) states the following concerning the topic:

[2] A C1 speaker can understand a wide range of demanding, longer texts, and recognize implicit meaning. The speaker can express him/herself fluently and spontaneously without much obvious searching for expressions and can use language flexibly and effectively for social, academic and professional purposes. He/she can produce clear, well-structured, detailed text on complex subjects, showing controlled use of organizational patterns, connectors and cohesive devices.

> No function is available to the bilingual speaker that is not already available to the unilingual, unidialectal speaker. The only difference seems to be the degree of use the speaker makes of each of the relevant cerebral systems. (p. 54)

According to this statement, can we believe that if bilingual learners have two lexical memory stores, do they simply grow a new one when they start to learn a new language? Is it a previously un-tapped part of the brain?

In literature, four controversial hypotheses can be found about how languages are processed in the brain. The following subsections will critically discuss these hypotheses.

### *2.4.1 The classical language area hypothesis*

This hypothesis used to be well accepted, explains Mundhra (2005), before other studies about brain areas or brain damages demonstrated why this hypothesis could not be true. It was first believed that all languages are localized in the same cerebral areas and that language processing in the human brain was completely done by the two classical language areas (Broca's area and Wernicke's area). The syntactic processing is supported by Broca's area while the semantic processing is supported by Wernicke's area. However, Mundhra mentions a study (Damasio, Tranel, Grabowski, Adolphs & Damasio, 2002) that has shown that languages are not only processed by these two areas, but other parts of the brain are also involved in the process. Linguists (Crystal, 1987, cited in Nagai, 1997; Paradis, 1995, cited in Bialystok, 2001) and neurolinguists (Fabbro, 1999, cited in Bialystok,

2001; Fabbro, 2001; Marrero, Golden & Espe-Pfeifer, 2002) have studied aphasia in bilinguals and have observed that bilingual speakers who had suffered from brain damage were able in some cases to recover one of the two languages they used to speak (it is not always the native language, in some cases, the second language was the one that has been recovered). This would imply that the languages are not stored in only one area of the brain and explains why the classical language area hypothesis was no longer accepted.

### *2.4.2 The two-switch hypothesis*

Bilinguals used to be described as having two independent systems and that they could use both, switching from one to the other, explains Neufeld (1976). Neufeld mentions that, earlier, authors were arguing that it was not possible to have one storage for two languages because of the interference of the two languages. If bilinguals had one storage only, they would constantly mix up their two languages and not be able to speak more than one language at the time. Others disagreed with this view of language processing. Neufeld (1976) mentions McNanama (1971) who pointed out that bilinguals can use one language without having any interference from the other language. They can keep their languages distinct from one another. Bialystok (2001) explains this fact by arguing that some bilingual speakers develop an “enhanced ability to selectively attend to information and inhibit misleading cues” (p. 245). The bilingual is able to focus on one important aspect only, blocking out the less important information. This ability is called *selective attention* by Bialystok. Because the bilingual has this ability to select and sort the information he needs, he is able not to pay attention to what he does not

need. This is what happens in the bilingual brain when he uses two languages and does not mix them up.

Hamers & Blanc (1993) explain that the existence of a switch mechanism for languages was a debate in the 1970s. McNamara (1967, cited in Hamers & Blanc, 1993) did not completely agree with the switch hypothesis and proposed a two-switch model, one for the verbal input controlled by the environment and one for the independent verbal output. This mechanism would allow the bilingual learner to encode in one language and to decode in another. The two languages would be simultaneously active but independent from each other.

The debate about how many storages there are in the bilingual brain continues to interest both linguists and neurologists. They do not all agree with one single hypothesis; the opinions about language processing are still controversial and the is why many theories have been proposed. The two-switch hypothesis was confirmed and adopted in the 70s, as Hamers & Blanc (1993) had mentioned, but was then contradicted by other hypotheses (discussed in the next subsections) only to reappear as a possible assumption as a result of new research. Hernandez & Bates (1999) believe that a bilingual speaker has two storage areas, one for each language. They explain it by looking at the effects of brain lesions on the processing of a bilingual's two languages. Brain lesions that affect one language and not the other would lead to the conclusion that languages are represented in different areas of the brain.

### *2.4.3 The tripartite system hypothesis*

Many researchers have investigated bilingualism and the brain, especially because the hypotheses that have been proposed still do not satisfy all researchers. Ojemann & Whitaker (1978, cited in Javier, 2005) found that some speech areas in the brain were involved in the two languages whereas other areas were specific to each language. Another study realized by Rapport, Tan & Whitaker (1983, cited in Javier, 2005) analyzed speech production and brain areas and they reported as well that bilingual speakers have different areas for each language.

Tomioka (2002) describes the tripartite system hypothesis claiming that identical items of L1 and L2 are stored as one item, but different items are stored separately in each system. Items that are in the intersection of the L1 and L2 systems are stored only once. The tripartite hypothesis differs from the other hypotheses in which language items cannot be stored as part of L1 if they are already stored as part of L2.

The Laboratory for the Neural Bases of Bilingualism in Texas (n.d.) affirms that neuroimaging work done with bilinguals shows that the two languages have different patterns of neural activity. Languages are connected with neural channels which influence each other. For example by learning a third language, the bilingual speaker can associate the two languages he already knows to help develop the third language. He can use the knowledge of both languages (syntactic, morphological, phonetical, lexical etc.). The more languages a speaker knows, the more connections he has between the storages in the brain.

### *2.4.4 The revised hierarchical model*

Foreman (2002) argues that when learning takes place early on, the brain treats multiple languages as one language but when one learns later in life, the sorting out seems to be done more spatially. Foreman also mentions a study conducted by a neuroscientist (Hirsch, 1997) that discovered that people who are fully bilingual in French and English use the same area of the brain as an internal dictionary, regardless of which language they are speaking. By contrast, people who are not truly bilingual need to recruit additional brain areas to find words in their non-native language. Kovelman, Baker & Petitto (2008) have the same opinion arguing that children who are bilingual from birth onwards will grow as if there were two monolinguals housed in one brain. Kovelman et al. looked at where reactions took place in the brain during language tasks for both monolingual and bilingual participants. Like Hernandez (2009), they found areas of the brain being used by bilinguals that were not found in the monolingual brain. Hernandez also says that many researchers speak about mixed models in which coexisting processors are linked together in a hierarchical structure system that gave the hypothesis its name. French & Jacquet (2004) describe the hypothesis as one of the newest theories that explains how languages are processed in the bilingual brain. The authors explain that there are two separate lexical stores (one for each language) and one common conceptual store which are all connected and influenced by the others. This model explains why some bilingual children have a higher proficiency level in one language when they talk about one particular topic (related to that language) and in the other language when they talk about another topic. For

example, a bilingual German-Spanish speaker who lives in Mexico starts a conversation about Mexican History with another German-Spanish speaker. He uses German because they both have the same native language and that should not cause any problems of understanding the conversation but suddenly changes the language into Spanish, and that gives him a larger vocabulary to express one's thoughts about Mexican History. If they had had the conversation about German literature, they probably would have switched the language into German again. This is explicitly explained with the model suggested by Levelt (1989) about language production. The author says that a bilingual speaker has three production components which are used to produce language: 1) the conceptualizer, responsible for generating the communicative intention; 2) the formulator, which converts the message into a phonetic plan, and 3) the articulator, the output or the motor execution of the message. Levelt mentions that bilingual speakers have strong connected channels between the three modules. It is possible that the speaker conceptualizes the intention in one language but that the formulator converts this intention into another language which is then produced by the articulator. The formulator is the module that turns the speech plan into words by activating the items in the lexicon that correspond to the different chunks of the message. The formulator stimulates the choice of the correct lexicon in the language needed.

The revised hierarchical model seems to me to be the more logical hypothesis about how bilinguals process their languages. I agree with the theory of having two separate storage areas, one for each language and one common

conceptual store (French & Jacquet, 2004). This would also explain why some bilinguals who have suffered from brain damage are able to recover one of the two languages only. I also find the language processing model proposed by Levelt (1989) very useful because it explains how the bilingual brain has developed strong connections between the cerebral areas. This supports the argument that bilinguals acquire stronger cognitive skills compared to monolinguals. They are able to use their cognitive skills for various tasks, including the encoding and decoding in two languages.

The constant use of the two languages not only results in stronger cerebral connections in general but also in highly developed relations between cognitive skills and the two languages. Müller (1998) mentions *cognitive transfer*, a process that occurs in bilinguals when they transfer their cognitive skills from one language to the other one, the same way they transfer linguistic information from L1 to L2. They are able to make those linguistic and cognitive transfers thanks to their strongly related channels.

### *2.5 Learning content in two languages*

Although learning content in a second language is still not well accepted everywhere according to my own experiences as a teacher, research continues to show that learning in two languages is positive for the brain. According to Espinosa (2008), children are totally capable of learning content in two languages. Their benefits from learning more than one language are not only linguistic but also cognitive. This is supported by Hutson (2008) who argues that bilingual education

increases logical thinking; by Bialystok (2001) who mentions the better cognitive control of linguistic processes by bilinguals over monolinguals and by Hamers & Blanc (1993) who point out the positive cognitive aptitudes bilinguals have when compared to speakers of one language only.

Brisk (2006) also refers to learning content in two languages and calls it “partial immersion”. She describes partial immersion as the process of acquiring a language through content matter instruction. It is important to notice that some authors will use the term “immersion” when talking about learning content in a language other than the native language.

Speaking about learning content in a second or foreign language, Clarkson (1992) mentions that competence in two languages is an important factor because being bilingual with low competences in the two languages is not an advantage for mathematics learning. According to Clarkson, bilingual programs should encourage the use of the two spoken languages. So if pupils can achieve high competences in two languages, they will have advantages in learning and will be able to take content classes in the L2.

The language competence of the participants of the present study is not an issue because at the institution, both languages are taught, developed and valued. All the bilingual participants do have a high language competence in their native language and this variable is crucial, according to Clarkson (1992), for the bilingual pupils to acquire and apply the cognitive skills.

Finally, a last aspect to be aware of is that when pupils learn content through a second language, the learning is on the topic, as mentioned previously, and not on the language itself. This means that the students are able to learn and improve a language by using it and not talking about it. Learning content in a second language is not learning grammar or syntax rules, it goes beyond that since the students are able to use grammar without even knowing it. According to Thornbury (1999), grammar should not be taught as a separate discipline at all. The author believes that it is possible to acquire a second language without talking about grammar, but only by using it and this is exactly what learning content in a second language does. It is here important to mention that the second language students need to have achieved the threshold level of language (explained in details on p.36) in order to be using the grammar in a content class.

### *2.6 Bilingualism and cognitive skills*

Do bilingual speakers have the same cognitive aptitudes as monolinguals? Many studies have shown that bilinguals have positive effects in several areas. Galambos & Hakuta (1988, cited in Myers-Scotton, 2006) compared bilingual and monolingual learners in making grammatical judgments and they found out that bilingual speakers had a consistent advantage over monolingual speakers. According to Hamers & Blanc (1993) bilingual students show in general more positive cognitive aptitudes than monolingual students such as mental flexibility, verbal and non-verbal intelligence, dealing with abstraction, forming concepts, sensitivity to semantic relations between words and many others. In their study, Bialystok, Craik, Klein & Viswanathan (2004) found that those who had been

bilingual most of their lives were better able to focus their attention on the demands of a complex set of rapidly changing tasks than those who had only been monolingual. Bialystok et al. also mention that bilingualism increases the attention ability.

Souviney (1983, cited in Clarkson, 1992) states that language ability also increases memory. This opinion is shared by Ransdell & Arecco (2001) who stated that bilingualism has positive aspects on long-term working memory.

Clarkson (1992) studied the competence of mathematical problem solving in monolingual and bilingual learners. His study demonstrated that bilingual students did not have any disadvantages in mathematics and in fact bilinguals perform overall better on mathematic tasks than monolinguals.

Bilingual students might have less vocabulary in their spoken languages, says Bialystok (2001) than monolingual students have, but they have more cognitive aptitudes which are not confined to the linguistic domain but extend as well to non-verbal cognitive abilities. She also mentions that bilingual children in general outperform monolingual learners in tasks involving the cognitive control of linguistic processes. These results were also found in Clarkson's study (1992). They build the bases for my own study; I expect to have similar results.

### *2.7 Mathematics and language competence*

Mathematics education research in bilingual settings has identified language as a social tool in the classroom and as a vehicle for mathematics learning as important

areas of investigation (Gorgorio & Planas, 2001, Secada, 1992, cited in Barton, Chan, King, & Neville-Barton, 2004). Clarkson (1992; 2006) wanted to show that bilingualism is not necessarily a disadvantage for learning. Each of his studies based on mathematics learning showed that bilingual students have more advantages than monolingual students. The fact that the content is taught in a language other than the native language has not shown any inconveniences in mathematical competences.

Ríordáin & O' Donoghue (2008) investigated the relationship between language and mathematics. They tested bilingual students of Gaelic and English in Ireland who are native Gaelic speakers having mathematic content classes in English, their second language. Ríordáin & O' Donoghue (2008) mention that competence in the language of communication/interaction is a prerequisite for engagement in the learning process. Mathematics learners are required to have competence in the language of instruction (Gaelic) and in the language of mathematics (English) and they state that mathematics understanding is influenced by language, personal conceptions and culture.

Cited in Ríordáin & O' Donoghue (2008) Cummins (1976) assumed that there may be a threshold level of language competence that bilingual learners must achieve in order to avoid cognitive deficits and to allow the potential benefits of being bilingual. He called this hypothesis the *Threshold Hypothesis*. Ríordáin & O' Donoghue had questioned this hypothesis in their study but discovered evidence to support it. For my study, I take into account Cummins' hypothesis. I agree with the threshold level a bilingual speaker needs to have in order to benefit

from the spoken languages. This is why the proficiency level of the participants in my study is a controlled variable. I go into details at the end of this subsection.

The following figure (Takakuwa, 2005) shows explicitly the *Threshold Hypothesis* proposed by Cummins (1976).

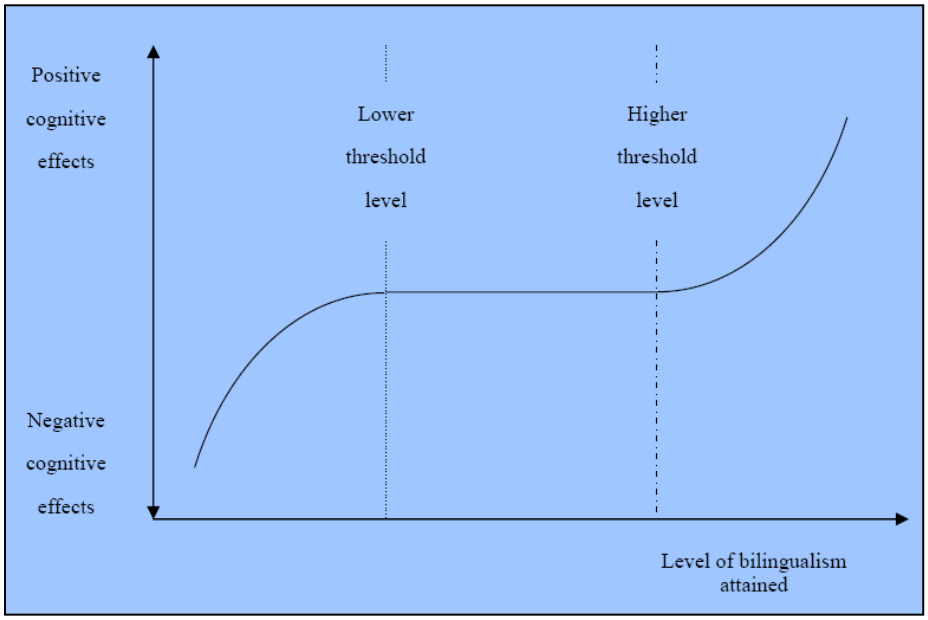


Figure 2: Threshold Hypothesis proposed by Cummins (1976)

Bilingual children must attain at least the lower threshold level in either language to avoid negative effects on their cognitive development, explains Takakuwa (2005). However, the fact that the bilingual child attains the lower threshold level does not automatically guarantee cognitive advantages. The child needs to attain the higher threshold level in both languages to obtain positive effects on his cognitive development. To summarize it can be stated that the higher the level of bilingualism and the higher the threshold level the child achieves, the more positive cognitive effects he will have. The *Threshold Hypothesis* explains why some children benefit from bilingualism whereas others do not. What

Cummins (1976, cited in Ríordáin & O' Donoghue, 2008) here means is the differences between subtractive and additive approach of bilingualism, described in section 2.3.

Cummins (1976, cited in Ríordáin & O' Donoghue, 2008) is not the single author who mentions that language proficiency is a crucial factor when learning content in a second or foreign language. Barton, Chan, King, & Neville-Barton, (2004) explains the importance of the level of language competence in the L2 for the success in learning content. They also mention researchers, such as Halliday (1978), MacGregor & Moore (1991) and Gorgorio & Planas (2001) who have investigated bilingualism, mathematics and cognitive skills and they all reveal several reasons why language is important for the education of mathematics. Most of the time, the reasons given explain that a lack of language competence in the L1 as well as in the L2 tends to lead to a subtractive approach of bilingualism, as Cummins had already discovered in his own study. This kind of approach might make the acquisition of the cognitive skills more difficult than it is for additive bilinguals.

In 1983, Dawe conducted a study in order to discover if additive bilinguals outperformed monolingual English speakers in mathematic problem solving and logical thinking. His findings correlate with Cummins Threshold Hypothesis (1976, cited in Ríordáin & O' Donoghue, 2008) indicating that language is clearly connected to mathematics learning.

According to the findings of the studies mentioned, language is an important variable that affect the results. For these reasons, in my study, the language variable is controlled; also the bilingual participants' education takes place in an additive setting. If the children participating in the study did not have a high level of German, they would not be in the bilingual group of the institution. As previously mentioned, in order to enter the bilingual group, they had to pass a language test. So if their proficiency level in L2 is sufficient, they can take content classes in the L2. The language test is written by language teachers, native speakers of German, and revised by language coordinators. The test is designed according the language goals of the Baden-Württemberg syllabus for German. The test changes depending on the age and there are six tests, one for each primary level. The children are tested on listening comprehension, writing, reading and grammar competence.

### *2.8 Language and gender*

Boys and girls process language differently. First language acquisition has been studied by many researchers and findings have shown that gender plays a role in how a child acquires a language. Melville (2006) states that girls prefer to use a system that is based on memorizing words and associations between them, whereas boys rely primarily on a system that governs the rules of language that is why girls and boys use different approaches in order to acquire their native language.

According to Melville (2006), neuroscientists from Georgetown University Medical Center have investigated differences between gender in learning the first language and they found out that boys and girls use different parts of their brains to process some basic aspects of grammar. Burman (2007) who investigated first language acquisition and sexes discovered that girls used both the left and right sides of their brains for language-related activities, whereas boys primarily used the left side. Thus, boys acquire their first language differently than girls do. So the differences between gender in first language acquisition led me to the decision to separate boys and girls for my study. I want to analyze their results separately in order to find out if the fact that they process language differently affects their results on cognitive tests.

Various authors (Cook & Cook, 2009; Lipsett, 2008; Huang, 1993) have already studied gender in mathematics competence. Interesting findings show that differences between girls and boys usually start with puberty but the participants in the present study do not have reached puberty yet. Does this mean that their results still should be similar? Lipsett mentions that if differences in mathematics appear, they generally come from the inequality of how boys and girls are treated in that society. She basically says that if both gender is considered equally, they should not show relevant differences in their mathematics results.

The next chapter explains and shows the methodology of the study considering the literature background found about the topic. The methods and procedure were designed in order to find out answers to the research questions, as well as to support or reject the hypotheses.

# III METHODOLOGY

This chapter informs the reader about the methodology used in the study. It introduces first the institution in which the study took place, gives a short explanation about the different programs they use and which of them were relevant for the study, and then let the reader know how the participants were selected. A next subsection explains in details the procedure of the testing: which tests have been chosen, where they come from and how the participants were assessed. The following subsection gives information about the coding of the tests (how they were checked and how the points were given) and the last one informs the reader about the pilot that has been conducted before the actual study started: it gives a short overview of the results obtained and if the materials needed an adaptation for the actual study.

## *3.1 Place of the investigation and description of the institution' programs*

The part of the research concerning collecting data took place in a bilingual school, located in the area of the city of Puebla, in Mexico. For the investigation, only children in the primary school were considered. The school offers different programs according to the German level of the pupil and in each primary grade, there are five groups with different levels of German. Table 1 below indicates the division of the groups within one grade. The division of the groups is the same from the first to the sixth grade. In each grade, there are three different programs: the first one for the native Spanish speakers, the second one for the bilingual pupils and the last one for the native German speakers.

| Name of the group | Number of groups within one level | Particularity of the group | Students native language in the group |
|---|---|---|---|
| DaF-group (*Deutsch als Fremdsprache:* German as a foreign language) | 3 | Spanish native speakers with German as a foreign language (7 hours/ week) | Spanish |
| DFU-group (*Deutscher Fachunterricht:* Content classes in German) | 1 | Bilingual students with content classes in German (18 hours/week) | • Spanish and German (Spanish as the home language and German as the educational language) |
| DM-group (*Deutsch als Muttersprache:* German as the native language) | 1 | German native speakers with content classes in German only and Spanish as a second language | • German |

Table 1: Description of the groups within one level

### *3.2 Participants*

The students who participated in the research are children from the DaF-group (monolingual) being Spanish native speakers learning German as a foreign language and pupils from the DFU-group (bilingual) who speak Spanish at home and German at school. For the investigation, the importance of the children of the bilingual group is that they are bilingual, irrespective of whether they acquired both languages at the same time or one after the other. The participants are 20 pupils of each group: monolingual and bilingual. In total, 40 children contributed to the research. The two groups were as shown in table 2:

| | Group | Number of participants | Number of girls within the participants | Number of boys within the participants | Spoken language(s) |
|---|---|---|---|---|---|
| 1. Monolingual group | DaF | 20 | 10 | 10 | Spanish |
| 2. Bilingual group | DFU | 20 | 10 | 10 | Spanish (home language)<br>German (education language) |

Table 2: Participants

The participants are between 10 and 12 years old. Both groups have more than 20 pupils, so the pupils have been randomly selected according to the Systematic Random Sampling procedure (Trochim, 2006) designed at Cornell University in the Center for Social Research Methods. All possible participants were first divided into the four initial groups (N = entire population within one group between 10 and 12 years old at the bilingual institution): monolingual girls, monolingual boys, bilingual girls and bilingual boys. Then, on each of the four lists, the pupils received a number, starting with 1 and going on chronologically until each student had one number. Ten participants of each list were needed (n = 10). For example, there were 29 bilingual girls between 10 and 12 years old at the bilingual institution and only 10 bilingual girls were needed for the study. The question is now how to proceed to select them randomly? The interval size, k, is N/n and is needed to be able to count the intervals between each participant, starting on a randomly selected number between 1 and k. Every $k^{th}$ pupil has been chosen. The same procedure was repeated for each of the four groups. N was in each group a different number (according to the entire population of each group

between 10 and 12 years old available at the institution) whereas n = 10 has been used for each group (10 participants were needed in each group). The total of the participants reached 40 pupils.

The example below shows how the bilingual girls had been chosen, following the steps of the Systematic Random Sampling (Trochim, 2006). The pupils that already participated in the pilot were taken out of the population.

**Selection of the bilingual girls for the study:**

**N = 29** (number of bilingual girls between 10 and 12 years old at the bilingual institution)

**n = 10** (number of bilingual girls needed for the study)

**k = N/n** = 29/10 = 2.9 → 2.9 has been rounded up to 3.0

Randomly selected starting number between 1 and k: 3

Each third sample has been selected starting with the third one. Once the complete list has been used, the count goes back to the first sample again until *n* is full.

Chosen samples: 3, 6, 9, 12, 15, 18, 21, 24, 27, 1.

Each participant kept his anonymity in the study.

### *3.3 Procedure for the realization of the tests*

Each group performed four cognitive tests. The explanation of the tests was given in German for the bilinguals and in Spanish for the monolinguals. The questions of the test 3 were originally in Spanish and had been translated into German by a professional translator and the questions of the test 4 were originally in English and had been translated into German and Spanish by the same professional translator. Tests 1 and 2 were taken on the computer and could not be copied and thus are

not in the appendix of this thesis and the tests 3 and 4 were printed on paper (see appendix 1 – 4).

The choice of the languages for the written tests had been made according to the language of education of the groups (language in which the students take the mathematic class). The monolingual group was taught mathematics in Spanish whereas the bilingual group was taught in German. The languages of education needed to be kept in order for the results to be compared. The pupils took the tests in the same language used in class. Table 3 indicates the cognitive skills and the test used to evaluate these skills of the participants.

| | **Cognitive skill** | **test** |
|---|---|---|
| 1. | velocity | spatial speed test |
| 2. | memory | visual memory → pattern recognition |
| 3. | logic | logical thinking test |
| 4. | abstraction | abstract reasoning test |

Table 3: Cognitive skills and their tests

I had four reasons to have selected these skills for my study and not others. The first reason is that they involve the most important cognitive skills and second, because they are all being used in other subjects than mathematics. For example, velocity is needed for languages or music, memory skills for history or geography, logical thinking for sciences such as chemistry and abstraction for arts. A further reason was to choose cognitive skills for which adequate tests have been designed to assess the skill. There are plenty of tests that can be found on the internet, but for this study, it was important to select tests that had been designed by linguists,

professors or neuroscientists. The last reason was the limitation of time. I needed to take into account the time I had to conduct this investigation and according to it, I limited the choice for these four cognitive skills.

The participants performed only one test per day in a classroom at the bilingual institution. The first group (monolingual) was asked to enter, one child at the time, and sat in front of the computer (for tests 1 and 2) where the participant received the instructions. Only after the child had completed the task, did the next child come into the room. The participants were not able to see each other during the procedure. They were waiting in a separate room before they took the test. The same procedure was repeated with the second group (bilingual) on the same day for the same test. On the next day, they all completed test 2, repeating the very same procedure. For tests 3 and 4, the participants of each group were in the same room, one child per desk. Each group (monolingual and bilingual) took the test separately and the same instructions have been given to each group, respecting their language of instruction. Both groups took the same test on the same day.

### *3.3.1 Test 1: Spatial speed test*

For the Spatial Speed Test, the student saw one geometric figure, had to remember it (see figure 3) and then saw another figure and had to choose between two options: if the figure is the same as the one before or if it is different. He had to perform the task as fast as possible. This test was created by Luminosity Lumos Labs (2009), a laboratory in California specialized in brain functions. Lumos Labs is

a cognitive neuroscience research and development company that builds software tools for improving brain health and performance. The software was created by a team of nine neuroscientists from Stanford University[3]. This test investigates the speed of identifying geometrical figures in spatial setting according to the neuroscientists of Luminosity Lumos Labs. Figure 3 shows an example of one question of this test.

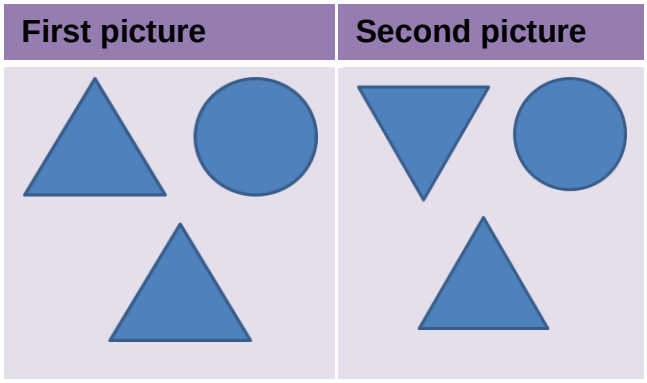


Figure 3: Sample of test 1

### *3.3.2 Test 2: Visual memory test*

For the Visual Memory Test, the student had to memorize 12 figures, one at a time, as shown in figure 4 under memorization phase. After the 12 figures had been shown, the student had to recognize them by choosing between pairs (one correct and one wrong) until the 12 figures had been identified (see recognition phase in figure 4). The maximum amount of points for this test was 12. This test was also

[3] Moriah Thomason, Ph.D., Cris Niell, Ph.D., Russell Fernald, Ph.D., Michael Walker, Ph.D., Elizabeth Race, Ph.D., Jennifer Tsui, Ph.D., Elizabeth Buchen, M.S., Ph.D., Raag Airan, MD, Ph.D., Wesley C. Clapp, Ph.D.

created by Luminosity Lumos Labs (2009) and according to the neuroscientists who designed the test, it investigates the short-term visual memory.

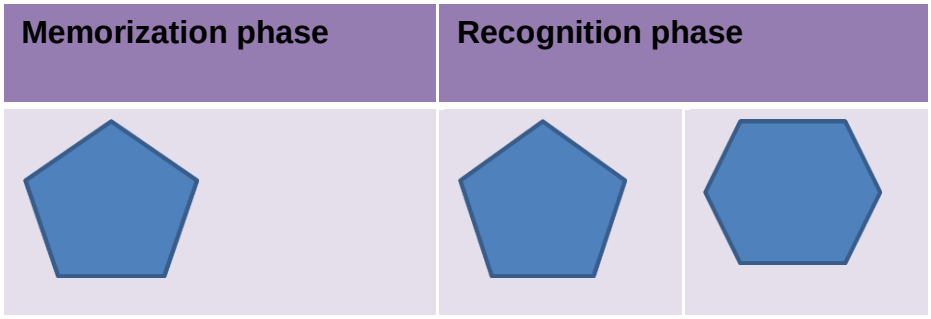


Figure 4: Sample of test 2

### *3.3.3 Test 3: Logical thinking test*

In the Logical Thinking Test, the student answered 10 questions about logical thinking. The test was an adaptation of the TOLT test invented by Tobin & Capie (1980, cited in Trifone, 1987). After having chosen the answer, the student had to find an explanation from five multiple choices options. The maximum amount of points was 10. The original TOLT test could not be used because it is meant for adults but the idea of the TOLT test was respected where a question was asked and five possible answers were proposed. The content of the questions asked was kept, but the level of difficulty needed to be adapted to the mathematical knowledge of children between 10 and 12 years old, therefore the five questions were taken from the *ENLACE exam 2008* for fifth graders from the mathematical section which is a national written exam in Spanish performed in every primary school in Mexico. The purpose of the exam is to compare the academic level of the schools. The mathematical section tests logical thinking ability: the student needs to use common sense and logic to find out the answers; it is not an exam where

the content can be learned by heart previously. Yet none of the participants had taken this test previously because at the time it was applied, they were in the third and fourth grades. This is why the questions were taken from the 2008 exam, that is the exam that was applied to fifth graders two years ago. (Test 3 is in the appendix 1 in Spanish and 2 in German.)

### *3.3.4 Test 4: Abstract reasoning test*

The Abstract Reasoning Test required the student to look at a series of symbols and find out which one completes the sequence. An example can be seen in figure 5. The student had to identify the relationship between the figures in order to find out which one was correct and fit to the schema. This test was created by Psychometric Success (2009) an organization that creates tests to improve students' cognitive skills, for example before applying for a job. According to the designers of Psychometric Success, the test has been created to find out the ability to analyze symbols on an abstract level. To perform the test, students need to picture themselves these symbols that follow a sequence. Without an abstract reasoning ability, the student would not be able to find the correct answer. (Test 4 can be seen in the appendix 3 in Spanish and 4 in German.)

Example:

1. Which symbol in the Answer Figure completes the sequence in the Problem Figure?

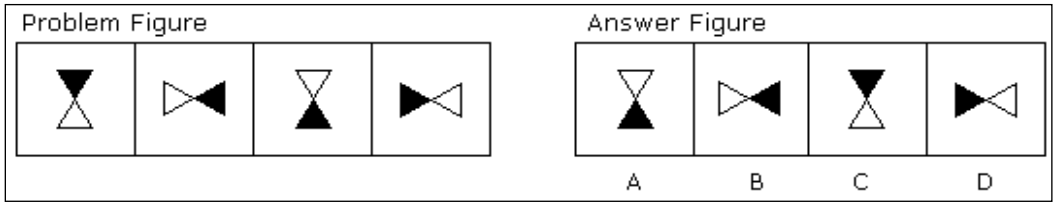


Figure 5: Sample of test 4

### *3.4 Coding of the tests*

Each test was coded separately by the researcher. The results are generally organized and visualized in tables, according to the two main groups – monolingual and bilingual learners – and by gender. For each test, there are two main tables, one for the results in general with the percentages of correct answers (see table 4) and another one for the significance of the results (see table 5). The results are shown and explained in chapter 4.

#### *3.4.1 Spatial speed test*

The spatial speed test, as mentioned previously, tested the speed of dealing with geometric figures. The participant took the test on the computer, where the time was recorded in seconds. When the child finished the task, the final time was given. The time of each participant was filed and an average of each group was calculated. Each group (monolingual, bilingual, boys and girls) also received its own average. Table 4 shows how the averages are compared in chapter 4.

| | **boys** | **girls** | **average** |
|---|---|---|---|
| monolinguals | | | |
| bilinguals | | | |
| **average** | | | |

Table 4: Table for the results of the tests

A second table (see table 5) shows then if the results are significant or not for test 1. The significance has been calculated with the t-test in an Excel program. The t-test has the purpose to compare the means of two groups and shows if the results are significant or not, according to the critical value. If the t-score is greater

than the critical value, the results are significant. In the case that the t-score is smaller than the critical value, the results are not significant. In order to find out the t- score, the following formula was needed:

$$t = \frac{M1 - M2}{\sqrt{\frac{(SD1)^2}{N1} + \frac{(SD2)^2}{N2}}}$$

M1 = Mean of group 1

M2 = Mean of group 2

SD1 = Standard deviation of group 1

SD2 = Standard deviation of group 2

N1 = Number of subjects in group 1

N2 = Number of subjects in group 2

The same formula was used for each test. N1 and N2 are the same for all tests whereas M1, M2, SD1 and SD2 are different numbers in each test.

| | **Monolinguals** | **Bilinguals** |
|---|---|---|
| Mean | | |
| Standard deviation | | |
| Variance | | |
| **t - score** | | |
| $\rho < .05$ (confidence level) | *df* = 39 (population) | 1.697 (critical value) |
| Interpretation | The results are significant if the t-score is greater than the critical value. | |

Table 5: Table for the significance of the tests

### *3.4.2 Visual memory test*

The visual memory test was computerized and the score of the participant automatically appeared at the end of the test. The scores of the participants were calculated in an average so that they can be compared. In total, the test had four averages: one for monolingual girls, one for monolingual boys, one for bilingual girls and one for bilingual boys, as shown in table 4. The same table used for the results of the test 1 is kept as such for the results of the test 2 (see table 4). Also, a second table (see table 5) shows if the results of test 2 are significant or not. There was no time limit for this test.

### *3.4.3 Logical thinking test*

The logical thinking test was a written test which was given in a classroom. Every participant of the same group took the test at the same time and when every student finished, the tests were recollected and corrected by the researcher. For each correct answer, the participant got one point and for each correct reason given, the learner also got one point. In total, the participant could get up to 10 points. The results of each participant of the same group (monolingual boys, monolingual girls, bilingual boys and bilingual girls) were put in an average. The results are represented in the same table, as shown in table 4 followed by the indication of the significance of the results of test 3 illustrated in a table identical to table 5. There was no time limit for this test: the participants handed in their test, once they were finished.

### *3.4.4 Abstract reasoning test*

The abstract reasoning test was a written test. The same coding procedure for test 3 was repeated for test 4. Each participant got a maximum of 4 points, one for each correct answer. The tests were corrected by the researcher. The averages are represented in a table (see table 4) where the scores of each group can be compared and a second table (see table 5) indicates afterwards if the results of test 4 are significant or not. There was no time limit for test 3: the participants handed in their test once they finished answering it.

### *3.5 Pilot of the study*

The materials (the four tests) were piloted in order to find out if they were adequate. The pilot study took place at the same private institution where the actual study was done.

#### *3.5.1 Participants of the pilot study*

The tests were piloted with 20 participants, half of the number of the total participants of the final study. They were randomly selected from the groups that participated in the study, described previously in table 1. The participants of the pilot were all between 10 and 12 years old. The participants of the pilot were eliminated from the lists so that they did not appear again as participants of the actual study. Table 6 shows how the participants selected for the pilot study were divided into four groups.

| | Group | Number of participants | Number of girls within the participants | Number of boys within the participants | Spoken language(s) |
|---|---|---|---|---|---|
| 1. Monolingual | DaF | 10 | 5 | 5 | Spanish |

| | | | | | |
|---|---|---|---|---|---|
| group | | | | | |
| 2. Bilingual group | DFU | 10 | 5 | 5 | Spanish (home language) German (education language) |

Table 6: Participants of the pilot

### *3.5.2 Results of the pilot study*

Table 7 shows an overview of the most important aspects of the results of each test. The first column indicates if the bilingual group scored higher or not and, according to the literature discussed in chapter 2, it was expected that the bilingual students would score higher. The second column shows which group performed the highest on each test. The third column confirms if the test needs an adaptation according to the results obtained in the pilot. An adaptation is needed if for example the participants had difficulties understanding the instruction or the questions, or if the level of the content was not adequate for children between 10 and 12 years old. The pilot had the purpose to find out this kind of information. According to the results of the pilot, I personally took the decision of adapting the test or not. Finally the last column shows if the test needs to be piloted again.

| **test** | **Bilinguals scored higher** | **Best group** | **Needed to be adapted** | **Needed to be piloted again** |
|---|---|---|---|---|
| velocity | yes | Bilingual boys | no | no |
| memory | no | Monolingual boys and bilingual boys | no | no |
| Logical thinking | yes | Bilingual boys | no | no |

| | | | | |
|---|---|---|---|---|
| Abstract reasoning | yes | Bilingual boys | yes | yes |

Table 7: Summary of the results

As illustrated in table 7, the bilingual group performed better in three out of four tests, so this means that in general they have better skills than monolingual learners and that they can apply them in mathematics. The fact that monolingual students have better memory skills might be the consequence of having too few participants since the average of the bilingual group lies just under the average of the monolingual group with a difference of 0.1.

Every group in general scored poorly on test 4. The cause could be that the test was too difficult for the age of the participants. Based on the fact that each group had a low score, this test was adapted for the thesis study. The first and the last tasks were kept the same as in the pilot but the second and the third ones were changed to have less difficult tasks. The adapted questions were taken from an IQ test written by McConochie[4] (1999), from the section *abstract reasoning*. The two questions taken from this test were, as well, testing the pattern recognition ability in abstract reasoning. A series of figures were given to the child who needed to find the correct figures that followed the first ones. He had to choose one out of four or five. The test was piloted again after the changes in order to see if the adaptation was adequate or not. The population was smaller as for the other pilot: 6 bilingual participants (3 boys and 3 girls) and 6 monolingual participants (as well

[4] Dr. William McConochie has a B.A. from Carleton College, a Master's in School Psychology and Ph.D. in Counseling/Clinical Psychology from IIT in Chicago, and a post-doc in Clinical Psychology from Northwestern University School of Medicine.

3 girls and 3 boys) which is a total of 12 participants for the second pilot of test 4. The participants of the first pilot could not be chosen again for the second pilot and the participants of the second pilot of test 4 could not take part of the actual study. The first reason to select only 12 participants was that I did not need a large population to see if test 4 was properly adapted and adequate for the age of the participants, meaning that the level of difficulty had decreased. The second reason was that I would not have enough bilingual participants between 10 and 12 years old for the actual study if I selected too many for the pilot study.

An interesting aspect that can be seen is the one in the second column of table 7 where bilingual boys always had the best scores. Once they performed as well as the monolingual boys (see table 7), but the fact that they always were the best leads to the conclusion that boys are better at mathematics than girls and that they are able to apply their cognitive skills more efficiently than girls. The gender variable, as mentioned earlier, was taken into consideration for the thesis study.

Tables 8 and 9 below indicate the results (the numbers indicate the averages of correct answers in the group) of the test 4, abstract reasoning test, before and after the changes.

**Abstract reasoning test before the modifications:**

| | **Boys** | **Girls** | **average** |
|---|---|---|---|
| Monolinguals | 2.0 | 1.6 | **1.8** |
| bilinguals | 2.2 | 2.0 | **2.1** |
| **average** | **2.1** | **1.8** | |

Table 8: Results of test 4 of the pilot before modifications

**Abstract reasoning test after the modifications:**

| | Boys | Girls | average |
|---|---|---|---|
| Monolinguals | 3.6 | 3.6 | **3.6** |
| bilinguals | 4.0 | 3.8 | **3.9** |
| **average** | **3.8** | **3.7** | |

Table 9: Results of test 4 of the pilot after modifications

All the participants scored higher after the modifications had been made. The test was kept as such for the study. Table 10 shows a summary of the results of test 4 after the changes.

| test | Bilinguals scored higher | Best group | Needed to be adapted | Needed to be piloted again |
|---|---|---|---|---|
| Abstract reasoning | yes | Bilingual boys | no | no |

Table 10: Summary of the results of test 4 after modifications

The next chapter shows the results of the four tests and gives an explanation for the results obtained. A statistical analysis calculated with the Excel program will define if the results were significant or not.

# IV RESULTS AND DISCUSSION

This chapter shows the results of the four tests illustrated with tables so for each test, the table shows results for monolingual and bilingual learners separately, as well as for boys and girls. In the last column on the right, the averages of the scores obtained by monolingual and bilingual students can be observed. The averages of the scores obtained by boys and girls can be found in the last line of the table. After the results of each test, an explanation is given to clarify the outcomes, taking into account the findings from other studies. The results of the four tests listed for each participant separately is possible to verify in the appendix 5. The last subsection of this chapter contains the answers to each research question asked at the beginning.

## *4.1 Results of test 1: Spatial speed test*

The first test investigated the speed of identifying geometric figures. Tables 11a and 11b show the results of the four groups.

This test gives various results: the first column of tables 11a and 11b indicates the time the child spent on the task, the second column shows the amount of points obtained for correct answers and the last column gives a percentage taking into account the time and the correct answers. The column of percentages is the one that indicates the end result because both variables, time and correct answers, both observed for test 1, are taken into account in the percentage.

| | Boys | | | Girls | | |
|---|---|---|---|---|---|---|
| | **sec.** | **Pts.** | **%** | **sec.** | **Pts.** | **%** |
| Monolinguals | 17.05 | 430 | 90.5% | 16.73 | 453 | 83% |
| Bilinguals | 16.84 | 510 | 92.5% | 17.29 | 540 | 93.8% |
| **average** | **16.95** | **470** | **91.5%** | **17.01** | **496.5** | **88.4%** |

Table 11a: results of test 1

| | Average | | |
|---|---|---|---|
| | **sec.** | **Pts.** | **%** |
| Monolinguals | **16.89** | **441.5** | **86.75%** |
| Bilinguals | **17.07** | **525** | **93.15%** |

Table 11b: results of test 1

Interesting results can be observed within the time parameter: The monolingual group did answer faster than bilingual group but they did more mistakes than the bilinguals students so this results in a larger amount of points for bilingual speakers. Their answers were better according to the time they used. In other words, monolingual learners answered faster but with more mistakes whereas bilingual learners answered a little slower but with a higher percentage of correct answers. The third column shows the percentage accumulated taking into consideration time and correct answers and we can see that the bilingual group had in the end a higher percentage than the monolingual group (93.15% vs. 86.75%). The group that achieved the highest percentage (this means that the participants were the fastest and had the most correct answers) was the group of the bilingual girls (93.8%). The group that had in the end the lowest percentage was the group of monolingual girls.

The time spent on answering the task was very similar for each group (there were differences but they are not major) which means that they all were almost as fast but the percentage of correct answers differed. Monolingual learners in general tended to be faster (a possible reason could be that they were more concerned about the time than about giving the correct answer) whereas the bilingual group in general was slightly slower than monolinguals (0.18 seconds slower). Possibly they were thinking more about the answer they gave. Although the monolingual speakers were faster this did not result in a higher amount of points. The test needed to be answered as fast as possible but correctly as well, which is a task that the bilingual girls performed the best. All participants received the same instructions: they needed to be fast *and* correct.

### *4.1.1 Significance of the results of test 1*

A statistical analysis of the results of the monolingual and bilingual groups (the t-test) shown in table 12, demonstrates that the results are significant for test 1 with the population used for this study. Using $\rho < .05$ as the level of confidence, the results indicate that 95% of the results with the population tested are based on truly happening facts. This means that 95% of the results obtained are not accidental; this is no coincidence that the bilingual students scored higher than the monolingual students. The t-score has been calculated with the formula shown under subsection 3.4.1 on page 49 using the standard deviations, the means and the number of participants (see table 12.).

| | **Monolinguals** | **Bilinguals** |
|---|---|---|
| Mean | 86.75 | 93.15 |
| Standard deviation | 7.18 | 4.11 |
| Variance | 51.57 | 16.87 |
| **t - score** | **3.4598** | |
| $\rho < .05$ (confidence level) | *df* = 39 (population) | 1.697 (critical value) |
| Interpretation | Results are **significant**<br>(t-score is greater than the critical value) | |

Table 12: Significance of the results of test 1

The standard deviation is the indicator of dispersion of the average of all scores from the mean. The more spread apart the data is, the higher the standard deviation. In the case of test 1, the standard deviation is 7.18 for the monolingual learners and 4.11 for the bilingual learners which means that the bilingual participants obtained scores closer to each other. This also indicates that the monolingual speakers had scores that are more spread out than the bilingual speakers (some of the monolingual students scored high while others scored low).

### *4.1.2 Interpretation of the results of test 1*

Bilingual learners need to be fast in their thinking because they have the necessity to decode in one language and to encode in another language. These strategies of decoding and encoding involve mental speed, which may explain why bilinguals are faster and able to find correct answers.

The results of test 1 seem to point to the conclusion that bilingual speakers are able to think fast and find the appropriate answer. The cognitive process of

thinking fast and correct is due to the mental gymnastic that bilingual or multilingual speakers are able to do with their two or more spoken language that enables them to switch from a language to another, explains Holmes (2001). This phenomenon is known as code switching or code mixing[5]. They start to speak in English for example and because of a change in the situation, such as the arrival of a new person, they switch and speak in French when it is the code of the new interlocutor. Code switching occurs automatically when a situation obliges the speakers to do it and code switching and code mixing help bilingual speakers to think faster and be more efficient in their communication. They need to change the language and the grammar structures within one conversation even sometimes within one sentence. Most of the time, bilingual speakers switch the language without having problems to keep speaking because they are able to think in both languages. They do not have to translate what they want to say, they just say it. The difference between monolingual speakers when they want to say something in a foreign language is that they need to translate, bilinguals on the other hand cannot translate, they transfer their thoughts in the other language: it is not a translation. This ability allows them to switch languages and as a consequence they are used to thinking fast because every bilingual speaker is able to code switch, says Holmes. Bilingual speakers have the training to listen, react and give output very promptly. This gives them an advantage in thinking fast in general, as shown with the test of spatial speed, which had no relation to language, only

[5] Code switching and code mixing are mostly associated with the sociolinguistic function of bilingual communication. It is a rule governed process that does not occur randomly. The speaker is changing the language in the part of the sentence where that makes sense. The difference between code switching and code mixing is evident: Code mixing can occur in the middle of a sentence while code switching happens only after the sentence is finished (Holmes, 2001).

mathematics. The conclusion is that bilingual learners can transfer their ability of thinking fast to tasks other than code switching / mixing.

Bilingual speakers have to deal with linguistic contexts at the time of retrieval that is sometimes different from the linguistic context at the time of encoding. As a result, they need to adjust their encoding strategies and encode information consistent with the language of retrieval (Marian & Fausey, 2006). These processes require a quicker velocity in thinking and sorting out information. The training bilingual speakers have to sort out information in more than one language gives them a general ability to think faster than a monolingual speaker which may explain the differences in the results of this test.

### *4.2 Results of test 2: visual memory test (pattern recognition)*

The visual memory test had 12 points, one for each correct answer. Table 13 indicates the results of the four groups and the averages. The percentages refer to the average of correct answers given (12 correct answers = 100%). The percentages help the reader to compare the results in a scale of 100.

| | **Boys** | | **Girls** | | **average** | |
|---|---|---|---|---|---|---|
| | **Pts** | **%** | **Pts** | **%** | **Pts** | **%** |
| Monolinguals | 10.1 | 84.2% | 9.5 | 79.2% | **9.8** | **81.7%** |
| Bilinguals | 11.6 | 96.7% | 11.1 | 92.5% | **11.35** | **94.6%** |
| **average** | **10.85** | **90.4%** | **10.3** | **85.85%** | | |

Table 13: results of test 2

The best group resulted to be the bilingual boys with an average of 11.6 points out of 12. The weakest group was the monolingual girls with only 9.5 points out of 12. Bilingual students in general outperformed monolingual students on that test (94.6% vs. 81.7%). The difference, 12.9%, indicates that the bilingual learners in this study have better skills for memory than monolingual learners. Boys in general scored higher than girls in both language groups (90.4% vs. 85.85%). The difference of percentages between the girls' and boys' results on the other hand is much smaller (difference of 4.55%). Bilingual students had better results than boys in general (94.6% vs. 90.4%). This seems to indicate that language variable is stronger than the gender variable.

### *4.2.1 Significance of the results of test 2*

Table 14 shows that the results of test 2 are significant using the population mentioned in this study. Using $\rho < .05$ as the confidence level, the results indicate that in 95% of the results obtained for test 2 with the population tested are not accidental. The t-score has been calculated with the formula shown under subsection 3.4.1 on page 49.

The standard deviation for test 2 is 1.40 for the monolingual participants and 0.93 for the bilingual participants (see table 14). These numbers indicate that the bilingual students scored closer to the mean than the monolingual students: There are no large difference between the best and the lowest scores for the bilingual participants; they are all relatively close to the mean when compared to monolingual participants.

| | **Monolinguals** | **Bilinguals** |
|---|---|---|
| Mean | 9.80 | 11.35 |
| Standard deviation | 1.40 | 0.93 |
| Variance | 1.96 | 0.87 |
| **t-score** | **4.1213** | |
| $\rho < .05$ (confidence level) | *df* = 39 (population) | 1.697 (critical value) |
| Interpretation | Results are **significant**<br>(t-score is greater than the critical value) | |

Table 14: Significance of the results of test 2

### *4.2.2 Interpretation of the results of test 2*

These results are very positive and meet the expectations expressed in the research questions. In the pilot, the monolingual participants outperformed the bilingual participants, which was a surprise. Although the difference between the groups was very small in the pilot, the outcome was not the one expected. The test has been kept as it was for the pilot study (no adaptation was made). In the present study, bilingual speakers outperform monolingual speakers (94.6% vs. 81.7%). The fact that the results between the pilot study and the actual study did not coincide may be caused by a smaller population in the pilot study. The actual study was conducted with twice the number of the participants, which could explain a possible difference in the results.

In this study bilingual learners showed a better aptitude of memorizing mathematical figures than monolingual learners. According to Souviney (1983, cited in Clarkson, 1992), bilingual speakers have a greater ability to memorize than

monolingual speakers and the results of test 2 correspond with Souviney' statement.

French & Jacquet (2004) studied bilingual speakers and memory and they showed that, independently of whether the bilingual has one big storage or two storages, he is able to activate the channels in the brain that look for the correct item. This process requires a well developed memory, since bilinguals need to find the correct word out of two storages, or out of one big storage, in both cases twice the amount of words that a monolingual speaker has. Simply the fact that bilingual learners need to remember more words in two languages helps them to develop their memory skills. And they do not only improve it through vocabulary, they also memorize structural patterns and grammar rules in two languages. Researchers (Thorell, Lindqvist, Bergman Nutley, Bohlin & Klingberg, 2009) have shown that memory increases by its use. They have found that training in working memory can have significant effects in other cognitive skills. Bilingual speakers develop their memory skills more than monolingual speakers do, which lead to better results in memory tasks, such as in test 2.

The group that received the best results is that of the bilingual boys. In this test, gender is not stronger as the language variable since the two best groups are both bilinguals. By comparing gender with language variable, it is possible to deduce that boys are not automatically better at memory skills than girls. However, it can be concluded that bilingual students in this study have better memory skills than monolingual students due to their need of memorizing vocabulary and linguistic structures in two languages and also to the constant training they have

using two linguistic codes. According to the results of test 2, bilingual education seems to have a positive effect on memory.

### *4.3 Results of test 3: logical thinking test*

The logical thinking test was a written test which had 10 points if the child answered every question correctly. Table 15 shows the results of the four groups and the averages. The participants had to answer five questions and find for each one the correct explanation. The test had multiple choice options for answers and explanations and in case they found the correct answer and the correct explanation, the participants received 2 points. If children chose a wrong answer but a correct explanation, they would get only one point. The table below shows that the best group was the bilingual boys (85% of correct answers) followed by the bilingual girls (82%). Both bilingual groups outperformed the monolingual groups (83.5% vs. 75.5%). The weakest group is the monolingual girls with 73% of correct answers.

| | **Boys** | | **Girls** | | **average** | |
|---|---|---|---|---|---|---|
| | **Pts** | **%** | **Pts** | **%** | **Pts** | **%** |
| Monolinguals | 7.8 | 78% | 7.3 | 73% | **7.55** | **75.5%** |
| Bilinguals | 8.5 | 85% | 8.2 | 82% | **8.35** | **83.5%** |
| **average** | **8.15** | **81.5%** | **7.75** | **77.5%** | | |

Table 15: results of test 3

### *4.3.1 Significance of the results of test 3*

For test 3, the results are significant, as illustrated in table 16 using the population mentioned in this study. The confidence level $\rho < .05$ indicates that for test 3 with the population tested 95% of the results are based on truly facts and no coincidence. The t-score has been calculated with the formula shown under subsection 3.4.1 on page 49.

| | **Monolinguals** | **Bilinguals** |
|---|---|---|
| Mean | 7.55 | 8.35 |
| Standard deviation | 1.43 | 1.14 |
| Variance | 2.05 | 1.29 |
| **t-score** | **1.9570** | |
| $\rho < .05$ (confidence level) | *df* = 39 (population) | 1.697 (critical value) |
| Interpretation | Results are **significant**<br>(t-score is greater than the critical value) | |

Table 16: Significance of the results of test 3

For test 3, the standard deviations obtained were 1.43 for the monolingual students and 1.14 for the bilingual students. Again, the bilingual participants scored closer to the mean than the monolingual participants which means they are a more homogenous group.

### *4.3.2 Interpretation of the results of test 3*

Bilingual students performed better than monolingual students in this test where logical thinking ability was tested. According to a study conducted by Clarkson

(1992), the fact that bilingual speakers scored higher may be due to their greater ability to solve mathematical problem compared to monolingual speakers. By participating in bilingual education, students may have increased their logical thinking (Hutson, 2008).

Another variable that should be taken into consideration is that this test involved language and not only mathematical symbols. It is the only test in this study that examines how the participants deal with mathematical tasks described with language and not with only symbols. The participants had to read the questions first, to understand them linguistically and mathematically. The questions were asked according to the educational language (in Spanish for the monolinguals and in German for the bilinguals) but the fact that they had to first deal with the linguistic structures and then with mathematical reasoning might have given the bilingual speakers an advantage. Bialystok (2001) explains how bilingual children in general outperform monolingual children in tasks involving the cognitive control of linguistic processes. This is one possible explanation why bilingual participants had better results in this test.

In this test, the highest percentages of correct answers were not achieved by the two groups of boys since the bilingual girls outperformed the monolingual boys (82% vs. 78%). The results seem to indicate that logical thinking is a cognitive skill that bilingual speakers dominate better than monolingual speakers, independently of their gender.

The results lead to a general conclusion that bilingual education may increase the logical thinking skills of the learners because bilingual speakers performed the test with better outcomes than children who received an education in one language only.

### *4.4 Results of test 4: abstract reasoning test*

This test was a written test investigating the abstract reasoning ability and they could only get four points as the maximum. Table 17 indicates two results per group: first the amount of points achieved in the test, then the percentage of correct answers. Bilingual speakers in general scored higher than monolingual speakers (92.5%. vs. 82.5%). The group that scored the highest was the bilingual boys with an average of 3.8 points out of 4 which means a 95% of correct answers were given. The group that scored the lowest was the monolingual girls with an average of 3.2 points achieved out of four.

| | **Boys** | | **Girls** | | **average** | |
|---|---|---|---|---|---|---|
| | **Pts** | **%** | **Pts** | **%** | **Pts** | **%** |
| Monolinguals | 3.4 | 85% | 3.2 | 80% | **3.3** | **82.5%** |
| Bilinguals | 3.8 | 95% | 3.6 | 90% | **3.7** | **92.5%** |
| **average** | **3.6** | **90%** | **3.4** | **85%** | | |

Table 17: results of test 4

#### *4.4.1 Significance of the results of test 4*

Table 18 indicates that the results of test 4 are significant using the population mentioned in this study. Using $\rho < .05$ as the confidence level, 95% of the results

are no coincidence: it was meant to be that the bilingual students will score higher than the monolingual students in test 4. The t-score has been calculated with the formula shown under subsection 3.4.1 on page 49.

| | **Monolinguals** | **Bilinguals** |
|---|---|---|
| Mean | 3.30 | 3.70 |
| Standard deviation | 0.66 | 0.47 |
| Variance | 0.43 | 0.22 |
| **t-score** | **2.2143** | |
| $\rho < .05$ (confidence level) | *df* = 39 (population) | 1.697 (critical value) |
| Interpretation | Results are **significant**<br>(t-score is greater than the critical value) | |

Table 18: Significance of the results of test 4

The standard deviations (0.66 for monolingual participants and 0.47 for bilingual participants) indicate that the bilingual students, as well as in the three other tests, scored closer to the mean than the monolingual students. These results also give the information that the bilingual speakers tend to have a similar aptitude to use the four cognitive skills tested than the monolingual speakers (bilingual participants obtained in the four tests a smaller standard deviation). In the monolingual group, there are children with high abilities and at the same time with low abilities of using cognitive skills (see SD). But the averages of the four tests show significantly that the bilinguals are better at using cognitive skills.

### *4.4.2 Interpretation of the results of test 4*

In these results bilingual participants in general performed better on the test than monolingual participants (92.5% vs. 82.5%). These results confirm that bilingual speakers in this study have a greater ability of abstract reasoning. However, the results show that both groups, monolingual and bilingual, scored high. The difference between the groups is exactly 10% which means that bilingual participants over scored monolingual participants by 0.4 points. According to Hamers & Blanc (1993), bilingual speakers show in general more positive cognitive aptitudes than monolingual speakers. The authors mention dealing with abstraction as one of the positive cognitive aptitudes more developed by bilingual individuals. The results of test 4 and Hamers & Blanc's statement are coherent. Another factor that I feel played a role in these results is the amount of attention the bilingual participants paid to the task. Bilingual students have a better ability to focus on a task than monolingual students (Bialystok, Craik, Klein & Viswanathan, 2004). This ability, called *selective attention* by Bialystok (2001), explains how the bilingual learner is able to focus on one important aspect while blocking out the less important information. Because bilingual speakers have this ability to select and sort the information required, they are able to pay attention to only what is needed. These findings might be one possible explanation for the differences in the results between monolingual and bilingual participants.

Having well developed abstract reasoning ability means that the individual can see the mental picture of what is asked. The abstract reasoning test uses this skill by asking the correct pattern that follows a series. If the participants answer

correctly, it means that they are able to develop a mental picture of what is coming next. According to Tomioka (2002), this ability is more developed in bilingual speakers than monolingual speakers because of their capacity of having different items stored separately in each linguistic system and when they want to use one item, they need to locate it in the correct linguistic system. This comes from the tripartite system hypothesis described by Tomioka who states that the fact that they have to find the right item needed increases their abstract reasoning ability. For example, the item needed is stored in only one linguistic code (or language), and the speaker needs it in the other code. This abstract reasoning ability leads to an appropriate translation of the item, if this item has not been stored in the other language yet. The results are congruent to what Bialystok & Hakuta (1994) had found: The mind of a speaker who has learned two sets of linguistic aspects for a single conceptual representation has possibilities that the monolingual speaker does not, in this case, this abstract reasoning ability.

The ability of the child to reason deductively lies in mathematical understanding, and according to Dawe (1983) this is highly related to the development of abstract thought. In order to answer correctly the questions of test 4, the participants need to have a mathematical understanding of the tasks asked which also means that their abstract thinking ability is well developed. The results obtained from the two groups lead to the conclusion that the ability of abstract thinking is better developed by bilingual speakers than by monolingual speakers because of the higher percentages of correct answers that were achieved by the bilingual participants.

Another interesting fact observed in the results of test 4 is that boys have higher percentages compared to girls (90% vs. 85%). Gender seems to play a role in test 4 as well and these gender differences are discussed under the next subsection, in the answer of research question 4.

### *4.5 Answers to the research questions*

This subsection is a summary of the results explained previously formulated in concrete answers to the five original research questions.

1. How do monolingual students between 10 and 12 years old score on cognitive and mathematic tests?

Table 19 indicates the results of monolingual participants only in percentages of correct answers in each test.

| Test | Scores obtained by monolinguals |
|---|---|
| 1. Spatial speed | 86.75% |
| 2. Visual memory | 81.7 % |
| 3. Logical thinking | 75.5% |
| 4. Abstract reasoning | 82.5% |

Table 19: Summary of the results of monolinguals

The test in which the monolingual participants performed best is that of the spatial speed test. The one that they scored the lowest is the logical thinking test and the results showed that monolingual speakers do have a well developed capacity of using cognitive skills. They had an average of 81.61% of correct

answers for the questions in the 4 tests. The results lead to a conclusion that the monolingual speakers in this study have skills for spatial speed, visual memory, logical thinking and abstract reasoning.

2. How do bilingual students between 10 and 12 years old score on cognitive and mathematic tests?

Table 20 shows the results of the bilingual participants on the four tests. The percentages indicate the amount of correct answers.

| Test | Scores obtained by bilinguals |
|---|---|
| 1. Spatial speed | 93.8% |
| 2. Visual memory | 94.6% |
| 3. Logical thinking | 83.5% |
| 4. Abstract reasoning | 92.5% |

Table 20: Summary of the results of bilinguals

Bilingual participants achieved high percentages in all of the four tests, especially in visual memory, spatial speed and abstract reasoning. The average of correct answers in general is 91.1% and logical thinking had been the test in which bilingual speakers achieved the lowest percentage. These results are extremely positive, since over 90% of the tasks were completed correctly. Bilingual learners in this study, according to the results, have a well developed capacity for using cognitive skills in spatial speed, visual memory, logical thinking and abstract reasoning. Their strength seems to be visual memory, closely followed by spatial speed, and abstract reasoning. The difference of correct answers given between

the three skills is very small (2.1%) showing that they all are almost equally well developed. The reason why logical thinking had weaker results might be caused by the fact that this test not only involved mathematical knowledge, but as well, linguistic knowledge. In order to perform this test, the participants had to understand mathematical tasks through language, which makes the questions more complex. The results of this test, 83.5%, are still very high and show that bilingual speakers have the capacity to connect mathematical knowledge and language skills to complete successfully the task. Mathematics understanding is influenced by language, say Ríordáin & O' Donoghue (2008) who investigated the relationship between language and mathematics.

3. What similarities and differences can be found between the monolingual and bilingual students' results of the four cognitive tests? Are these results significant?

Monolinguals' and bilinguals' results have been analyzed separately. In table 21 (on page 76), the results are shown again, in order to compare the two groups. The numbers in bold indicate which group had the highest score.

The biggest difference in the results between monolinguals and bilinguals can be observed in the second test: visual memory (81.7% vs. 94.6%). The bilingual participants had a higher percentage of appropriate answers compared to the monolingual participants. Due to the difference between the two groups one can infer that bilingual education has a positive impact on visual memory.

| Test | Monolinguals | Bilinguals | Significance |
|---|---|---|---|
| 1. Spatial speed | 86.75% | **93.8%** | Difference is significant |
| 2. Visual memory | 81.7 % | **94.6%** | Difference is significant |
| 3. Logical thinking | 75.5% | **83.5%** | Difference is significant |
| 4. Abstract reasoning | 82.5% | **92.5%** | Difference is significant |

Table 21: Comparison of the monolinguals' and bilinguals' results

Bilingual participants not only scored higher on the visual memory test; they achieved a higher percentage of correct answers in all four tests. The difference between the results was significant in all the four tests. These results were expected and to have the evidence that bilinguals in this study scored significantly higher on cognitive tests makes the argument stronger for bilingual education. In other words, bilingual education seems to have a positive impact on cognitive skills such as spatial speed, visual memory, logical thinking and abstract reasoning.

The results in general are high in the four tests. Bilingual learners are not the only participants who were able to use their cognitive skills to perform the tasks because monolingual learners as well achieved good scores. Both monolingual and bilingual speakers have cognitive skills that they use to perform mathematical tasks. Paradis (2000) mentions that there is no function available to the bilingual speaker that is not already available to the unilingual. The difference is, as these results confirm that bilingual speakers either make better use of their skills or have

more developed skills than monolingual speakers. For Paradis, the only difference seems to rely in the degree of use of the mental skills since bilingual education seems to increase the ability to apply cognitive skills appropriately. The results obtained by the analysis of the tests in this study are evidence that children are totally capable of learning content in two languages and that the benefits of learning more than one language are not only linguistically but also cognitively significant, as Espinosa (2008) explains.

4. What similarities and differences can be found between the girls' and boys' results of the four cognitive tests?

The following table shows first percentages of correct answers obtained by boys and girls and then the results of monolingual and bilingual participants combined by gender (see total). The bold numbers indicate which gender in which group performed better on the test.

| Test | Boys | | | Girls | | |
|---|---|---|---|---|---|---|
| | monolinguals | bilinguals | total | monolinguals | bilinguals | total |
| 1. Spatial speed | 90.5% | 92.5% | 91.5% | 83% | **93.8%** | 88.4% |
| 2. Visual memory | 84.2% | **96.7%** | 90.4% | 79.2% | 92.5% | 85.85% |
| 3. Logical thinking | 78% | **85%** | 81.5% | 73% | 82% | 77.5% |
| 4. Abstract reasoning | 85% | **95%** | 90% | 80% | 90% | 85% |

Table 22: Comparison of boys' and girls' results

In three of four tests, boys scored higher than girls. As mentioned previously in the individual results of each test, the gender variable was weaker than the language variable: boys were better than girls (see total), but not better than both sexes of bilingual participants. The fact that boys achieved in three of four tests better results than girls might be a coincidence, but the theoretical background found by linguists can explain these differences between the sexes. Neuroscientists have studied differences between boys and girls in language processing and have found that they use a different part of the brain to process some aspects of language such as grammar, for example, when they start to learn their first language (Melville, 2006; Burman, 2007). But, does this have an impact on how they apply cognitive skills? Globally, boys tend to outperform girls in math (Lipsett, 2008) but according to new research published in the journal *Science*, Lipsett explains that boys are not automatically better at mathematics than girls anymore. The fact that the masculine gender was better at mathematics is disappearing in societies that treat both sexes equally. Lipsett mentions that in countries such as Sweden, both sexes have equal results in mathematics. However, in countries such as Turkey, boys generally outperformed girls. A question I can now ask is, would this mean that the differences in results between girls and boys in this study do come from the fact that the society in Mexico does not treat boys and girls equally? Lipsett mentions that any difference in test scores is due to nurture rather than nature.

A study conducted by Huang (1993) investigated cognitive skills between gender of high school Chinese students. Their findings are interesting since they

do not totally match the findings of the current study. Girls were superior to boys on memory, and verbal composites, whereas boys were superior to girls on the spatial composites. They did not find any differences in logical thinking tests and other reasoning tests, whereas this study explicitly showed that boys outperformed girls. Using Lipsett's suggestions (2008) concerning the equality of treating both sexes, can we then imply that in Puebla, girls are not considered equal to boys? If not what is the cause of the difference between boys and girls in mathematics in this study?

Cook & Cook (2009) studied differences and similarities between girls and boys. They found out that in cognitive skills, the largest and most consistent difference appeared to be in language and certain spatial skills but that usually the differences favoring boys start at adolescence and increase during high school, especially in areas involving mathematical problem solving. The participants in the study had not reach adolescence yet, however the differences already exist. Cook & Cook give a plausible explanation for why boys tend to be better at mathematics than girls. They mentioned studies (Eccles, Wigfield & Schiefele, 1998; Maccoby, 1998; Perie, Moran & Lutkus, 2005) which found that girls hold less positive attitudes toward mathematics, show less interest in this subject, and receive less encouragement due to the fact that society believes that boys are better than girls in mathematics. This explanation seems to be a more appropriate one for the differences found in the current study because the participants are all between the age of 10 and 12 years old so the factor of adolescence is not taken into consideration as a reason for the difference. Cook & Cook also mentioned that

since the late 1970s boys have consistently scored about 10% higher than girls on the math portion of the SAT (a standardized test required by many colleges in the USA for admission). In the current study, the percentage of difference is not as high, finding only an average of 4.2% higher for the boys.

My personal explanation for the difference between boys and girls is caused by a different level of expectations: the fact that society (parents and maybe teachers) has higher expectations for boys than they have for girls about mathematics has the consequences that boys tend to be better. I agree with the findings of the studies mentioned by Cook & Cook (2009) because since boys know that good results are expected from them, they tend to work harder to meet these expectations. In a certain way, it is an inequality of treatments between gender, a theory that Lipsett (2008) supports.

5. Based on the results, what recommendations can be made regarding taking content classes in a language other than the one spoken at home?

The results of this study showed that bilingual education seems to lead to positive cognitive advantages. It presents a strong argument encouraging bilingual education. The results are explicit: In none of the 4 tests did the monolingual participants outperform the bilingual participants. These excellent results for the bilingual participants appear to be caused by their education which is bilingual.

Theoretical backgrounds and studies have shown many advantages for children taking content classes in a language other than the native language. The results of the study confirm the other results found in the literature and give parents

the evidence that bilingual education is also working well in Mexico, as long as the schools respect the rules of bilingual education. As mentioned previously, a school that offers some hours of English or any other second language during the week is not bilingual education. In order to increase the skills investigated in the study, the child needs to have content classes in his L2, not only language classes, in order to assure positive cognitive advantages.

Another important aspect is the difference between additive and subtractive bilingualism. Positive results on the brain are only guaranteed, according to literature and to the results of this study, if the speakers come from an additive bilinguality setting. Clarkson (1992) mentions that competences in two languages bring advantages for bilingual students but the level of language competence in each language is an important factor. Being bilingual with low competences in the two languages is neither an advantage for mathematics learning nor for the use of cognitive skills. This explains why a true bilingual institution should encourage learning in both languages. If the pupils want to gain advantages from their bilingualism, they need to come from an additive background which values the home and the educational languages and accepts their use in society. Competence of language is the crucial point for their benefit and if the proficiency level is not high enough, the learner will not be able to acquire the advantages a competent monolingual speaker could obtain.

### *4.6 Evaluation of the hypotheses*

In chapter 1, four hypotheses were presented. With the results obtained in this study, summed up in table 21, it is now possible to accept or reject the hypotheses.

Null hypothesis: There is no difference between the monolinguals' and bilinguals' results.

This hypothesis is rejected. The results showed a significant difference between monolingual and bilingual group results which is why the hypothesis must be rejected. The fact that the null hypothesis has been rejected opens the possibility to accept the other three hypotheses.

1. Speaking two languages does not cause any interference nor overwhelm the students in content classes. Bilingual education is not negative.

The results have shown that bilingual speakers did not score lower than monolingual speakers. This seems to indicate that bilingual education is not negative so the results obtained in this study support this hypothesis.

2. There is a difference in the use of cognitive skills depending on if a child is bilingual or monolingual.

The results have shown significant differences. They imply that the use of cognitive skills depends on if a child is bilingual or not so this hypothesis is also accepted.

3. Bilingual students have advantages over monolingual students in content classes such as in mathematics. Bilingual education is positive.

Again, the results demonstrate that bilingual education is positive, since the bilingual speakers achieve significantly higher scores than monolingual speakers on all four tests.

The three hypotheses presented at the beginning are accepted. The outcomes for these hypotheses were expected and because they resulted to be correct they have become now strong claims arguing for bilingual education.

The last chapter of this thesis offers a general conclusion, pointing out the most important aspects found in the investigation. As well, it mentions various further research possibilities to add to the already found results. Finally, the chapter reveals what is going to happen with the information obtained in the study.

# V CONCLUSION

Bilingual education started some decades ago but its benefits have not been acknowledged from the beginning and even today, it is still a controversial topic for parents. Some agree that bilingual education is positive whereas some others have the feeling that their children would be overwhelmed learning content in a language other than the one spoken at home. This study has shown that this is incorrect and that students learning content in a second language do have more developed cognitive skills than the students learning content in their native language. This study is evidence that bilingual education has a positive impact on the brain.

Bilingual students used to be regarded as being at a disadvantage in learning mathematics because of an assumed interference between their two languages, according to Clarkson (1992). Various studies (Dawe, 1983; Clarkson, 1992, 2006; Ríordáin & O' Donoghue, 2008) including this one, showed that the facts that people have believed are not supported. Results were found, showing that bilingual students did perform as well as or better than monolingual students on math tests. Bilingual education has to be encouraged in order to give the speakers the opportunity to improve in both languages and develop better cognitive skills.

Choosing a bilingual institution which provides content classes in a second language is the first step to a successful education. The study shows that after only 5 years of being part of a bilingual program (the participants were in their fifth or sixth year of the program), children already had developed a better ability to use

cognitive skills to complete tasks. They are advantaged over monolingual learners in velocity, memory, logical thinking and abstract reasoning. These skills are not only used in mathematics or in other subjects but as well in everyday life. Improving the ability to use cognitive skills will not only have an impact on academic education but also on the individual in general.

By increasing his cognitive skills, the individual also increases his self-esteem (Barrett, Webster & Wallis, 1999; Taylor & Montgomery, 2007). Researchers in psychology mentioned have studied the impact of cognitive skills on self-esteem and found that there was a correlation between the two aspects. This explains why psychology today uses cognitive-behavioral therapy to treat patients with low self-esteem, such as reported by Taylor & Montgomery. It can be said that indirectly bilingual education increases self-esteem, developing the cognitive skills which help the individual to have a better image of himself. Psychologists describe self-esteem as a fundamental aspect of a person's experience and quality of life (Crocker & Wolfe, 2001). A positive self-evaluation is a crucial predictor of one's general well-being. If parents want their children to become learners with a high level of self-confidence, they should see bilingual education as a chance to achieve this goal.

Choosing an institution which provides bilingual education is not an easy task. Parents should be aware that many schools in Mexico promise bilingual education but that actually means language classes only, such as grammar, conversation or listening comprehension. This kind of education is not considered bilingual education and therefore does not automatically generate the same

cognitive advantages found in this study. The study was based on the author's definition of true bilingual education, which means, that the participants of the bilingual group were taking content classes in a second language. They speak Spanish at home and have mathematics, biology, art classes etc. in German at school, which is the meaning of a true bilingual education. The impact of usual language classes (not content classes) on cognitive skills was not investigated in this study and therefore positive consequences from this kind of education are not guaranteed.

An important aspect regarding bilingual education is that the pupils need to have a high proficiency level of the language of education in order to benefit from positive development of cognitive skills (Ríordáin & O' Donoghue, 2008). The results of tests where the participants had to use cognitive skills to complete the tasks were related to the language proficiency level. In order to have a good performance in content classes, students should have high competences in both languages, the first and the second, as mentioned previously by several authors. This is why the participants of the study had to pass a language test which indicated if their linguistic level were high enough or not. In order to avoid that the child fails the test, it is preferable to choose a bilingual education program as early as possible. These kinds of programs usually start at the level, which means that the best moment to start being part of a bilingual program would be the first grade. The threshold level needs to be reached to facilitate the benefit of positive effects on the learner (Cummins, 1976, cited in Takakuwa, 2005). This encourages parents to choose a bilingual education option as early as possible.

Further research could be focused on the differences between gender in mathematics. Does Lipsett's statement (2008) about mathematical results defined by the equality of treatment between boys and girls play a role in Mexico? Or are the differences caused by other factors? This could be a basis for a new investigation in order to find an explanation for the differences of the results between boys and girls obtained in this study.

Another possible research area to investigate would be testing the participants in another content subject to see if the results in mathematics match those found in another subject, however, the four cognitive skills would need to be the same.

The difference between adults and children learning languages has been a topic on which researchers have focused a lot. It has interested linguists, especially those who believe in the critical period hypothesis[6] or those who want to contradict it. How would adults perform on mathematical tests where they need to use their cognitive skills to complete the tasks? Would the differences between monolingual and bilingual adults also be similar? Would gender be an important variable as well? These questions could be answered with a further investigation using adults for participants.

[6] Theory that explains why it is difficult to learn to pronounce a second language without foreign accent after puberty. The Critical Period Hypothesis is a biologically determined period in which the brain keeps its plasticity for acquisition of any language. Between the ages of three and the early teens, the child is more sensitive to stimuli and has some innate flexibility for the organization of brain functions. After puberty, the ability for acquisition and adjustment to the physiological demands of verbal behavior quickly declines (Lenneberg, 1967, cited in Nagai, 1997).

The participants came from an additive bilingual setting. Literature has shown that bilingualism must be additive in order for the speakers to benefit cognitively from their languages. Another research could use participants coming from a subtractive background in Mexico, for example, from a bilingual indigenous community. Comparing them to monolingual speakers, would they score lower? Do attitudes towards language define the amount of cognitive impact on the individual?

Bilingualism leads to a better use of the speaker's cognitive skills. Does multilingualism outperform bilingualism regarding the ability to use these cognitive skills? A further study could investigate if speakers of three languages are able to make an even better use of the skills than bilingual speakers. Does the number of spoken languages gradually increase the capacity of using the cognitive skills?

This study investigated four cognitive skills which are velocity, memory, logical thinking, and abstract reasoning but there are more than only four cognitive skills. The same participants could take tests in which they need to apply other skills. Are bilingual speakers good at using cognitive skills in general or are they only in the four investigated in this study?

Finally, the most important finding of this study is that children have more advantages in the cognitive aspects if they are bilingual. And if the child is not bilingual from birth on, parents should find a possibility to give him/her the chance to become one. Bilingual education is the solution for all children to become bilingual and better users of their own cognitive skills. Alladina already stated in

1985 that all children can benefit cognitively, linguistically, and culturally, from learning more than one language. The cognitive aspect that Alladina mentions has been shown in this thesis.

This study has been designed to find evidence to demonstrate the positive aspects of learning content in a second or foreign language. The question that can be asked now is how can parents be informed about the results of the study? The work is not done yet by stating the findings in this thesis; in order for parents to receive all this information, I will plan a conference at the bilingual institution to share my study and my results. I think that a conference is an excellent possibility to inform the parents, answer directly their questions and clarify their doubts. One of my goals, as I mentioned earlier, is to make people change their beliefs about bilingual education. This may occur if I speak directly to parents about the outcome of this thesis.

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APPENDIX 1

# **Test 3** (español)

**Grupo:**

**Niño** ◯ **Niña** ◯

| Total de puntos: |
| --- |
| ____ / 10 |

## Instrucción:

- Lee las preguntas y encierra la letra con la respuesta correcta.
- Lee las explicaciones de cada pregunta y encierra la letra que tiene una explicación lógica a la pregunta.

1. Para llenar dos depósitos de una gasolinera llegaron dos pipas; la primera llevaba 25 875 litros de combustible y la segunda 38 760 litros. ¿Cuántos litros de más traía la segunda pipa?

a) 12 885 litros b) 13 885 litros c) 54 635 litros d) 64 635 litros

**Explicación:**

a) Divido el segundo número entre el primero
b) Resto el segundo número del primero
c) Adiciono los dos números y los divido entre 2
d) Calculo la diferencia de los dos números

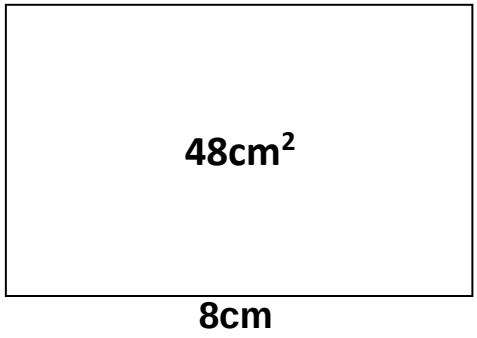
2. En la librería “El buen lector” el precio de una enciclopedia es de $7 560. Los estudiantes que presenten su credencial tendrán un descuento del 20%. ¿Cuánto deberá pagar un estudiante por la compra de esta enciclopedia?

a) $9 072 b) $ 6 048 c) $ 4 536 d) $1 512

**Explicación:**

a) Multiplico el precio de la enciclopedia por 20, lo divido por 100 y me da el descuento.
b) Multiplico el precio de la enciclopedia por 20, lo divido por 100 y me da la respuesta.
c) Multiplico el precio de la enciclopedia por 100, lo divido por 20 y me da el descuento.
d) Multiplico el precio de la enciclopedia por 100, lo divido por 20 y me da la respuesta.

3. Analiza cuidadosamente la siguiente figura:



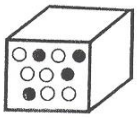
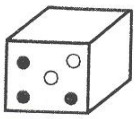
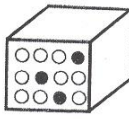
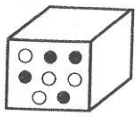

¿Cuáles deben ser las medidas para construir otro rectángulo que tenga igual área pero su perímetro aumente en 10 unidades?

a) 12cm y 4cm b) 16cm y 3cm c)24cm y 2cm d) 48cm y 1cm

**Explicación:**

a) Cada lado tiene que aumentar también de 10 cm.
b) Cada lado tiene que aumentar de 5cm.
c) La suma de los cuatro lados de la nueva figura tiene que ser 38cm.
d) La suma de los cuatro lados de la nueva figura tiene que ser 58cm.

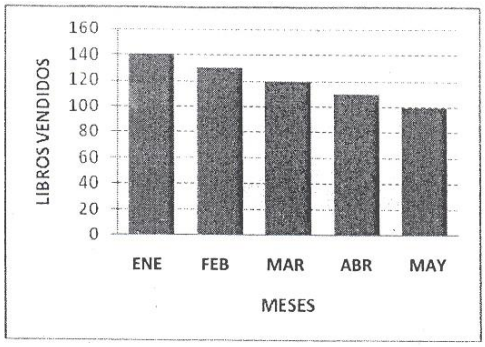
4. Al sacar una canica al azar, ¿de cuál de las siguientes cajas es más probable que la canica sea negra?

A)  B)  C)  D) 

**Explicación:**

a) Tiene que ser donde hay el número más alto de canicas negras.
b) Tiene que ser donde hay el número más alto de canicas blancas.
c) Tiene que ser donde el número de canicas negras es, comparándolo con el número de canicas blancas, más alto.
d) Tiene que ser donde el número de canicas en total es lo más alto.

5. Rodrigo vende libros. Durante los primeros 5 meses el registro en una gráfica la cantidad de libros que vendió como se muestra a continuación:




Si Rodrigo mantiene la tendencia de ventas como se muestra en la gráfica anterior, ¿Cuántos libros venderá a finales del mes de julio?

a) 90 libros b) 80 libros c) 70 libros d) 60 libros

**Explicación:**

a) Cada mes vende 20 libros menos.
b) Cada mes vende 10 libros menos.
c) El mes de julio tiene que ser la mitad del primer mes.
d) El último mes en la gráfica indica 100, entonces en julio vendió 10 libros menos.

APPENDIX 2

# **Test 4** (Deutsch)

**Gruppe:**

**Junge** ◯ **Mädchen** ◯

Total Punkte:

____ / 10

## Anweisung:

- Lies die Fragen und umkreise den Buchstaben mit der richtigen Antwort.
- Lies die Erklärungen jeder Frage und umkreise den Buchstaben, bei dem du eine logische Erklärung findest.

1. Zu einer Tankstelle kamen zwei Benzinlieferungen. Die erste brachte 25875 Liter Treibstoff, die zweite 38760 Liter. Wie viel Liter mehr brachte die zweite Lieferung?

a) 2 885 Liter b) 13 885 Liter c) 54 635 Liter d) 64 635 Liter

**Erklärung:**

a) Ich teile die zweite Zahl durch die erste.
b) Ich ziehe die zweite Zahl von der ersten ab.
c) Ich addiere beide Zahlen und teile sie durch 2.
d) Ich errechne die Differenz zwischen beiden Zahlen.

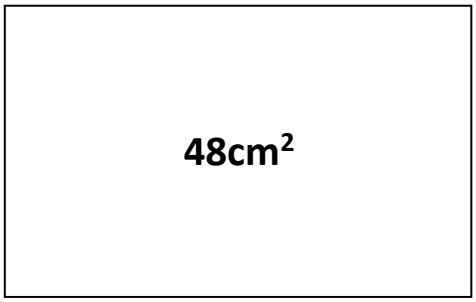
2. In der Buchhandlung „Der gute Leser“ kostet eine Enzyklopädie 7 560 $. Die Schüler, die einen Ausweis vorlegen, erhalten 20% Preisnachlass. Wie viel muss ein Schüler für eine Enzyklopädie zahlen?

b) $9 072 b) $ 6 048 c) $ 4 536 d) $1 512

**Erklärung:**

a) Ich multipliziere den Preis der Enzyklopädie mit 20, teile ihn durch 100 und ich erhalte dadurch den Nachlass.
b) Ich multipliziere den Preis der Enzyklopädie mit 20, teile ihn durch 100 und erhalte das Ergebnis.
c) Ich multipliziere den Preis der Enzyklopädie mit 100, teile ihn durch 20 und erhalte den Nachlass.
d) Ich multipliziere den Preis der Enzyklopädie mit 100, teile ihn durch 20 und erhalte das Ergebnis.

3. Untersuche sorgfältig folgende Figur:



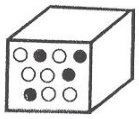

Wie lauten die Maße für ein Rechteck mit der gleichen Fläche, dessen Umfang aber um 10 Einheiten größer ist?

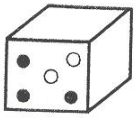
a) 12cm und 4cm b) 16cm und 3cm c) 24cm und 2cm d) 48cm und 1cm

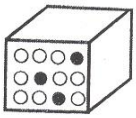
**Erklärung:**

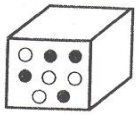
a) Jede Seite muss auch um 10 cm verlängert werden.
b) Jede Seite muss um 5 cm verlängert werden.
c) Die Summe der 4 Seiten des neuen Rechtecks muss 38 cm sein.
d) Die Summe der 4 Seiten des neuen Rechtecks muss 58 cm sein.

4. Bei welcher der folgenden Kisten ist es am wahrscheinlichsten, eine schwarze Murmel zu ziehen, wenn zufällig eine herausgenommen wird?

A) 

B) 

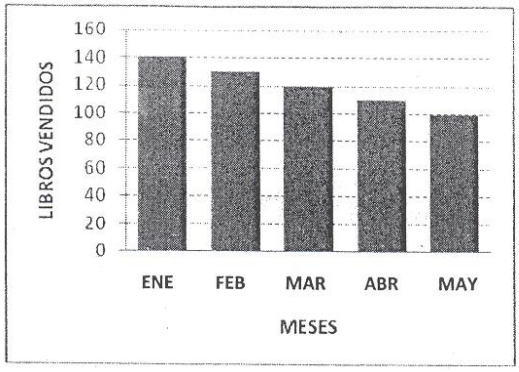
C) 

D) 

**Erklärung:**

a) Es muss die sein, die am meisten schwarze Murmeln enthält.
b) Es muss die sein, die am meisten weiße Murmeln enthält.
c) Es muss die sein, die im Vergleich zur Anzahl der weißen Murmeln am meisten schwarze Murmeln enthält.
d) Es muss die sein, die insgesamt am meisten Murmeln enthält.

5. Rodrigo verkauft Bücher. Während der ersten fünf Monate verlief der Verkauf so, wie in der folgenden Grafik dargestellt:




Wenn Rodrigo den in der Grafik dargestellten Verlauf der Verkäufe beibehält, wie viele Bücher verkauft er dann Ende Juli?

b) 90 Bücher b) 80 Bücher c) 70 Bücher d) 60 Bücher

**Erklärung:**

a) Er verkauft jeden Monat 20 Bücher weniger.
b) Er verkauft jeden Monat 10 Bücher weniger.
c) Im Juli muss es genau die Hälfte vom ersten Monat sein.
d) Der letzte Monat in der Grafik zeigt 100 an, also hat er im Juli 10 Bücher weniger verkauft.

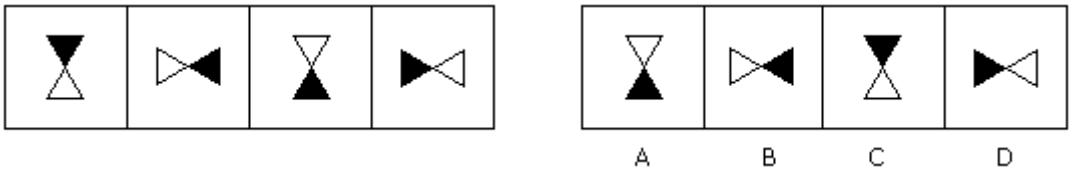
APPENDIX 3

# **Test 4** (español)

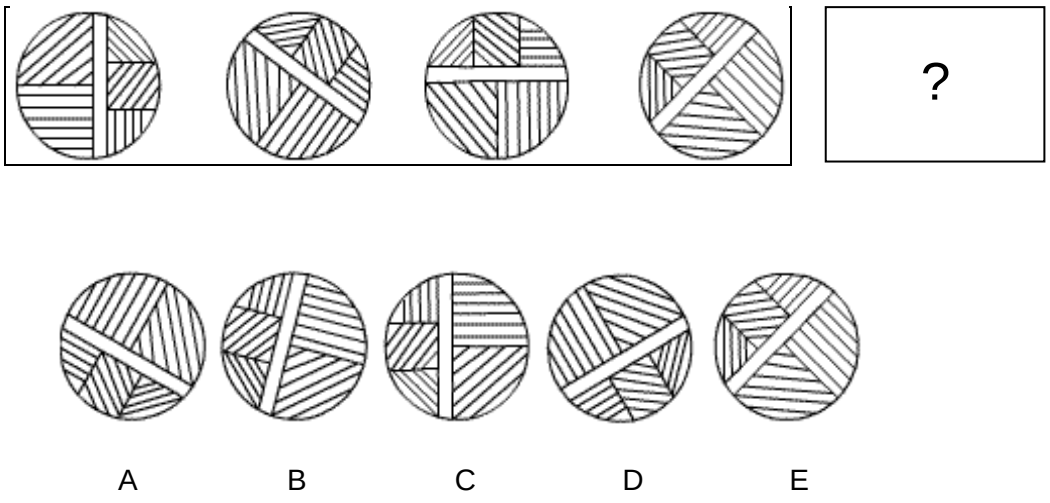
**Grupo:**

**Niño** ◯ **Niña** ◯

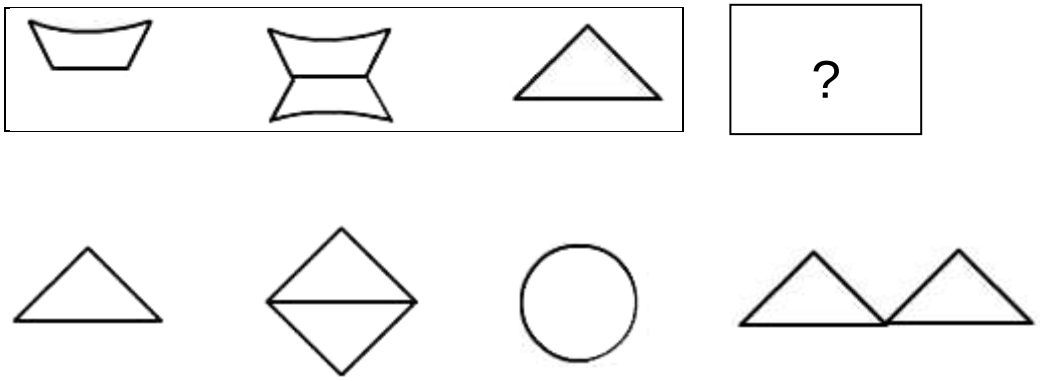
1. ¿Cual de las figuras A, B, C o D continua la serie? Encierra la letra correcta.



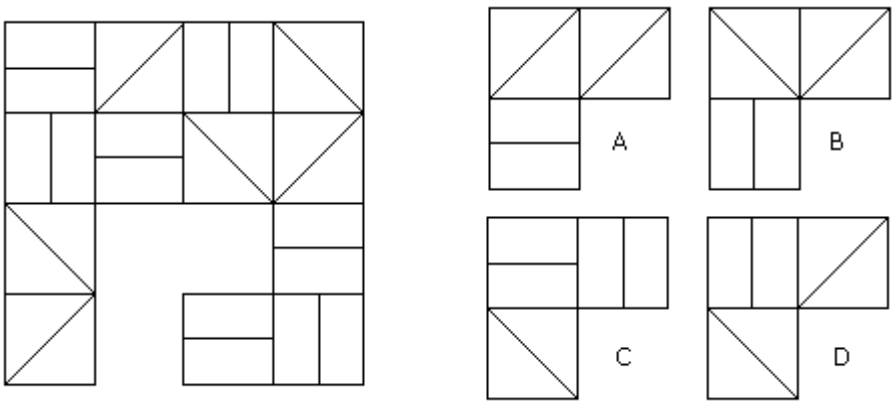

2. ¿Cual de las figuras A, B, C, D o E continua la serie de manera correcta? Encierra la letra.



3. ¿Cual de las figuras A, B, C o D continua la serie de manera correcta? Encierra la letra.




4. ¿Cual de las figuras A, B, C o D rellena el espacio del rompe cabezas correctamente? Encierra la letra.




*¡Muchas gracias por tu participación!*

Total de puntos: _____ / 4

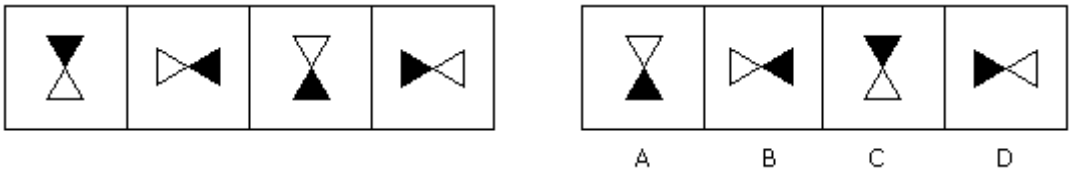
APPENDIX 4

# **Test 4** (Deutsch)

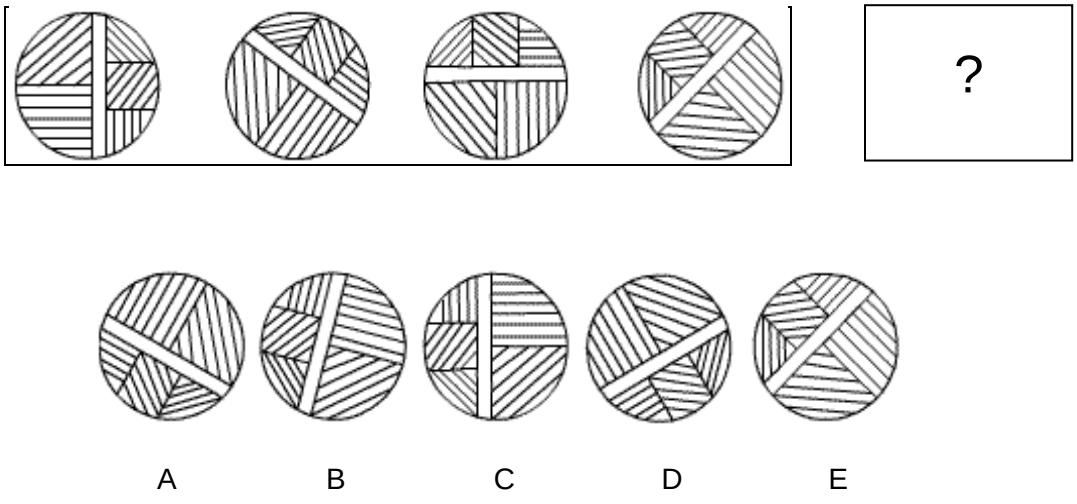
**Gruppe:**

**Junge** ◯ **Mädchen** ◯

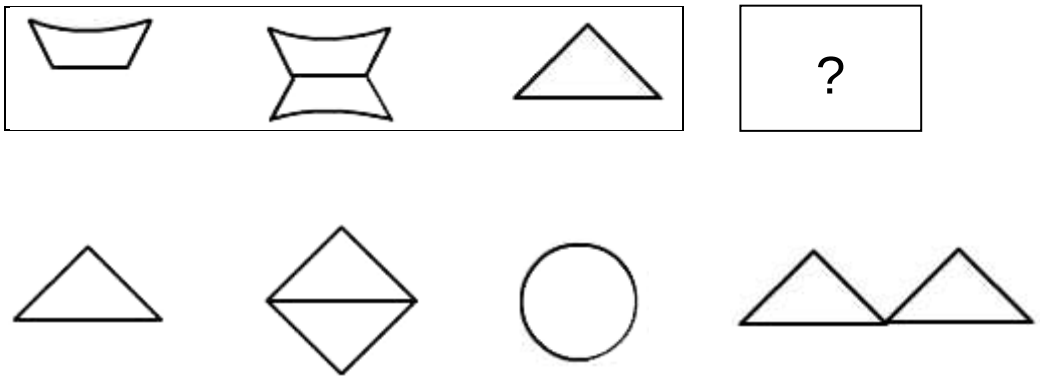
1. Welche der Figuren A, B, C oder D führt die Reihe fort? Umkreise den richtigen Buchstaben.



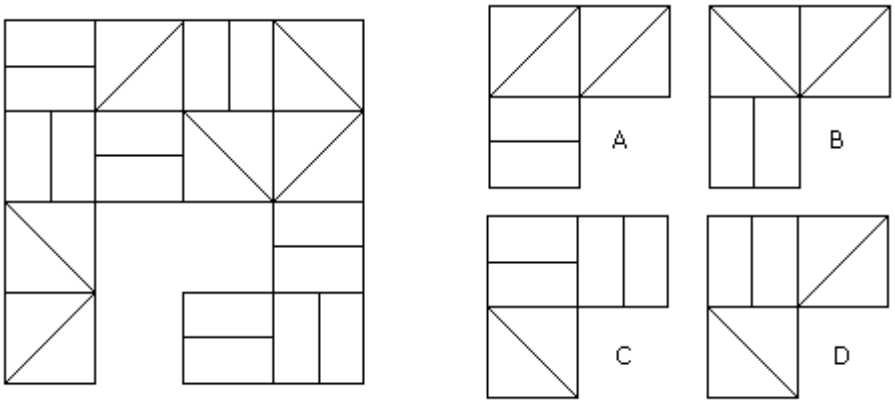

2. Welche der Figuren A, B, C, D oder E führt die Reihe fort? Umkreise den richtigen Buchstaben.



3. Welche der Figuren A, B, C oder D führt die Reihe fort? Umkreise den richtigen Buchstaben.




4. Welche der Figuren A, B, C oder D füllt die Lücke im Puzzle aus? Umkreise den richtigen Buchstaben.




*Danke für dein Mitmachen!*

Punkte: _____ / 4

## APPENDIX 5

Results of the four tests listed separately per group and individually for each participant

| **Test 1** | total of 100 | | | |
|---|---|---|---|---|
| | | | | |
| | **Monolinguals** | | **Bilinguals** | |
| Participant | Boys | Girls | Boys | Girls |
| 1 | 94 | 88 | 98 | 95 |
| 2 | 88 | 79 | 100 | 97 |
| 3 | 87 | 96 | 89 | 99 |
| 4 | 84 | 87 | 94 | 95 |
| 5 | 97 | 81 | 85 | 90 |
| 6 | 85 | 73 | 88 | 92 |
| 7 | 89 | 76 | 90 | 89 |
| 8 | 92 | 87 | 96 | 95 |
| 9 | 93 | 74 | 92 | 89 |
| 10 | 96 | 89 | 93 | 97 |
| Total | 905 | 830 | 925 | 938 |
| average | 90,5 | 83,0 | 92,5 | 93,8 |
| | | | | |
| MEAN | 86,75 | | 93,15 | |
| **Test 2** | total of 12 | | | |
| | | | | |
| | **Monolinguals** | | **Bilinguals** | |
| Participant | Boys | Girls | Boys | Girls |
| 1 | 9 | 8 | 12 | 12 |
| 2 | 8 | 9 | 11 | 12 |
| 3 | 10 | 9 | 12 | 12 |
| 4 | 11 | 8 | 11 | 11 |
| 5 | 11 | 10 | 12 | 9 |
| 6 | 9 | 11 | 12 | 11 |
| 7 | 12 | 11 | 11 | 12 |
| 8 | 12 | 9 | 11 | 9 |
| 9 | 9 | 8 | 12 | 12 |
| 10 | 10 | 12 | 12 | 11 |
| Total | 101 | 95 | 116 | 111 |
| average | 10,1 | 9,5 | 11,6 | 11,1 |
| | | | | |
| MEAN | 9,8 | | 11,35 | |

| **Test 3** | total of 10 | | | |
|---|---|---|---|---|
| | | | | |
| | **Monolinguals** | | **Bilinguals** | |
| Participant | Boys | Girls | Boys | Girls |
| 1 | 9 | 9 | 8 | 7 |
| 2 | 10 | 6 | 7 | 8 |
| 3 | 8 | 5 | 9 | 7 |
| 4 | 7 | 9 | 10 | 9 |
| 5 | 9 | 8 | 10 | 10 |
| 6 | 7 | 6 | 9 | 9 |
| 7 | 9 | 7 | 7 | 8 |
| 8 | 6 | 6 | 9 | 9 |
| 9 | 6 | 8 | 8 | 9 |
| 10 | 7 | 9 | 8 | 6 |
| Total | 78 | 73 | 85 | 82 |
| average | 7,8 | 7,3 | 8,5 | 8,2 |
| | | | | |
| MEAN | 7,55 | | 8,35 | |
| **Test 4** | total of 4 | | | |
| | | | | |
| | **Monolinguals** | | **Bilinguals** | |
| Participant | Boys | Girls | Boys | Girls |
| 1 | 4 | 3 | 4 | 3 |
| 2 | 3 | 4 | 4 | 3 |
| 3 | 4 | 3 | 4 | 4 |
| 4 | 4 | 2 | 4 | 4 |
| 5 | 3 | 3 | 3 | 3 |
| 6 | 3 | 3 | 3 | 4 |
| 7 | 3 | 4 | 4 | 4 |
| 8 | 3 | 2 | 4 | 4 |
| 9 | 3 | 4 | 4 | 3 |
| 10 | 4 | 4 | 4 | 4 |
| Total | 34 | 32 | 38 | 36 |
| average | 3,4 | 3,2 | 3,8 | 3,6 |
| | | | | |
| MEAN | 3,3 | | 3,7 | |