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The Effect of the Acquisition of Mathematical Reasoning Skills on the Acquisition of Foreign Language Skills, Focusing on High School Students

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Although most people conceive that the subjects of mathematics and foreign language reside on the two opposite hemispheres of the brain, many students come to realize the intertwining of the two as they continue to absorb more knowledge about each subject and the influence of one on the other. Psychological studies provide seemingly obvious evidence that students with struggles in learning language will also have trouble learning mathematics, as "there is evidence that dyslexic children experience problems with mathematics and lag behind their peers" (Durkin 11). This statistic further implies, however, that language indeed has a direct influence on mathematics education, but the question arises as to "whether there are differences in learning and development as a function of the particular language or languages employed." The education of mathematics and the education of foreign language have direct impact on each other, specifically focusing on high school students.

Recent mathematics educators have become accustomed to the term of "modern mathematics," in which math became a "collection of unintelligible rules which, if memorized and applied correctly, led to the 'right answer'" (Skemp 13). In trying to reform mathematics education beyond a subject that appears merely as a collection of facts or rules to memorize, though, some reformers attempt to present mathematics as a "logical development" (Skemp 13). This approach seems feasible in that it aims to show mathematics as sensible and not arbitrary, but instead it confuses two different approaches to learning mathematics. This logical presentation of mathematics serves to convince doubters, or to bring struggling students or doubting students to understanding, but it also provides solely the end of a mathematical discovery. Approaching mathematics education as "logical" versus "psychological" fails to bring the learner to those very "processes by which mathematical discoveries are made" (Skemp 13). Thus, the problems in both learning and teaching mathematics lie in a psychological approach, which directly correlates to similar struggles in foreign language education. Similarly, strengths in the education of one of these subject areas of mathematics and foreign language relates to those of the other subject area as well.

The relation between the two subjects may seem less clear than the understanding that both share a commonality in being psychological issues in the education of them. Learning both math or a foreign language do indeed require more than the knowledge of how to arrive at the right answer, or a logical method of reasoning; instead, the mind must go through the process to understand the material and its application to life. With this in mind, one follows how aspects of strict high school mathematical concepts, such as factoring quadratic equations or integration of an area bounded by two curves on a twodimensional Cartesian plane. The information adheres to a unique cognitive theory in psychology that explains in detail how individually these subjects follow a direct path to knowledge, and thus their similarities allow the two to grow on and adapt each other.

As research continues to develop, psychologists notice how education of any type of information in general (such as academic subjects like mathematics or foreign languages or practical life situations like the basic human skills of writing and walking) relates the intuitive mode of thinking with the analytical mode of thinking, both of which are necessary in the psychological approach to education. The distinction between what is intuitive and what is analytical defines itself by the cognitive process of thinking known as the *dual-process theory* (Leron 108). A student's misconception defines itself as a disconnection between what a student's intuition is and what is actually true. According to the dual-process theory, the human cognition and behavior fall within two systems of the human brain, simply named as *System 1* and *System 2* (Leron 108), where the first system corresponds to intuition and the second to analytical thinking (*System 1* may be known as *S1* and *System 2* may be known as *S2*). As these are separate systems of the human mind, each functions on a different level. They require different modes of operation, different parts of the brain for activation, and evolve in different times during a lifetime. It may seem fairly certain the distinction between perception and cognition, that is, what is well known and what is interpreted to be known. However, this concept of the S1 system is fairly recent, and influences heavily the results of psychological studies involving rationality and its application to mathematics education.

Similar to perception, operations in S1 processes have the characteristics of being “fast, automatic, effortless, unconscious and inflexible,” (Leron 108) meaning that these mental operations in S1 do not require energy or effort from the human mind. What differs from perception in S1 processes, however, is that S1 can also be mediated by language as well as relate to events that our not happening in the current. For example, an S1 operation can be the ability to plan out a map of a route that one will drive in the future for an upcoming vacation, as the mind will call upon previously-stored information in the S1 processes to do this despite the fact that the vacation and the destination are not in “here-and-now.” S2 processes, however, differ most greatly from S1 processes in their level of accessibility, or how fast as well as how easily things come to mind. In many situations the S1 and the S2 work together, but situations occur in which the S1 reacts quickly and the S2 does not intervene. Because the S1 will produce quick and automatic responses, the S2 will simply not have the time to play a part.

The S2, however, as the system that corresponds more to analytical thinking, plays a role more of monitor and critic to the actions and reactions of the brain and those results. The reason that the S2 acts slower than the S1 is because of this very role – the S2 must react to the S2 response and continue its role as monitor. The responses from S1, besides being effortless and rapid, are also defined as non-normative, which refers to the fact that they are unexpected compared to what society has come to recognize and accept as normal. The "failure of S2 to intervene in its role as critic of S1" causes these responses of S1 to often become non-normative. Thus, as soon as a response from S1 occurs often enough to monitor by S2 and then correct the mistake, the response no longer remains non-normative.

Examples of mathematics education questions can easily represent this psychological process of thinking of the *dual-process theory*. One example is the following, taken from Leron's article which he used from an article printed by D. Kahneman in 2002: (Leron 109)

> A baseball bat and ball cost together one dollar and 10 cents. The bat costs one dollar more than the ball. How much does the ball cost?

According to the dual-process theory, most everyone will report an initial tendency to answer with "10 cents" because one can easily split the sum of $1.10 into a dollar part and a cents part – in this case, $1 and 10 cents. The S1 will confirm this answer because the 10 cents hovers around the correct amount. However, obviously one must solve for the correct answer with simple calculations. First, set the cost of the bat equal to an arbitrary variable x and the cost of the ball to y, thus x plus y equals one dollar and ten cents. Then, by the given information that the bat costs one dollar more than the ball, set x equal to y plus one. Use substitution to solve for x equals five cents and y equals one dollar and five cents. In mathematical terms:

$$x + y = 1.10$$

$$x = y + 1$$

By substitution: $y + 1 + y = 1.10$

$$x = 1.05$$

$$y = 0.05$$

This result also shows that the ball equals five cents and the ball equals a dollar and five cents.

Because of the dual-process theory, this situation creates a "cognitive illusion," which is similar to the optical illusion known well in cognitive psychology (Leron 109). The obvious features of this problem, or the ball and the bat and the dollar part and cents part that are given in the original value (one dollar and ten cents), cause the S1 of many people to jump immediately to the conclusion of one dollar and 10 cents, since these two numbers are obvious. For others, in contrast, the “S1 had also immediately jumped with this answer, but in the next stage, their S2 interfered critically and made the necessary adjustments to the answer” (Leron 110). The importance of noticing the S1 and S2 systems here is that the S1 normally provides good results under “natural conditions” (Leron 110), such as when searching for food or for predators. The rapid and natural instinct of the S1 can be vital to survival such as in these conditions, but in other cases such as the mathematics problem described above, it can lead to incorrect responses.

One thing to note is that these two systems of thinking do not remain entirely mutually exclusive. Different skills may indeed pass between thee two systems. When a person becomes an expert of one skill, perhaps “after a prolonged training” (Leron 110), a previous S2 behavior becomes an S1 skill for this person. A good example of this is driving. When first learning how to drive, a beginner must consciously remain in deep concentration and give full attention on the motions and the reactions involving the car and the surroundings. Thus, any quick movements made that could cause any damage during the drive are S1 processes, and the corrections to the driving are the S2 processes (such as turning back onto the road when the S1 overcorrects a bad swerve on the road). After repeating this process numerous times, the S2 behavior becomes the norm, and will modify into a S1 process. Thus, in applications to mathematics education, a common mistake in mathematics that had been an S1 reaction can become overridden by an S2 correction to allow the mistake to no longer occur. An example of this is a high school algebra student consistently making the mistake of multiplying the exponents of two exponential terms with the same base. Seeing the two numbers in a relatively similar position (the exponent), the student takes this obvious information and allows the S1 to process this multiplication as the correct result. Then, however, the S2 system of the brain will take the information learned from the algebra course and correct this mistake, as the student will no longer multiply the two powers but instead add them. It may require multiple trials for this correction to occur, but in time the S2 correction will translate this action from an S2 into an S1 action, or the student will learn to naturally add the powers of two exponential terms of the same base instead of multiply them.

This dual-process theory applies further than to mathematics, though. The psychological theory just as easily explains the acquisition of a foreign language as well. During a child's younger years, he or she "is a specialist in learning to speak" (Harley 4). This is due to the fact that a child's brain has a much greater capacity to be molded (in a fashion similar to how one molds plastic) in comparison to the brain of an adult, according to the brain plasticity hypothesis (Harley 4). Once beyond childhood, however, the brain becomes "progressively stiff and rigid (Harley 4), which makes the acquisition of a foreign language that much more difficult for a human mind.

The brain plasticity hypothesis leads to the opportunities for the systems to develop in the dual-process theory. A child's brain is "elastic" enough to acquire the "early set or the units of language," despite the fact that an older learner may appear to have an advantage due to an expanded vocabulary. The secret to the success of allowing the brain of a child to adapt to learning a foreign language is the acquisition of a "switch mechanism" (Harley 4). If a child becomes exposed to more than one language at the formative period of his or her childhood, the switch mechanism enables the child to turn from one language to another "without confusion, without translation, without a mother tongue accent" (Harley 4-5).

This switch mechanism, which takes time to develop, also refers to the System 2 processes in the dual-process theory. A mechanism to help a child distinguish a word, phrase, or grammatical concept in a foreign language allows the child to transfer that information from a completely foreign concept into a piece of information that is recognized and thus no longer attempting to be corrected, as this information moves from S2 into S1.

Further, one cannot undermine the time and process necessary to move a skill or another piece of information from S2 into S1. As an anecdote, in the nineteenth century, François Gouin of France headed to Hamburg to learn German (Diller 51). As a Latin teacher at a school in France, Gouin believed that the quickest way to master German would be to memorize a German grammar book as well as a table of 248 irregular German verbs (Diller 51). He was able to achieve all of this in merely ten days, as he concentrated intensely on finishing this task in the isolation of his room. With this new information and a sense of accomplishment, Gouin headed to the university in Germany to test his new knowledge in the German language. Upon arrival in Germany, however, Gouin discovered his inability in the language, as he recounts (Diller 51):

> "in vain did I strain my ears; in vain my eyes strove to interpret the slightest movements of the lips of the professor; in vain I passed from the first class room to a second; not a word, not a single word would penetrate my understanding. Nay, more than this, I did not even distinguish a single one of the grammatical forms so newly studied; I did not recognize even a single one of the irregular verbs just freshly learnt, though they must certainly have fallen in crowds from the lips of the speaker."

Gouin’s lack of time spent on truly absorbing and understanding the German language, despite having acquired all the knowledge from the German grammar book as well as the table of 248 German verbs, was not adequate for the switch mechanism to develop and monitor and correct mistakes and move information from an S2 into an S1 process.

The research shows clearly that both mathematics and foreign language acquisition skills fall under the dual-process theory of learning in terms of classifying this education under one type of psychology. However, can the two possibly link to each other? More specifically, how will the knowledge of one indeed aid in the process of gaining knowledge about the other? The polarization of these two subjects becomes “increased by the common belief that people are either mathematically-scientifically or linguistically interested or talented” (Rolka 105). Instead, the two can be taught in unison and thus incite academic improvement in each because of the effects they have on each other. Psychological evidence again shows that the acquisition of mathematically reasoning skills has a positive effect on the acquisition of foreign language skills, specifically focusing on high school students when they are in the midst of learning this information.

Mathematics educators have long recognized the “importance of reading, writing, symbolizing, and communicating,” because otherwise their subject would be nearly impossible for high school students to comprehend (Draper 928). Further, the mathematics education requires an initial understanding of communication such as reading and writing so that students can "communicate their thinking with others so that students can develop a deep understanding of important mathematical concepts and ideas" (Draper 928). The basis of reading and writing as tools for learning more abstract ideas, such as mathematics concepts, proves necessary to succeed academically.

The field of mathematics education has been previously been viewed as a frame of thinking that "[helps] students develop mathematical understanding and the ability to engage in authentic mathematical activity" (Draper 929). However, two new views of learning mathematics have emerged as of recently, both of which focus less on the student's ability to suddenly understanding mathematics concepts and more on the process of solving problems in mathematics. In this perspective called *problem-solving view of mathematics*, humans tend to take their own experiences and "organize and interpret" them into their own problems that must be solved (Draper 930). The problems become known as ideas that are continually expanding and needing constant revision. The human mind constantly performs problems of mathematics because mathematical activity has the broad definition of solving problems involving boundaries, quantities, and relationships between quantities, as well as inventing, testing, and proving conjectures. All of these actions, when practiced consistently and well, will lead to a natural development of the ability to know what procedures to solve problems, which can then be generalized into concepts that may be shared with the public such as definitions, facts, and theorems. To arrive at this information, one needed to utilize the process of critical thinking in first creating a problem from the observations made in the surroundings, then create and test hypotheses until arrival at the correct solution, which can then turn into common information that can build further discoveries. This view of mathematics – where the focus is on solving problems and the process of arriving at the right answer – differs on an extreme scale from the more accepted view of mathematics known as the *instrumentalist view of mathematics*, which is the perspective that mathematics remains only a “set of facts, algorithms, and skills used to complete mathematical exercises (usually those found at the end of each section in the textbook)” (Draper 930). According to this view, mathematics consists mainly of selecting the appropriate skill from one’s collection of mathematics concepts and abilities to perform a simple or perhaps a complicated series of computations or symbol manipulations to produce an answer exactly similar to that of the teacher or the back of the textbook. Performing mathematics according to this definition translates to quoting facts and performing computations correctly, skills that require only memorization and a bit of practice to master. Mathematics educators in support of this view of mathematics education and learning assume that the procedures to arrive at the final correct answer are concepts, which means that these concepts will eventually become apparent to any student of the material once they have received enough of the facts and they have mastered enough of these concepts.

Mathematics education researchers and professional mathematics teacher organizations have come to more strongly disfavor the instrumentalist view of mathematics. Mathematics reformers as early as 1978 (Draper 930) started to acknowledge the two different views of mathematics education, and have since then advocated the problem-solving view of mathematics in favor of the instrumentalist view of mathematics because it supports the understanding and sense making of the material, and the idea that this requires time as a process. In fact, over the past twenty years, the National Council of Teachers of Mathematics published in their document named *Standards* that they have come to notice and develop concern for students having a lack of understanding of the results of the mathematics taught under the instrumentalist approaches to instruction (Draper 930). National educators in the field of mathematics have commenced in putting mathematics education emphasis on the problem-solving view, so that students may grasp "understanding, meaning, sense making, and reasoning in authentic mathematical activity" (Draper 930).

All this emphasis on problem-solving in mathematics, then, correlates directly to the acquisition of language. In teaching literacy in a language, a teacher must focus on developing the skill of literacy that the student already possesses. This may appear as one major difference between mathematics education and foreign language education – mathematics teachers, especially in high school, may need to teach seemingly completely foreign concepts to students so that they may develop the information in their minds as it becomes knowledge as it transfers from unknown material to an S2 process to an eventual S1 process. In literacy of a language, however, a teacher will take what a student does know and continue to develop the individual skills in mastering the language. This remains obvious because communication happens constantly, thus all students are always reading, writing, listening, and speaking, which are the four major components of any language and the main areas to focus on in teaching a foreign language to a student. It can then seem that mathematics education and foreign language education are incomparable in this respect, but in actuality they share similarities in this respect. To someone who has no experience whatsoever in another language, or even small amounts of exposure but no level of anything resembling proficiency, a teacher will have to show them completely new concepts so that the student can convey basic information via any form of communication. A high school student taking his or her first ever class in French is not expected to know the subject pronouns or the conjugations of a regular –er verb. In fact, the student may not comprehend the fact that there exist six major subject pronoun groups that govern verb conjugation. His or her usage of these subject pronouns in the native tongue of English may be so ingrained their teachers, when the student was first learning English, never had to group the subject pronouns into a list of six major ones. The student must master this foreign yet basic concept of subject pronouns before even attempting the skill of conjugating regular –er verbs in present tense, which would be the first step in learning about verbs before mastering a past tense such as passé compose.

The similarities in both mathematics and foreign language run deeper past this commonality of having to teach a basic concept, help develop it, then repeat the process as students begin to master more and more information and knowledge, in either subject area. In learning a language and becoming literate in it, any student will draw from the experiences around them. Coming from a more social constructivist view of learning and knowing, one can assume that people do not have the ability to convey meaning directly to other people. This means that instead of being able to verbally or act out in some other fashion a concept and the other human completely understanding this, a human must “endow objects with meaning, and negotiate meanings as they try to make sense of their world and to communicate with one another” (Draper 931). In either foreign language or mathematics learning, students will draw upon their own personal experiences to create their own schema, and thus from their further manipulate the information as the brain attempts to use and apply it to life. This is the process that the problem-solving view of mathematics refers to, as mathematical concepts transfer from S2 into S1 processes. Similarly, as students receive more exposure and more explanation from teachers about foreign language concepts such as new vocabulary or a different verb tense, the students will apply these words and concepts to what they do know (such as the English language for students within the United States of America) and learn to develop the knowledge naturally in their minds, thus it will move from S2 system thinking, where the brain monitors and must purposefully conjugate verbs, into S1 system thinking, where the brain naturally is able to remember and apply the conjugated forms of the regular –er verb “parler” when wanting to express a French sentence about someone currently talking.

The evidence makes it extremely clear that indeed the learning of both mathematics and a foreign language fall under the same psychological view as information moves into the S1 system of thinking from the S2, and that each require time and a process for the information to move. As just mentioned, the processes require time and student personal experience for maturation of the information and overall complete comprehension of the material of the two subjects of mathematics and a foreign language. However, how can a student within his or her own mind be able to take in one of these subjects and its material and translate it into acquired knowledge without first basing the new information on what he or she previously knew? Researchers in the field have recently coined the term *metalinguistic awareness* to refer to a student’s “linguistic ability that enables a language user to reflect on and analyze spoken or written language” (MacGregor 451). This is what students use when they pay attention to not just the meaning of a word or phase, but also the form of function of it as well. For example, in learning a language, in this case English being the foreign language, a student noticing that the word *school* rhymes with both the words *pool* and *rule* and wondering why *school* is not spelled as *skool* and *rule* not is spelled as *rool* (MacGregor

451). The student here has paid enough attention to the sounds and the spellings of the linguistic signs instead of simply to their meanings.

This metalinguistic awareness allows the students learning the material to reflect on the structure and function of the text as an object, to make choices about how they want to communicate the information they have learned, and then to manipulate perceived units of language. Because the analysis of structure, making choices about how to accurately represent concepts or ideas, and manipulation expressions all appear to relate to the field of mathematics, and particularly to the common high school field of algebra, it seems quite likely that “metalinguistic awareness in ordinary language has an equivalent in algebraic language” (MacGregor 451). One component of algebraic competence is the ability to mentally manipulate abstract objects in accordance with properties of the classes of objects to which they belong. This ability in algebra operates at a similar level of abstraction as metalinguistic awareness in ordinary language when words and groups of words are treated as instances of variables with general properties. For example, the word *simplify* could be considered as an instance of the variables *string of eight letters*, *transitive verb, word of three syllables*, or *word starting with s* (MacGregor 451).

Two of the seven accepted components of metalinguistic awareness in ordinary language are *word awareness* and *syntax* *awareness*, which can also be related similarly to algebraic methods of thinking. One of them is *symbol awareness*, which relates to the *word awareness* in linguistics learning. This includes knowing that “numerals, letters, and other mathematical signs can be treated as symbols detached from real-world referents” (MacGregor 452). It logically follows that symbols can be manipulated to rearrange or simplify an algebraic expression, no matter what the original referent. Another aspect of symbol awareness is the ability to know that groups of symbols can be used as basic meaning-units. For example, (x+3) can be considered as one single quantity for the purposes of manipulation in algebra.

Secondly, the quality of *syntax awareness* is shared between mathematics and language education. Syntax awareness refers to the “recognition of well-formedness in algebraic expressions” and the “ability to make judgments about how syntactic structure controls both meaning and the making of inferences” (MacGregor 452). The recognition of expressions that are in good form in mathematics refers to being able to realize that 2x=10, which translates to x=5, are in good form, whereas 2x=10=5 would not be in good form since that is incorrect (impossible for a number to equal both 10 and 5 at the same time). An example of the ability to make judgments regarding the syntactic structure is knowing that if *a-b=x*, then it is generally true that b-a=x, for it shows how the knowledge of the structure of a subtraction problem can help determine what can and cannot be equivalent to a certain term because of the subtraction and the meaning of the subtraction.

Students are taught to increase their metalinguistic awareness in several different ways in both mathematics education as well as foreign language education. To develop symbol awareness in linguistics, high school educators often teach their students that words are "arbitrary names" and can be represented as "groups of symbols," and this develops during the early primary grades and is associated with learning to read (MacGregor 452-453). Thus, symbol awareness can often be used to develop word games, jokes, and puzzles that children can understand and often do enjoy. This translates directly to the ability to be aware of and identify symbols in mathematics as well, as students can play math games to understand how numbers may be represented in different ways according to mathematical concepts such as simplification of the basic order of operation properties.

In seeing how exactly the areas of mathematics and foreign language can relate in metalinguistic awareness, it is easy to make the connections on how mathematics education can influence that of foreign languages. If a student continues to practice his or her metalinguistic awareness in mathematics, the concept of defining terms and being able to manipulate them can easily relate to foreign language as well, particularly in the area of grammar. For example, if a student understands the previously stated concept that if *a-b=x* then generally *b-a=x* is not true, then they can understand that the conjugation of “he guesses” in French, for example, would is *il devine*, is not the same as “he becomes in French,” which is *il devient*, despite the fact that both use similar letters. The metalinguistic awareness permits the student to understand that these same letters that make similar sounds in French are rearranged to mean two completely different things. However, as discussed previously, the ability to understand these concepts and allow them to transfer in the brain from initially received new information into a processed brain function in the S2 state of thinking that requires purposeful cognitive effort into an S1 state of thinking all requires time and a process.

So the most useful application to this information is having the knowledge of how to improve each of these abilities now that one understand how improving the skills of one can directly relate to improving in the other subject area as well. As previously mentioned, games and puzzles that build these basic thinking skills and processes have proven to be a good source of student education at a young age, particularly when they are young and “immature” in the knowledge of the subjects. Arguments have been made as to how effective these methods can be when having to teach the absolute basic and introductory material, which is very necessary in high school education of foreign languages since most all students will have had no formal exposure to the language whatsoever. In mathematics, this may be true with students who have disabilities in learning mathematics or another reason to struggle in the high school mathematics classroom and be at a disadvantage, such as not having the subject previously or not being in a classroom that as intensely studied the material in the past (particularly ESL students who could function in math at a level of a regular native speaker of English because of the basic need to be able to communicate in the language before learning a content area in the language). It seems apparent and inevitable for teachers, when teaching the absolute basics of a subject, will have to do so with a more lecture-based format of teaching and not a more open process of learning such as the games and puzzles described, where students will have the opportunity to express themselves freely and interact with others to build constructs and schemas in their mind about the information. This may sound less effective and contrary to many popular theories of education today, but this basis of information is required for students to be able to apply it to their own experiences, which is the problem-solving view of mathematics and overall the problem-solving view of education discussed previously. Fuson says in her book *Language in Mathematical Education: Research and Practice* that the "number word-sequence is originally learned as a rote sequence much as the alphabet is learned" (Fuson 28). At first, many of these number words have no meaning to the student. The errors that they make in learning the sequence seem to depend upon the structure of the sequence of number words, and in the English sequence the number words start with a rote list of twelve words (the numbers 1 through 12), then the next seven words repeat a similar word ending (-een) with a word beginning similar to one of the original twelve, then a "decade pattern of x-ty, x-ty one, x-ty two, …, x-ty-nine in which the x words are regular repetitions of the first nine words for "four" and "six" through "nine" but are not regular for two, three, of five (such as "twenty," "thirty," and "fifty") (Fuson 28). This material may appear boring to a student at first as they try to understand the very basics of the language of mathematics in the knowledge of what the first one hundred integers are (similar to memorizing the alphabet when trying to learn a language), especially if it was simply fed to a student via a lecture style of learning, but the information here is vital to allow students to then build their own schema as they store knowledge and eventually obtain deeper and deeper knowledge as the process of learning it sees the child transferring information, over time, from S2 processes into S1 processes, both in the fields of mathematics and foreign language education.

Although this paper seems to merely scratch the surface on the effect of mathematical reasoning skills on foreign language skills and vice versa, particularly in high school education when the material remains a foreign concept to most students, the point has been made. Following the dual-process theory of learning, the psychology of mathematics education and foreign language education argues that obtaining information in one of these subjects relates similarly to the manner in which the other is obtained. Further, the mental processes required to understand both actually remain the same, thus practicing one can influence the other and cause overall academic improvement in both areas.

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