COMENIUS UNIVERSITY IN BRATISLAVA

FACULTY OF MATHEMATICS PHYSICS AND INFORMATICS

Relationship between Musical Abilities and Science, Technology, Engineering and Mathematics in Elementary and Middle School Students

Diploma thesis

Study Programme:	**Conitive Science (Single degree study, mater II. deg., full time form)**
Study code:	**2503**
Field of study:	**Cognitive Science**
Supervisor:	**PaedDr. Vladimíra Čavojová, PhD.**

2017 **Bc. Matej Sedláček**

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THESIS ASSIGNMENT

Name and Surname: Bc. Matej Sedláček
Study programme: Cognitive Science (Single degree study, master II. deg., full time form)
Field of Study: Cognitive Science
Type of Thesis: Diploma Thesis
Language of Thesis: English
Secondary language: Slovak

Title: Relationship between Musical Abilities and Science, Technology, Engineering and Mathematics in Elementary and Middle School Students

Aim: Summarize previous literature on the relationship between STEM (Science, Technology, Engineering and Mathematics) and music via different aspects. Investigate and analyse new data on this phenomenon. Compare the results with previous eperiments and make suggestions for future use of this research.

Literature: Helmrich, B. H. (2010). Window of opportunity? adolescence, music and algebra. Journal of Adolescent Research, 25(4), 557–577. http://doi.org/10.1177/0743558410366594
Cranmore, J., & Tunks, J. (2015). Brain Research on the Study of Music and Mathematics : A Meta-Synthesis. Journal of Mathematics Education, 8(2), 139–157.
An, S. A., & Tillman, D. A. (2015). Music Activities as a Meaningful Context for Teaching Elementary Students Mathematics: A Quasi-Experiment Time Series Design with Random Assigned Control Group. European Journal of Science and Mathematics Education, 3(1), 45-60.

Annotation: Until today it is still not clear, whether there is any connection between the two and if so, how strong this relationship is and what we can tell about it. The theoretical part of the work consists of different approaches such as cognitive neuroscience, education and psychology. The research part focuses on the analysis of 356 students. The methods used include questionnaires, testing and inferential statistics. The further extension of this work might support the general elementary school curriculum in offering new ways of teaching natural sciences with integration of music.

Supervisor: PaedDr. Vladimíra Kurincová Čavojová, PhD.
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Assigned: 20.11.2015

Approved: 08.02.2016 prof. Ing. Igor Farkaš, Dr.
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Declaration

I hereby declare that the work presented in this thesis is original and result of my own investigations. Formulations and ideas taken from other sources are cited as such.

Bratislava, 2017

Acknowledgements

The data were collected within participation on the project Development of creative method of evaluation of critical and creative skills of pupils (https://crp.gov.sk/projekt-vyvoj-inovativnej-metody-hodnotenia-schopnosti-ziakov-kriticky-a-kreativne-mysliet-zvysenie/) in collaboration with CERI – OECD. I want to give my thanks to my supervisor for leading me and always having time to consult and also my parents for unbelievable patience and support. Also I would not be able to finish this work without immense help from my partner, who took care of everything in my life that didn't include my diploma thesis itself.

Abstrakt

Táto práca skúma vzťah medz prírodnými vedami pod skratkou STEM (Science, Technology, Engineering and Mathematics) a hudbou z pohľadu vzdelania, psychológie, kognície a neurovedy. Tento vzťah je založený na zákone transferu – spôsobu učenia, keď človek využíva predošlé vedomosti z iných sfér na naučenie sa nových konceptov v novom prostredí. Tento fenomén skúmame na behaviorálnej a neurálnaej a je rozdelený na rôzne kategórie v závislosti od kontextu. Teoretická časť práce zastrešuje interdisciplinaritu v zmysle preskúmania spoločných čŕt rôznych aspektov tohto fenoménu. Táto práca má poukázať na zlepšenie porozumenia vzťahu medzi hudbou a prírodnými vedami a potenciálne využitie transferu v základnom školstve, v ktorom sa v súčasnosti transfer nevyužíva. Výskum prebiehal v spolupráci so Slovenskou Akadémiou Vied a oddelením CERI organizácie OECD, ktoré v súčasnosti vykonáva medninárodné testovanie vedomostí a kreativity študentov na základných školách. Toto testovanie prebieha formou pre- a post-testov s intervenciou. Obe sady testou sú odvodené od testov OECD PISA a TIMMS a skladajú sa z testovania 3 rôznych oblastí. STEM testovanie, VAM test (Visual Arts and Music), z ktorého sa použili dáta zahŕňajúcúe hudobné vedomosti a EPoC testovanie matematickej kreativity. Na základe tohto testovania, konkrétne pretestov boli vybratí ôsmaci ($n = 81$) a tretiaci ($n = 162$), ktorí spĺňali kritéria tejto štúdie. Výsledky preukázali signifikantné, no pomerne rôznorodé korelácie a regresnou analýzou sme v týcho koreláciách objavili isté trendy. Objavené vzťahy u tretiakov sú medzi hudobnými vedomosťami a STEM skóre ($r = 0.227$; $R2 = 0.051$) a tiež medzi hudobnými vedomosťami a divergentnou matematickou kreativitou ($r = 0.184$; $R2 = 0.034$). U ôsmakov sa nečakane vyskytli 2 signifikantné negatívne korelácie , ktoré tiež prejavili trend, a to medzi aktívnym angažovaním sa v hudbe a STEM skóre ($\tau = -0.187$; $rs = -0.251$; $R2 = 0.073$) a medzi množstvom aktivity, nie priamo súvisiacej s katívnym angažovaním sa v hudbe na hodinách hudobnej výchovy a STEM skóre ($\tau = -0.265$; $rs = -0.355$; $R2 = 0.136$). Tieto výsledky naznačujú vzťah medzi sférami hudby a prírodných vied, aj keď povaha a ani sila tohto vzťahu nie je rozhodne jednoznačná.

Kľúčové slová:

Zákon transferu, vzdelávanie, kognitívna neuroveda, matematika a hudba

Abstract

This thesis explores the relationship between STEM (Science Technology, Engineering and Mathematics) and music from different aspects, including education, psychology, cognition and neuroscience. This relationship is based on transfer of learning, which represents a way of learning, when knowledge is obtained in one field and is available to utilize in some other field. This phenomenon may be approached on neural and behavioural levels and is divided into different categories, based on its context. The aim of theoretical part of this thesis is finding a common intersection of different scientific fields to reinforce interdisciplinarity. This study is carried out in collaboration with Slovak Academy of Sciences and OECD – CERI department, which is currently in the state of conductuding international testing of knowledge and creativity in order to explore the international differences between elementary school students. The experiment was in form of pre-/post-tests with intervention. Both series of tests consisted of 3 different types of tasks, derived from OECD PISA and TIMMS testing, exploring knowledge in STEM, VAM (Visual Arts and Music) from witch music knowledge was determined, and mathematical creativity. The data obtained from this testing on Slovak students narrowed the selection of subjects to two groups – eight grade students (n = 81) and third grade students (n = 162). The outcome serves to emphasize the possibility of achieving better motivation and understanding of natural sciences integrating music into educational process and bringing this opportunity to public educational system, which currently does not utilize the potential of this phenomenon. The results have shown only weak significant correlation and regression analysis shown a significant trend between music and STEM scores ($r = 0.227$; $R^2 = 0.051$), music scores and divergent mathematical creativity ($r = 0.184$; $R^2 = 0.034$) on third-graders data and even negative non-linear significant correlations and trends in regression between STEM scores and the amount of two types of music lesson activity - active music engagement ($\tau = -0.187$; $r_s = -0.251$; $R^2 = 0.073$) and standard activity ($\tau = -0.265$; $r_s = -0.355$; $R^2 = 0.136$). This finding demonstrates relationship between the two fields at least to some extent, yet the nature of it is quite disputable.

Keywords:

Transfer of learning, education, cognitive neuroscience, mathematics and music

Contents

1 Introduction

The motivation for this research is grounded in two levels. Education, to begin with, is the first field, which led me to enhance my knowledge in the fields of mathematics and music and their interplay. The negative situation, which evolved around the education system in my country through the last years is reaching its critical point. Many teachers either do not have the tools or the 'know-how' to introduce mathematic or music problems to the pupils. Subject curricula are being taught as isolated units without an actual application in real life or in other fields. A deeper understanding of abstract forms is absent. There is really large potential in integrating fields of education together to create a better overview of application of problem solving in practical world just like they do in some other countries for years now.

The second biggest motivation is the possibility of approaching the transfer of learning from multiple angles, and therefore building a broader overview of the phenomenon. I began my musical story when I was 6 years old. Attending the piano lessons for little less than 3 years, I didn't know, why I've seen music in everything in my everyday life, only felt some strange connections between everything. As I started studying mathematics, I also learned to apply my knowledge into everything. Only after two years of interdisciplinary studies I've learned about this specific phenomenon. And while for some people the presence of mathematics in everyday life is evident, the abstract connection between music and mathematics doesn't occur to us very often. History shows that the idea of this connection has been thought of millennia ago. One of the earliest musical instruments with included full harmonics is happened to be around 8 000 years old flute from China. During the cultural evolution of the human race, many races approached music from mathematical point of view, creating distinct sets of tunes and harmony, utilized by linear algebra, group theory and other tools. The tuning system includes Pythagorean tuning, rooting to 2000 B.C., Pareja tuning from 1482, etc. All of these systems have base in mathematics and physics.

The aim of my work is to shed more light into possible interdisciplinary approach to general education and to supplement both the practical use and theoretical knowledge revolving around transfer of learning. This work will hopefully emphasise the potential of this phenomenon in elementary school education and eventually in all levels education.

1.1 Interdisciplinarity

What do natural sciences have in common with music? There are many journals, organisations and conferences hosted nowadays, including vast numbers of literature that focus on this question. These include Society for Mathematics and Computation in Music, International Congress on Music and Mathematics, Journal of Mathematics and Music, Bridges Organisation and Conferences and many more. All of these serve (not exclusively) one purpose. That is to foster and uphold the advance in exploring natural science in music and vice versa. Scientists meet on these conferences to discuss their work in mathematical models of music, integer programming on musical Patterns (Tanaka, Fujii, 2015), present the application of Markov model to describe polyphonic music style (Nakamura, Takaki, 2015) and many more.

This thesis explores the relationship between music and natural sciences on educational level, particularly on the scale of elementary and middle school education. This relationship is known amongst the experts in the field as transfer of knowledge. On the subject of cognitive science, education has been added to the list of disciplines by the journal Cognitive Science, despite the lack of potential for contribution. Nevertheless, education is a crucial area of application (Thagard, 2005). One year later, Ansari and Coch (2006) wrote down the possibilities of connecting cognitive science, particularly cognitive neuroscience and education even stronger by including teacher and researcher training and joint effort not only to increase the ability of applying cognitive science knowledge in education but also to enrich the perspectives of neuroscientists. The suggested collaboration between the fields of cognitive science and education is also emphasised by Reif (2008) in his book, where he talks about the difficulties which students experience while learning and approaching academic subjects, such as physics or mathematics and what could improve these thought processes by training the teachers to employ knowledge from cognitive science.

1.2 Constructivism

„In this volatile contemporary world, the goal of constructivist teaching is to develop self-directed yet interdependent learners who can access and use a wide range of cognitive structures in order to transfer learning to contexts they have yet to encounter."

– Sandra Kerka (1997, p.5)

This learning paradigm is, in contrast to behaviourism and cognitivism, the one which is mostly inclined to the theory of transfer of learning. The definition varies widely with regards to specific field and topic as noted by Sjøberg (2010). He also offers yet another interdisciplinary approach when mentioning that constructivism in the field of theories of learning is approached by the fields of psychology, philosophy, education, epistemology and sociology.

The general definition, based on Piaget (1964) suggests that learning is an active socially and culturally influenced cognitive process of assembling the subjective knowledge from the objective reality. This knowledge is not to be transcended from the external source; rather the concept is constructed by the learner. The important point is that the knowledge is obtained by incorporating the prior experience and knowledge in the means of interacting. Even though, there were sceptic opinions on the potential of transfer in education (Prenzel, Mandl, 1993), scientists searched for more evidence to reinforce the position of transfer in constructivism (Kerka, 1997). Olivares (2002) created a framework in which he connected constructivist approach and transfer of knowledge for teaching bilingual students. The analogical learning, which will be addressed later on, and transfer in constructivism is mentioned also in the book by Duffy and Jonassen (2013).

1.3 Scientific background for music – mathematics relationship

Regarding the history of scientific exploration of transfer between music and mathematics, it started in the second half of eighties with the construction of the model of cortical column composed of idealized subcortical structures called trions (Shaw, Silverman, Pearson, 1985) as seen below (Figure 1).

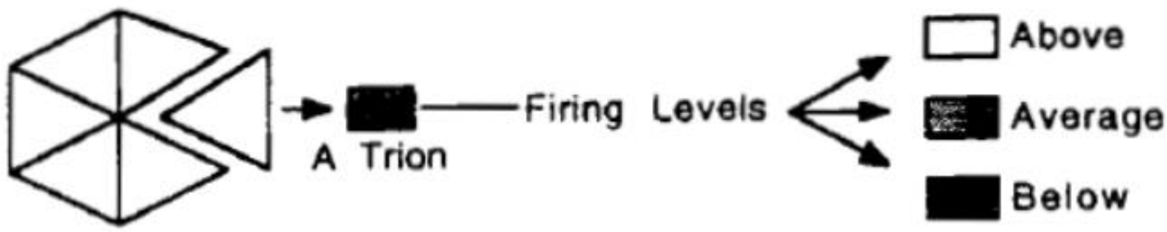

Figure 1: Representation of cortical structures, divided into trions. Each consists of hundreds of neurons with similar firing patterns and has can induce three different levels of activity. (Rauscher 1995)

These scientists suggested that the cortex can be separated into a number of segments – trions. Each of this trions represents hundreds of neurons, which have similar firing patterns and thus supposedly refer to the same function in the brain. They then simplified the sum of all neurons represented by a trion to have only three values to manifest, namely above, average and below. Based on the trion theory, Leng and colleagues (1990) came with the proposal of possible overlap between music and mathematics processing brain areas. By running simulations on this model, Leng observed emergence of quasi-stable spatial-temporal naturally evolving firing patterns and created a specific trion evolution. MIDI Synthesizer was mapped on this evolution, creating music that strongly indicated analogy with patterns in modern western music. Shaw (2003) then wrote a whole book based on these findings, infering that music engagement, whether passive or active involves spatial-temporal memory patterns. Along with Rauscher (1994,1995, 1997), Lawarence, Parsons and Fox (1995) also searched for the neural basis of mental rotation and came with the rhythm theory, pointing out that the basis for both rhythm and mental rotation is the cerebellum. Thus the suggestion that rhythm creation and processing might enhance spatial tasks based on mental rotations.

1.4 Mozart Effect

Mozart effect is as simple as this: If a participant listens to Mozart's Sonata for two pianos in D Major for appropriate time, the results in subsequent spatial – temporal testing should increase in comparison to not listening. Rauscher, Shaw and Ky (1993, 1995) conducted series of revolutionary experiments, where they tested spatial-temporal tasks, including mental rotations on students after listening Mozart and/or actively engaging in music. And since Brinner (1995) formulated the difference between passive music listening and active engagement in music, the second of Rauscher's Mozart effect experiment series included active intervention (Figure 2). The intervention had positive influence on results in both Rauscher's cases, even though the later studies (Nantais, Schellenberg, 1999, McKelvie, Low, 2002, Steele, Bass, Crook, 1999) weakened the assumed phenomenon of the so called 'Mozart Effect'.

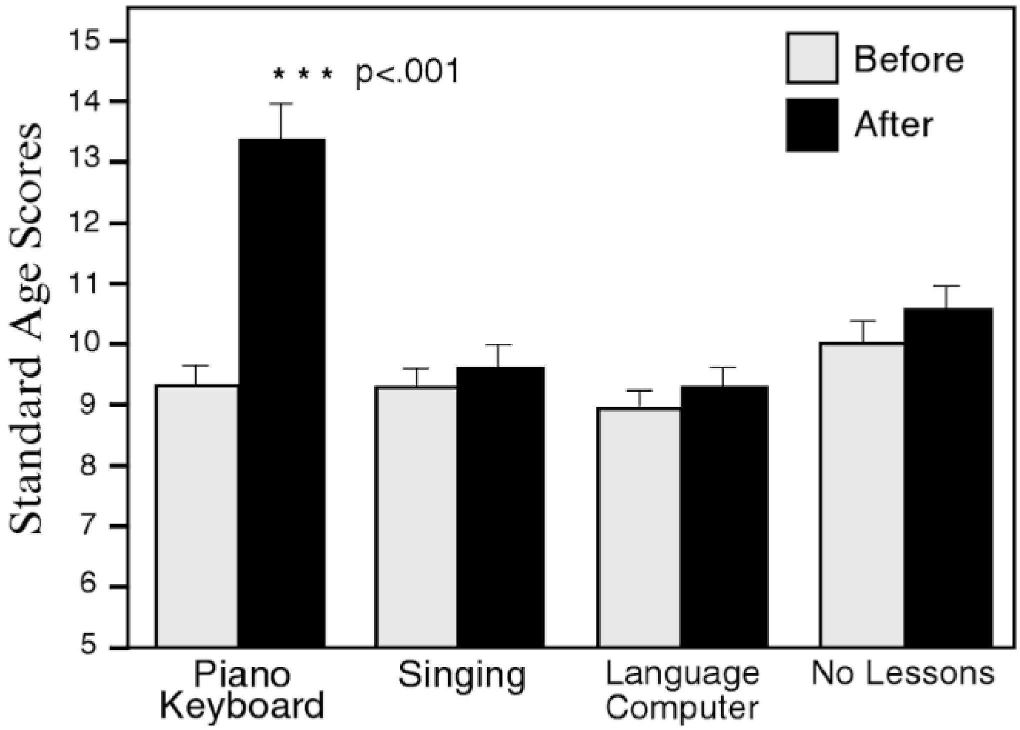

Figure 2: Change of pretest/post-test scores in spatial-temporal reasoning, based on additional training. Results by Rauscher, et al., (1997) intrepreted by Shaw (2004, p. 32).

One of the latest Mozart effect experiments was carried out by Graziano (2016) where 101 participants obtained four months training of piano playing, English or no training for control group. Results confirmed the Mozart effect once again (Figure 3). The final discovery was that active engagement (playing an instrument or creatively engage in music) out of all possible music activities (including passive listening or singing in chorals) influences the spatial-temporal abilities the most.

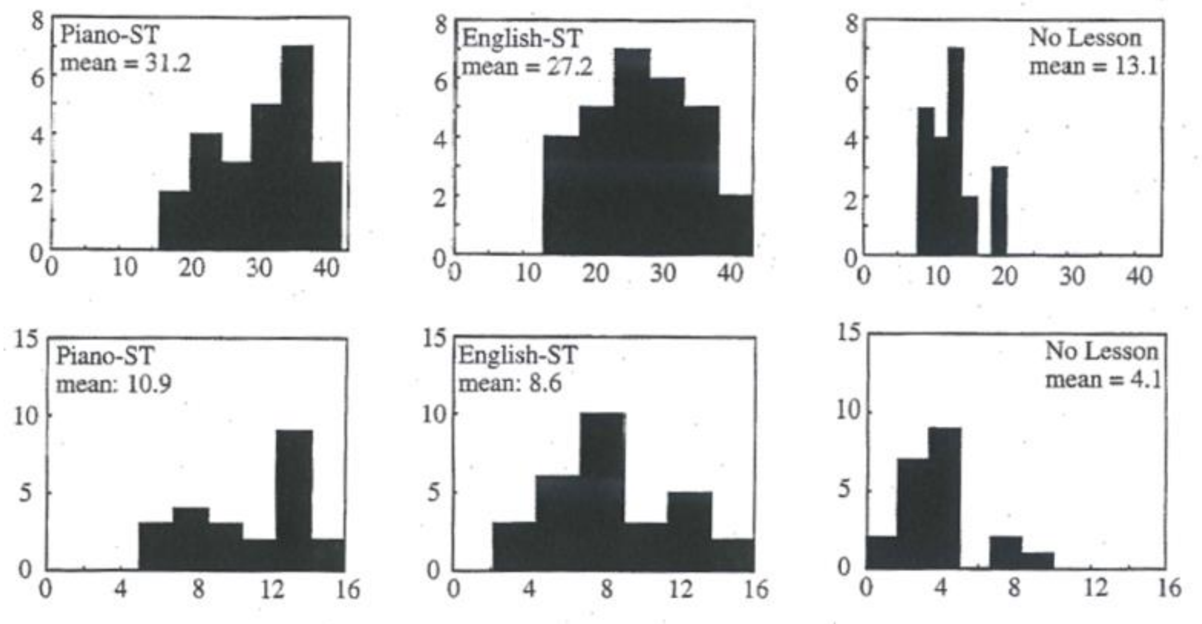

Figure 3: Results of 40 questions spatial - temporal test with regards to types of intervention. Out of these, 16 questions were directly focused on proportional mathematics. (Graziano, 2016)

2 Mathematics and music

Studies are being carried out globally, to find more precise and consistent data on the relationship between mathematics and music. The effect of music influence on the spatial tasks is still in the process of establishment. Miendlarzewska and Trost (2014) describe the importance of broader insight into music training, including reward, social and cultural context and impact of this music training on executive functions. One of the studies on this topic has shown that long lasting active music instruction improved solving of the spatial tasks and also some kinds of spatial-temporal tasks with the effect being moderate (r = .37) (Hetland, 2000). Another interesting finding is that the enhancement was greater in younger children.

There are studies that show us the understanding of the fractions in different context – part-whole, measure, quotient, operator, ratio, decimals (Kieren, 1976). The research carried out in 2007 (Clarke, Roche, Mitchell, 2007) amongst others (Quinn, 2013, Empson, 2003) confirmed that many children have problems to some extent to grab a hold of the fraction meaning. The study of 326 students in Victoria revealed that different graphical presentations of the fractions resulted in different levels of comprehension by these students. The scientists constructed a set of tasks, based on different graphical representation of fractions, inspired by previous research in this field (Cramer et al., 1997, Lamon, 1999, Baturo & Cooper, 1999, Behr, Wachsmuth, Post, 1985). Some of the images used for the task can be seen below (Figure 4, 5) Based on the task, the results in understanding the representation differed strongly.

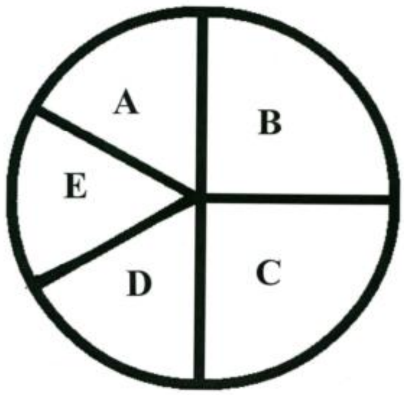

Figure 4: Fraction Pie task (Clarke,Roche, Mitchell, 2007)

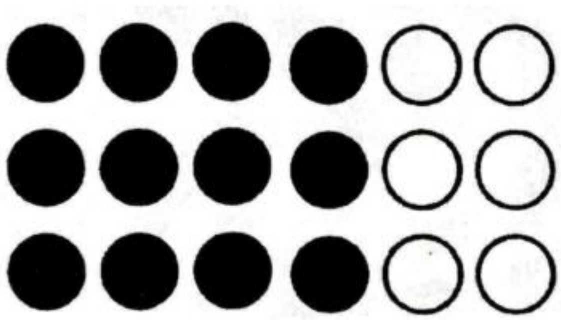

Figure 5: Dots Arraz task (Clarke,Roche, Mitchell, 2007)

The results seen in the Table 1 and 2 suggest that different approaches to fractions probem influence the understanding of fractions by students and there are more ways to explain this problem. Authors point out to the variability of the approaches and also to the teachers' questionable abilities to incorporate the different aspects of the fraction education (Clarke,Roche, Mitchell, 2007). Incorporation of rhythm can be associated with more than one form of the tasks mentioned above, which can lead to new representations, which would also include auditory stimuli. This idea has been also worked on (Kamrlová, Varhaníková, 2011).

Type of the Task	Fraction Pie task - standard	Fraction Pie task – non standard	Dots Array task	Draw a line – Measurement task	Construct a sum task	Fraction pairs task	Pizza task
Correct answers	83%	42.7%	76.9%	51.1%	Best:1.58% 2.nd best:23.8%	In table 2	30.3%

Table 1: Percentual success of students in the relationship with the different approaches to fraction problem (Clarke, Roche, Mitchell, 2007).

Fraction pair		*% correct*
3/8	7/8	77.1%
2/4	4/8	64.4%
1/2	5/8	59.4%
2/4	4/2	50.5%
4/7	4/5	37.2%
3/7	5/8	20.4%
5/6	7/8	14.9%
3/4	7/9	10.8%

Table 2: Success rate for fraction equasion evaluation, depending on the form of fractions. (Clarke, Roche, Mitchell, 2007)

The attempt to incorporate music into the mathematics class was based on the idea of connecting mathematics with music which stems from the previous research that suggests apparent relationship between the fractions and the rhythm. In this study, children encounter fractions via 3 approaches: fulfilment of the circle, music and notes and number. For the purpose of this study, the definition of rhythm was built on Aristoxenes, where rhythm incorporates the layout of the time into measured sections, whereas these sections are adequately distributed in the time frame. As the measurement units, the basic catalogue of notes was used (Figure 6).

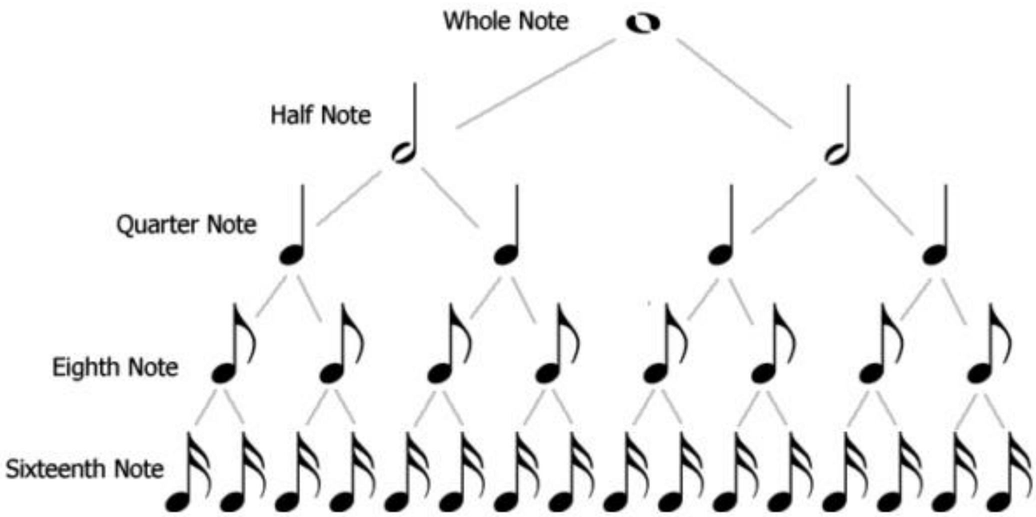

Figure 6: Basic catalogue of notes represented as binary tree of rhythm –time value (Kamrlová, Varhaníková, 2011)

Adequate length of the tact, respectively the value of the basic unit (denominator) and the amount of these units in it (numerator) was then set. After discussion, included in the experiment, children worked their way to the ideas of basic mathematical operations on fractions (addition, subtraction) by working with the rhythms. The task for the children was to fill in the whole (4/4) tact with different combinations of the notes. Older children who already came into contact with fraction commented that the „pizza“ model is well understandable. This confirms the finding of the previously mentioned study (Clarke, Roche, Mitchell, 2007). Another finding is that children considered the musical representation more interesting to explore. The design of the game is based on Lesh translation model (Lesh et al., 2003), which divides the understanding of mathematics into five different models, which are interconnected (Figure 7). Creating the comprehension of the multiple models and the relationships inside and between them leads to meaningful concepts.

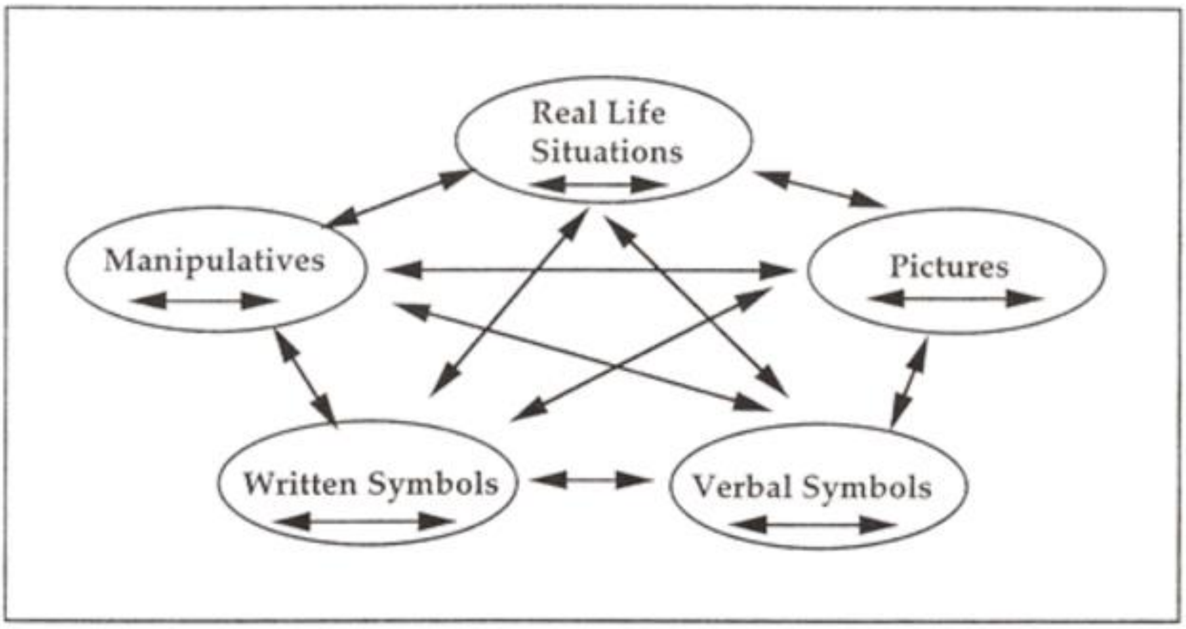

Figure 7: The Lesh Translation model (Lesh et al., 2003)

The results indicate the possible approach to learning mathematics via music and this approach to be strongly connected to everyday life. This is supposed to strengthen the learning process (Lesh et al., 2003). The process would not focus primary on the regular, mathematical representation of fraction but on the different side. The researchers in the end explicitly stated, that the children didn't really consider the tasks as 'Mathematics'.

3 Transfer of learning

"I never teach my pupils; I only attempt to provide the conditions in which they can learn."

– Albert Einstein(1964, p.126)

Throughout the last years, the number of studies which focused on the same ideas have grown in different countries. The aim of this thesis is to bring the potential improvement of learning process to regions, where it has been not applied yet, to shed light on current general schools curricula and to bring forth the idea of integrated lessons to teachers, who may or may not be aware of this possibility. Before approaching this specific topic, let us focus on the basic terms and elements included in this field. The most crucial element in this study is the transfer of learning. In other words, it is an ability to use learned knowledge of one field as an analogy, association or other helpful element in other field. In case of transfer of learning, there is always the transfer source and transfer target, which may also influence each other both ways (Maranville, 2015). The current model of transfer by Miendlarzewska and Trost (2014) shows transfer of learning in case of music instrumental training (Figure 8). In the middle, the grey rectangles represent factors that influence the training itself, the inner circles are skills that are coherently developed (near transfer) and the outer circle represents far transfer, in other words skills that alter depending on the transfer on different levels, e.g. aspect of life, manual versus mental activity, explicit versus implicit skills and more. The range of the types of transfer are mentioned later.

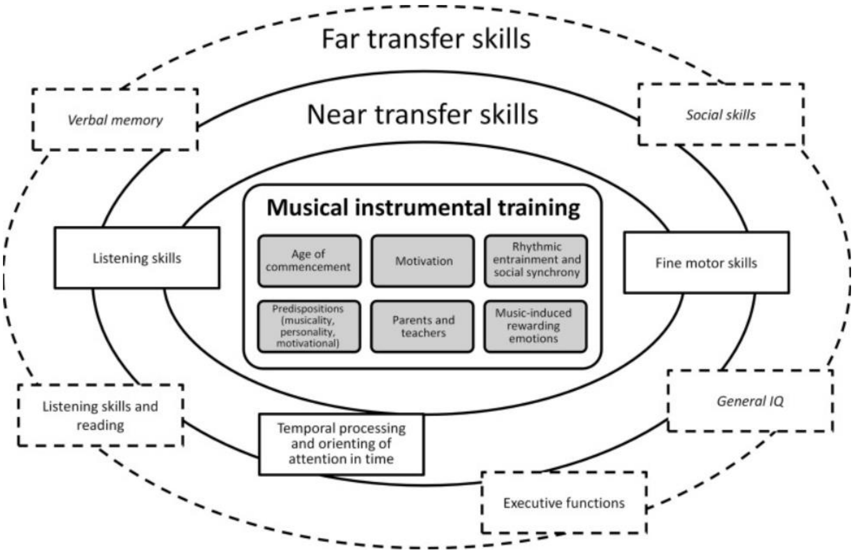

Figure 8: Transfer of learning model, consisting of factors, influencing the transfer, near and far transfer skills (Miendlarzewska, Trost, 2014).

Willis (2016) carried out an experiment focused on the supposed impact of music tuition on scores from mathematics. Amongst other goals, by using regression model, he was able to manifest significant connection between the two fields. His sample was a group of 116 eight–graders, inspired by Baker (2012) who presented positive influence of 'performance–based music' enrolment of 37 222 eight–graders when faced with high–stakes testing. These amazing results can be seen in the figure below (Figure 9). In summary, Willis proved that there is an actual positive relationship between music tuition and mathematics scores, and what is more important, he suggested that this relationship does not suffer dependence on some other variables such as socio-economic status or race. Another study, carried out by Helmrich (2010) has shown significant difference in algebra achievement (Maryland Algebra/data analysis HSA) of eighth and ninth grade students ($n = 6026$) between the ones who enrolled in formal music instruction during middle school (grade 6,7,8) and their non–instruction school mates ($p < .001$) (Table 3). He in fact confirmed the assumption that the actual instrumental training of students has more positive influence on their algebra achievement than singing or no instruction at all.

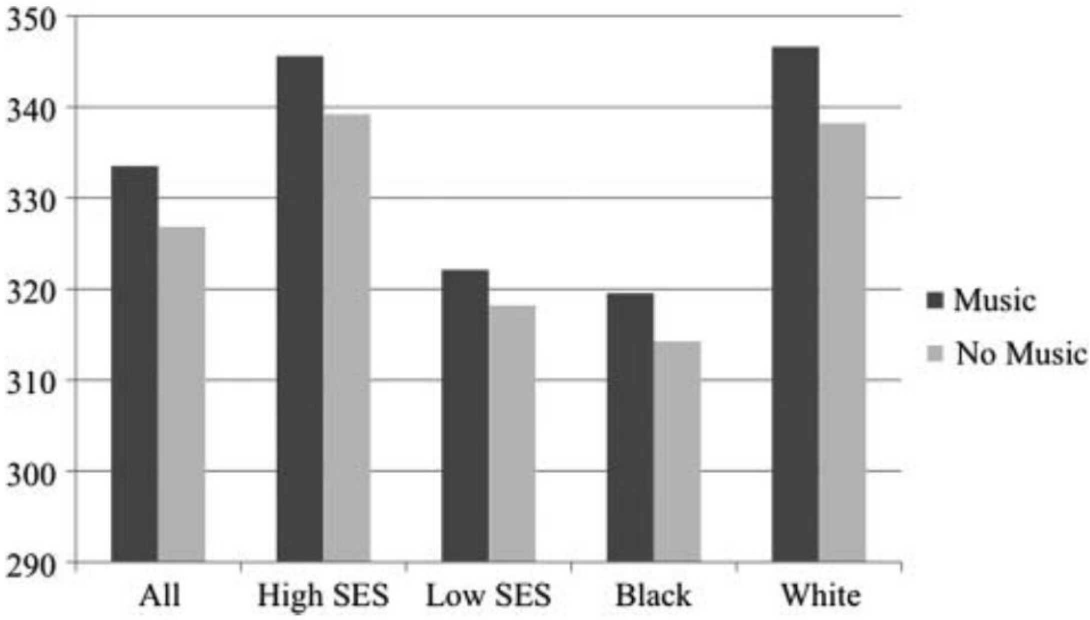

Figure 9: The difference between math scores of students, enrolled in active music education and those not enrolled. Including different SES (socio–economic status), and racial differences, all significant ($p < .001$). (Baker, 2012)

Group	*n*	*M*	*SD*	Minimum	Maximum	Percentage passing
Instrumental	1,952	442.71	24.22	323	650	90.62
Choral	1,287	433.19	26.81	240	501	81.51
Neither-instruction	2,787	429.37	30.63	240	533	75.03

Table 3: Table, describing the scores, means and other data on all instruction groups (music instruction, singing instruction, no instruction). (Helmrich, 2010)

Catterall (2002) in his essay also stated the strength of transfer phenomenon in later grades of elementary school and summarized how different artistic methods (including music) develop social and academic performance.

An and colleagues (2013) experimented on integrating music into regular mathematics lessons of 46 students of which 25 were third grade. During five weeks the teachers worked with the students which resulted in enhancement of different mathematical areas. Results can be seen in Figure 10.

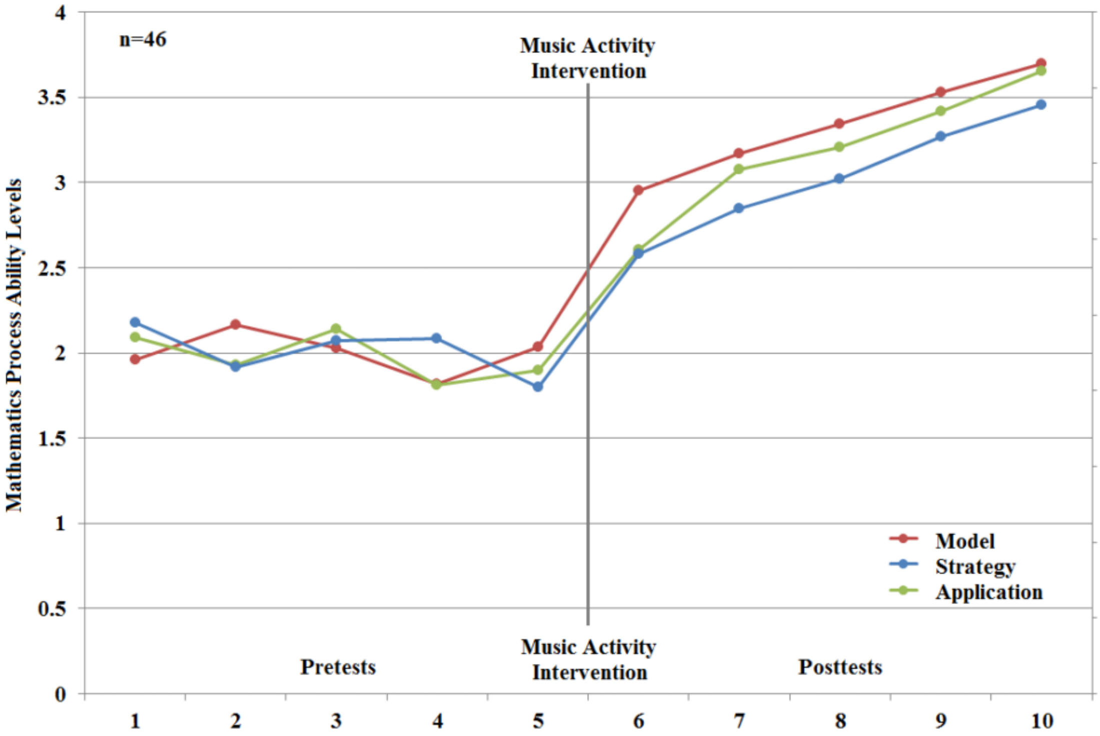

Figure 10: Mean mathematics process ability levels on model, strategy and application processes; Pretests to posttests. (An, Capraro, TIllman, 2013)

Later on, An & Tillman (2015) continued with building on the previous research, conducting another study. This time, they only took the third grade students (n = 56) and designed a random assignment pretest – midtest – posttest experiment. Again they observed the influence of music on mathematics results (California Standard Test – Standardized Testing And Reporting). The intervention included music enhanced mathematics lessons. The pretests and posttests consisted of two parts – mathematics achievement test and mathematics process ability test. After the intervention (14 music–themed mathematics lessons), results have been written down into the final table (Table 4). Again children with the music – themed mathematics lessons did better than those, who underwent regular mathematics lessons.

N=56		Pretest		Posttest	
		Music Group	Non-Music Group	Music Group	Non-Music Group
Mathematics Achievement	Mean	9.96	9.46	21.07	10.67
	SD	4.9	3.16	3.71	3.73
Independent t-test	*p*-value (*t*)	0.68 (0.453)		<0.001 (10.53)	
	Cohen's *d*	0.12		3.00	
Paired t-test (Music Group)	*p*-value(*t*)	<0.001 (10.53)			
	Cohen's d	3.38			
Paired t-test (Non-Music Group)	*p*-value(*t*)	0.031 (2.271)			
	Cohen's d	0.33			

Table 4: Results of t–tests show differences between the two groups of children, depending on intervention. (An, Tillman, 2015)

In their main study, Graziano, Peterson & Shaw (1999) conducted an experiment with 170 second/third–graders, including piano playing lessons and a special computer game. They tried to teach these children fractions during the four month time schedule. Intervention was done by administering active piano playing lessons and by playing a specifically designed computer game. The children were able to grasp the concept of fractions and the resulting difference between the control group, mathematics video game intervention group and mixed piano lesson and video game group was evaluated. The group, which played both piano and video game achieved best scores in proportional mathematics and spatial – temporal reasoning testing. Chobert with her team (2014) demonstrated the transfer of learning from music in their EEG experiment. They recorded mismatch negativity and voice onset time on 37 nonmusician third grade students from two Southern France elementary schools undergoing either music or painting training. Pretest and two posttests (after 6 and after 12 months of training) were conducted, resulting in demonstration of preattentive processing improvement.

The theories about the transfer of learning and its existence at all were evolving since early 20th century (Thorndike, 1901). There are many aspects of transfer, including cognition and learning concept (Greeno, Collins, Resnick, 1989) and a socio-cognitive approach described years later (Ringberg, Reihlen, 2008). Some of the theories of transfer are mentioned below, starting with the one by Thorndike:

3.1 Analogy

Learning by analogy is a theory very close to the essence of transfer of learning. Brown (1989) dedicates one whole chapter to describing, how the intrinsic reasoning is full of elements, which support analogy and transfer, including inductive thinking, creation of prediction, generalization, cognitive flexibility and more. These are all necessary for what he called an analogical transfer. Analogical transfer is a part of analogical cognition and includes phenomena such as metaphors or abstract schemata extracting. It is studied on tasks, that are different in content but there is an analogy in the form of the task. Barnett and Ceci (2002) discussed some of these studies and concluded that while most studies are successful in demonstrating transfer of learning via analogy, there are some studies, not to omit, which resulted in mixed or negative conclusion. Anyway, good example of problem solving, enhanced by analogy is shown by Spencer and Weisberg. (1986) who put participants in front of a seemingly difficult situation and then supported them with a solution for analogic problem.

3.2 Identical elements theory

This theory, in simple words, is based on the ‚closeness', or vicinity of the elements. It focuses on the relationship between the source and the target of the transfer. If the factors are identical, then the transfer of learning takes maximal effect. Thorndike referred to some jobs as the good environment to train one's ability to transfer the exact knowledge and skill from one situation to another, e.g. tea-tester, tobacco–buyer, wheat–taster or carpenter. These people gained the proficiency in accurately measuring different sorts of magnitudes, which was independent of the element measured.

3.3 Generalization

This theory is inspired by the identical elements theory and the main idea is understanding the principles of elements. Generalization is based on clustering elements based on similar or in ideal case, same principles (Judd, 2008; Royer, 1979). In this case of transfer, some assumptions and rules are created based on the knowledge obtained and generalization in the form of induction takes place. Furthermore to apply the right amount of generalization in some other field, optimization has to take place.

3.4 Transposition

The key idea is to focus on relationship between the elements. Not the deeper understanding of them, or even the principles of each element. It is based on gestalt and cognitive psychology (Reber, Reber, 1985; Kendler, 2007).

There are many approaches and definitions of this term, which are for example summarized also by Leberman and colleagues (Leberman, McDonald, Doyle, 2006). For the purpose of this study the transfer of learning is defined as a transition of prior learned and experienced skills processes and patterns from the previous to next situation, respectively a transfer of previous knowledge to creating new, further knowledge, habits and know–how (Chmel, Sawicki, 2010).

The transfer of learning has many different aspects and categories. These are based on a specific taxonomy of transfer of learning, which is illustrated in the tables below (Barnett, Ceci, 2002). The first one (Table 5) shows what individual contents and elements are transferred and what variable factor changes are to be observed. Next table (Table 6) approaches already concrete situations and contexts which are different based on the transfer distance and various angles (time, space, knowledge domain, functional, and social context and modality). The general categories of the transfer of learning build on the previous taxonomy and are shown in Table 7 (Shunk, 2014).

A Content: What transferred			
Learned skill	Procedure	Representation	Principle or heuristic
Performance change	Speed	Accuracy	Approach
Memory demands	Execute only	Recognize and execute	Recall, recognize, and execute

Table 5: What elements are affected by transfer of learning (Barnett, Ceci, 2002).

B Context: When and where transferred from and to					
	Near ←				→ **Far**
Knowledge domain	Mouse vs. rat	Biology vs. botany	Biology vs. economics	Science vs. history	Science vs. art
Physical context	Same room at school	Different room at school	School vs. research lab	School vs. home	School vs. the beach
Temporal context	Same session	Next day	Weeks later	Months later	Years later
Functional context	Both clearly academic	Both academic but one nonevaluative	Academic vs. filling in tax forms	Academic vs. informal questionnaire	Academic vs. at play
Social context	Both individual	Individual vs. pair	Individual vs. small group	Individual vs. large group	Individual vs. society
Modality	Both written, same format	Both written, multiple choice vs. essay	Book learning vs. oral exam	Lecture vs. wine tasting	Lecture vs. wood carving

Table 6: This table shows already specific examples for the dvision of transfer depending on the 'distance' and context (Barnet, Ceci, 2002).

Types of transfer.

Type	Characteristics
Near	Much overlap between situations; original and transfer contexts are highly similar
Far	Little overlap between situations; original and transfer contexts are dissimilar
Literal	Intact skill or knowledge transfers to a new task
Figural	Use of some aspects of general knowledge to think or learn about a problem, such as with analogies or metaphors
Low road	Transfer of well-established skills in spontaneous and possibly automatic fashion
High road	Transfer involving abstraction through an explicit conscious formulation of connections between situations
Forward reaching	Abstracting behavior and cognitions from the learning context to one or more potential transfer contexts
Backward reaching	Abstracting in the transfer context features of the situation that allow for integration with previously learned skills and knowledge

Table 7: General taxonomy of transfer with characterisitcs described by Shunk (2014).

The transfer of learning is also divided based on the way how the source element of knowledge affects the target element (Perkins, Salomon, 1992). It's apparently more pleasant to exercise positive transfer in learning (rewarding) before negative in the long term, yet the negative transfer of learning has also its important place, that is, for being effective in children with behavioural problems (Bransford, Brown, Cocking, 1999).

3.5 Positive and negative transfer

Positive transfer builds on positive results of the process. The knowledge of the source element positively affects the ability to learn and explore the target element (Burke, 1997). This enhances the learning process and enables faster learning and better acquisition of knowledge (Osman, 2008). This type of transfer can be sometimes mistaken for predisposition, whereas positive transfer comes from previous knowledge and experience collected through life, predisposition is a genetic issue, impossible to affect by conscious or unconscious actions.

In some cases, the transfer of learning from source element can also lead to worse results in target element. This is called a negative transfer (Chmel, Sawicki, 2010). This occurs, when there is a inference between the previous knowledge and new situation. A person, usually driving a car with manual transmission, which includes the use of both legs, might have a tendency to also use both legs when this person tries to drive a car with automatic transmission. This tendency is higher than for a person who didn't previously drive a manual transmission car. Concluding the main idea, the more training the subject obtains, the stronger the negative impact is on the later task (Woltz, Gardner, Bell, 2000).

4 Neuroscience of learning

Just like every other cognitive process in human brain, also learning consists of different level activities, which are intertwined and work in parallel. On this occasion there is an ongoing debate on the definition of the learning itself (De Houwer, Barnes–Holmes, Moors, 2013), from the view of neuroscience, learning goes hand in hand with memory, its creation and extraction. Simply put, it's an ability to adapt to changes in the environment, based on previous experience and manipulation with it (Gross, 2010). On molecular level we take into account activity on the synaptic connections (Carew, Sahley, 1986, O'Reilly et al., 2012), (Figure 12) in forms of potentiation and depression of this activity (Kirk et al., 2010) (Figure 13). These processes (Long term potentiation – LTP and long term depression – LTD) on synapses are considered to be the neural correlates to learning on this low, basal level (Mainberger et al., 2016).

There are different methods used to approach synaptic plasticity, which are mostly dependent on what is the aim of each study or experiment and also what is the target element, one wants to focus on. In case we want to affect the synapse directly, the non–invasive methods include transcranial magnetic stimulation, short TMS (Thickbroom, 2007, Mainberger et al., 2016), and there is also a possibility to directly influence the focused area by transcranial direct current stimulation (tDCS) and observe the changes with microscope (Chandrasekaran et al., 2015, Abrahamsson et al., 2016) as seen below (Figure 14) and optogenetics, a form of neuromodulation (Deisseroth et al., 2006, El–Gaby, Kohl, Paulsen, 2017).

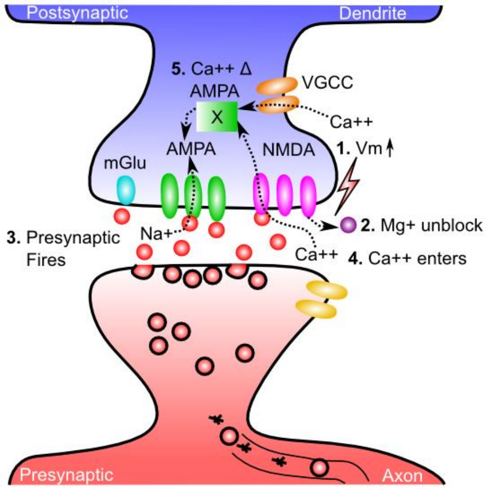

Figure 11: Illustration of hemical processes of creating synaptic plasticity in synaptic cleft (O'Reilly et al., 2012

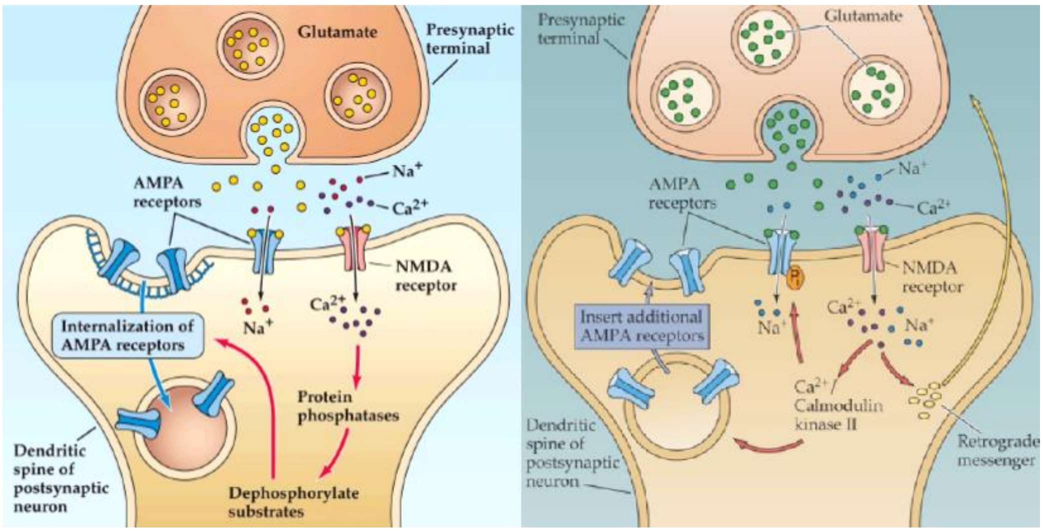

Figure 12: Long term depression and long term potentiation on synapses (Kirk et al., 2010).

Also in neuroscientific field, there was interest in the previously mentioned Mozart effect (Sarnthein et al., 1997). One of the experiments, which is worth mentioning is connected with patients suffering from epilepsy. Hughes and colleagues (1998) carried out test of Mozart effect on 29 patients with periodic lateralized epileptiform discharges in waking or comatose states. The results were as amazing as decreased duration of epileptic strokes during Mozart listening in the ictal phase (Figure 15).

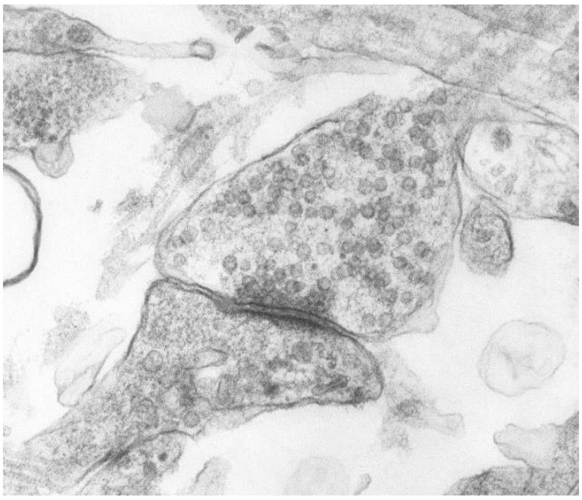

Figure 13: Synapse under the microscope. Retrieved on March 2017 from http://svt.ghediri.com/print–article–19.html?iframe=true&width=600&height=400&

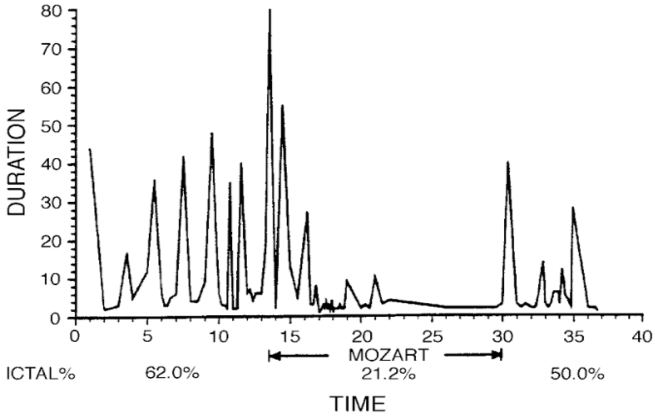

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Figure 14: Periodic occurence of ictal activity. Before Mozart effect, 62% of the time this activity was seen, while during mozart effect, the occurence lowered to only 21% of the time with radically lowered durations of ictal activity. After this phase, the occurence of ictal activity raised to 50%. (Hughes et al., 1997)

4.1 Neuroscience of transfer

As mentioned in previous chapter, the neural basis of all learning is neural plasticity. The vital part of it is that this phenomenon is happening throughout our whole life, not only during the childhood (”Understanding What Makes People Tick,” 2009, p. 6).

„This perspective enables us to see how such deeper learning can happen even in a traditional classroom. "

– Zull (2004, p.6).

One interesting model of learning in brain is the learning cycle (Zull, 2002), which was inspired by David Kolb (1984). The Mauritz Institute (Mauritz Institute, 2010) offers a summary of all important aspects of learning along with the model seen in the picture below (Figure 15), which is simplified and focuses on the connection between the brain areas, rather than the hierarchy. In his work, he describes four phases of the learning process. These phases are listed below.

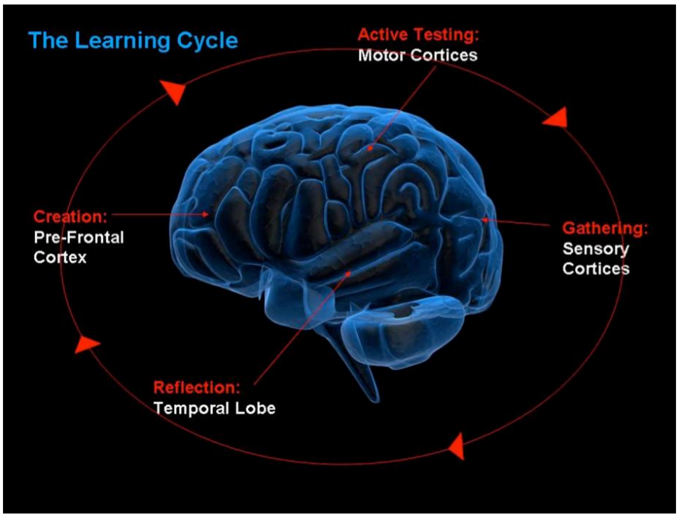

Figure 15: Learning cycle model by Zull. (The Maritz Institute, 2011)

1. Gathering

The stimuli are introduced and entering the sensory cortices, via hearing, sight, touch, etc. This is the basis for all further processing and work with the information. This phase is the most demanding one regarding focus and energy (Weinberger, 1995). Gathering includes all of the brain activities, which are prior to conscious realization of the stimuli being received.

2. Reflection

In this stage, the temporal lobe plays role in integration of the raw data obtained from sensory cortex. The information is being reflectively observed, processed, and evaluated and demands appropriate amount of time (McGaugh, 1966). This process works best, when there is no interference, noise and other unrelated stimuli flowing from the sensory cortex. Reflection is the cognitive representation of searching for connections and associations on both conscious and unconscious level.

3. Creation

Prefrontal cortex creates new constructs and structured notions from the processed information. This is where the transition from passive receiving and processing to actively creating knowledge happens. During this phase, one builds the understanding and conceptual knowledge in various forms such as ideas and representations. Based on the created connections, the brain is able to bend the information to different aspects, creating new network and levels of meaning in different contexts. This knowledge is incorporated to the appropriate prior knowledge of every human being based on what fits his/her previous experience best (Zull, 2002, p. 202) and gets far stronger when induced by active creation of knowledge than just indifferent absorption of context–less information (Richland et al., 2005).

4. Active Testing

The concepts from prefrontal cortex are being put to use and tested in the motor cortices. From there, the observation the results of the testing, based on how the brain was able to 'comprehend' the idea, is sent again to the sensory cortex, creating the so important feedback. Based on this circle, new connections arise, giving life to learning. The meaning of active testing is, simply put, a way of extracting the abstract form of knowledge on the specific topic and ability to form an actual action based on this knowledge, in form of language, physical action, or else. Zull (2002) considers any active performance and expression related with one's idea as active testing, whether it is an active search for more knowledge on that topic, discussing it or trying to do physical activity (e.g. doing cardio to supposedly lose weight) to confirm the information. Bjork and Linn (2001) carried this idea of active testing even to the proposal that the act of recalling a certain memory or information may be considered as active testing and reinforcement of this information.

4.2 Neuroscience of music

One can go as far as 1920's to read about how people perceive music, how it affects our brain and what positive and negative influence it may have (Vescelius, 1918). Positive effects of music on our performance (Rauscher, 1995, 1997; Rideout, Laubach, 1996; Wetter, Koerner, Schwaninger, 2009), mood (Stratton, Zalanowski, 1991; Brenneis, 1971), stress (Mornhinweg, 1992) are known for many years now. Anyway, the use of electronic devices to actually observe the events in our brain emerged with the possibility of using EEG (Lin et al., 2010), MRI (Gaser, Schlaug, 2003), fMRI (Pujol et al., 2000) and even TMS to map adequate brain areas (Pascual–Leone, 2001). The connection between emotions and music are now observable and readable. One EEG study showed 82.29% ± 3.06% accuracy in estimating this connection (Lin, Wang et al., 2010). Pan (2013) found out it's possible to identify music preference of a person with accuracy being 74.77% using frontal EEG. There is even a method from 1989 to translate the EEG signals into music to induce psychological and physiological states (Knispel, 1989). Harvey (2017) puts strong emphasis to differentiate the music from any language, which confirms former studies (Zatorre, Belin, Penhune, 2002), even though one role of music may serve as a way to express information, in other words, communicate.

Gaser and Schlaug (2003) used MRI and voxel based morphometry to examine the difference in motor, auditory and visual–spatial brain areas with positive results, namely in the difference of grey matter volume. Results can be seen below (Figure 16). Experiments like this give us the perspective (Figure 17) of how brain processes music and which brain areas are engaged (Schulkin, Raglan, 2014; Weinberger, 1999; Zatorre, 2005; Zatorre, Chen, Penhune, 2007).

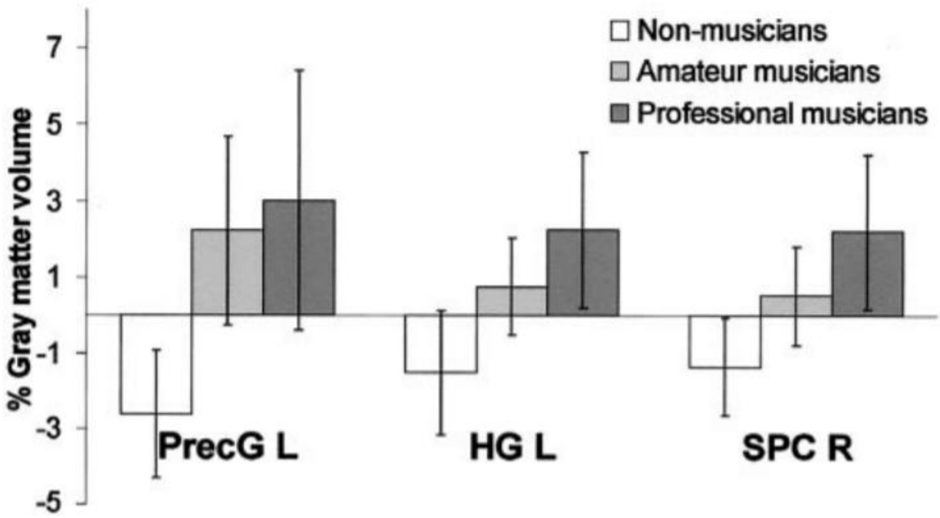

Figure 16: The difference in mean gray matter volume in examined brain areas in percentage between the 3 tested groups. (Gaser, Schlaug, 2003)

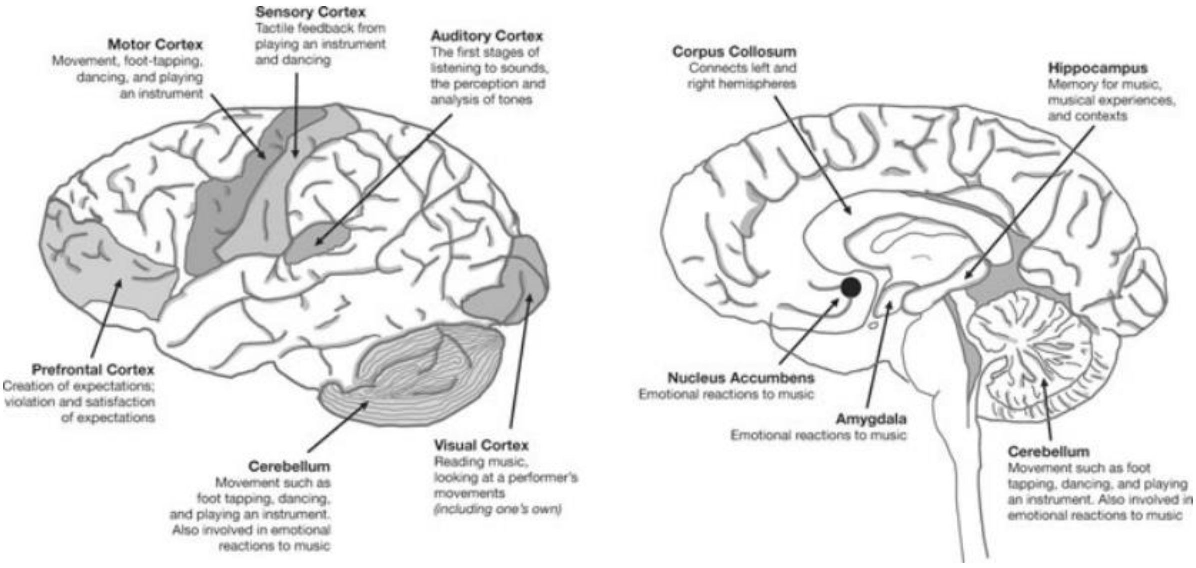

Figure 17: Brain areas connected with music. (Levitin, 2006)

4.3 Neuroscience of mathematics

As far as we know, humans are the only beings on this planet who actively use mathematics. Even though, in the past, there may have been some attacks on this assumption, for example the story of "clever Hans", the horse, who supposedly could count. This was finally seen to be the horse master unconsciously giving the horse cues (Davis, 1993). How does the brain process mathematics? When we are solving math tasks in text form, how closely is mathematics intertwined with language? The answers to these questions (and all other similar) are at our disposal nowadays, thanks to the brain imaging methods, also mentioned in sections above. To sum it up, the Learning Disabilities Association of Ontario's programme LD at School created this simple, yet approximate diagram of brain areas and math skills (Figure18). More detailed studies and experiments as to how this knowledge was collected is mentioned below the figure. One of the questions, the connection between language and mathematics has been focused on by a team of French scientists (Amalric, Dehaene, 2016). These took into account professional mathematicians and people on the same academic level in other fields and tasked them with answering to different problems from mathematical and nonmathematical (mostly historical) field, while scanning their brains with fMRI. The results shown that brains of mathematicians activated circuitry, which included bilateral intraparietal, dorsal prefrontal, and inferior temporal regions of the brain. Other than that, all of the subjects shown activity in language and semantic areas of brain during the nonmathematical tasks.

"Our findings shed light on the roots of mathematical abilities. Some authors have argued that mathematics rests on a recent and specifically human ability for language and syntax whereas others have hypothesized that it is a cultural construction grounded upon evolutionary ancient representations of space, time, and number."

– Marie Amalric (2016)

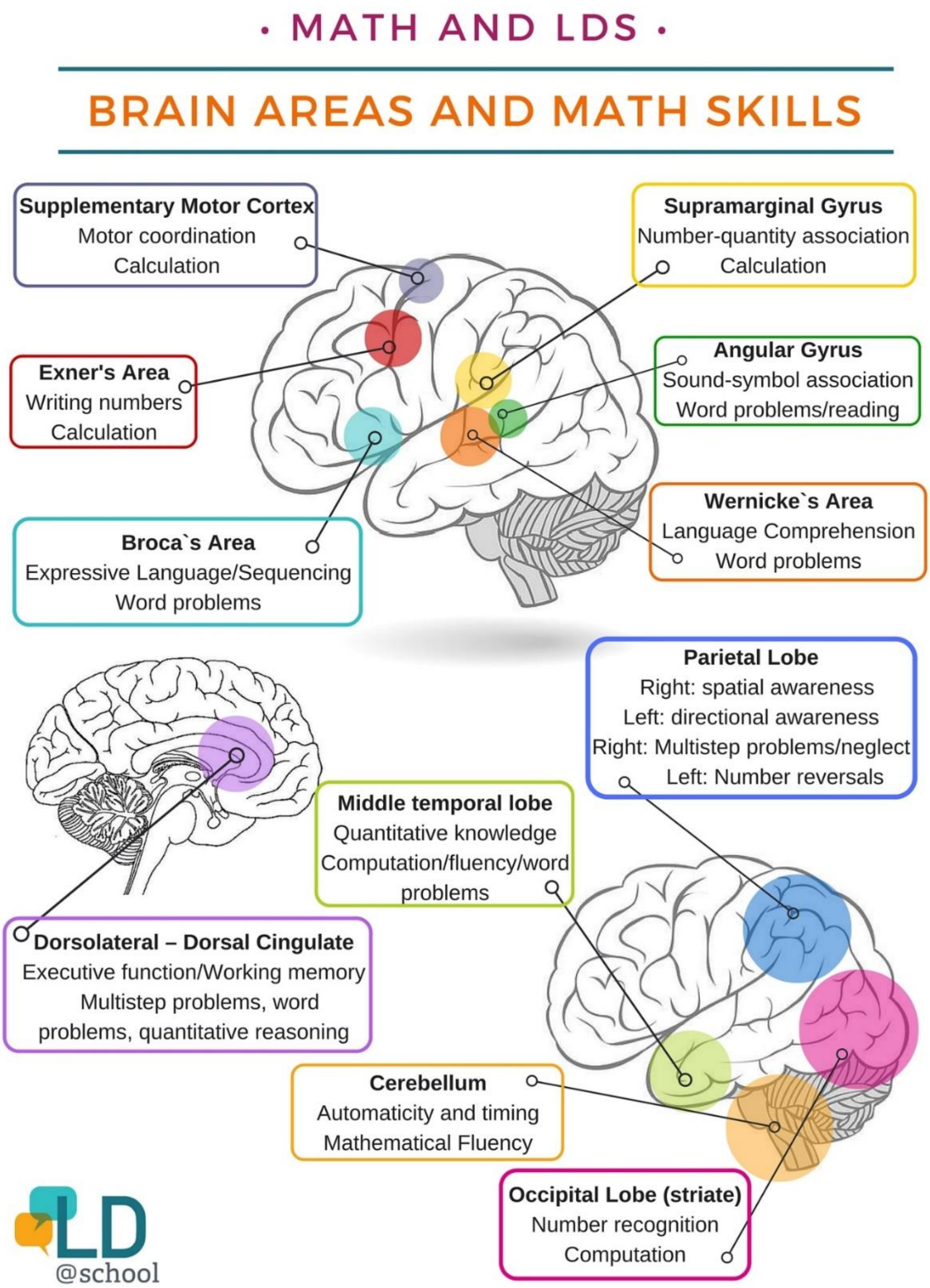

Figure 18: Diagram of brain areas according to math skills. (Kubas, Hale, 2015)

This results and also other ones (Ansari, 2007) add more comprehension into discussion whether and to what extent the format in which the problem was administered, plays role, confronted by different scientists (Daniels et al., 2003; (Dehaene, Cohen, 1995). Ansari emphasized the change of approach by focusing more on hemisphere differences instead of format differences. This emphasis was later supported (Arsalidou, Taylor, 2011) as seen in Figure 19. Diagnostic Imaging and Research Institute in Toronto further came up with a beautiful and rather complex meta–analysis of what the previous research on brain correlates for mathematics look like, summarized in Figure 20.

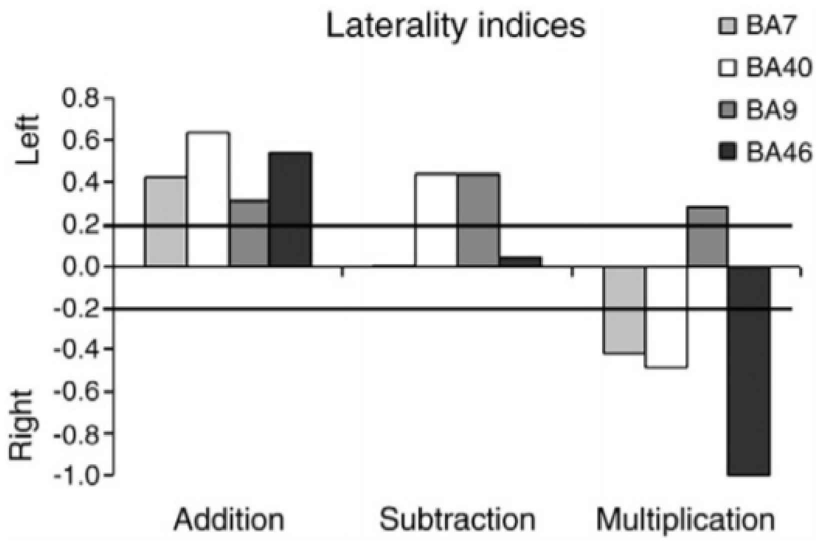

Figure 19: Laterality differences in activativation of Brodman's areas across parietal and prefrontal cortices, based on different mathematical tasks. (Arsalidou, Taylor, 2011)

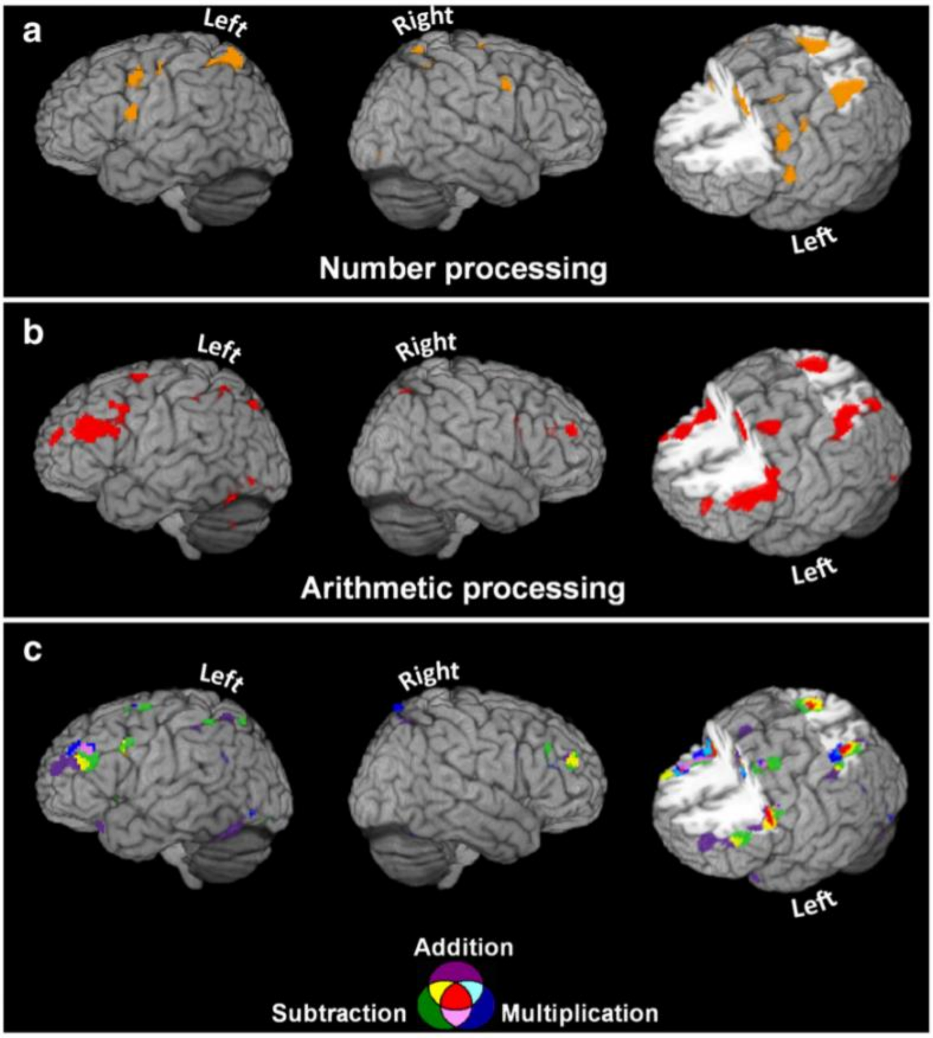

Figure 20: Rendered ALE (activation likelihood estimate) maps from 53 datasets of fMRI studies, on brain activation, dependent on mathematical tasks. (Arsalidou, et al. 2011)

5 Research design

The subject of research is to engage the supposed relationship between music and mathematics on the educational level and compare the results to previous research. The design itself is very simple, consisting of searching for the basic non-causal relationships, correlations and regressions. The aim of this study is to subsequently structure these proposed relationships and all the relevant final data into eventually utilizable material for further scientific purposes and to finally apply this knowledge in facilitating the general elementary school curricula.

5.1 Research question

Research question:

Is there any connection between the fields of music and mathematics on educational level?

This question carries with it a lot of possible superstructures, which all might possibly lead to eventual calibration of educational system, including change of curricula, change of the approach to educating preservice teachers and students, who incline to teach in future etc. But before all of these, this one question on the transfer of learning must necessarily be answered, reinforced and furthermore the significance and potential use be brought to the general public.

H_1: There is a positive correlation between the scores from musical testing and results from academic testing of third and/or eighth grade students.

H_2: There is a positive correlation between the scores from musical testing and mathematical creativity scores of third and/or eighth grade students.

The premise of these two hypothesis is based on the proposal by Schmithorst, Wilke (2002), Hyde (2009) and Helmrich (2010) that active engagement in music, such as plying some musical instrument or actively listening to music influences synaptic activity in a way of strengthening the synaptic connections just the same as performing cognitive activities. And while this synaptic activity is distributed widely in the whole brain, what we are interested in, specifically for this thesis, are the cortical correlates for spatial-temporal problem solving and mental rotation (Gaser, Schlaug, 2003, Hetland, 2000).

H_3: There is a positive correlation between the level of active musical engagement and results from academic testing of third and/or eighth grade students.

H_4: There is a positive correlation between the level of active musical engagement and results from mathematical creativity testing of third and/or eighth grade students.

These two hypothesis are derived from the proposal of enhanced Mozart effect (Graziano, 2016, Shaw, 2014) that children in elementary school, who actively play on musical instruments or actively engage in music also in other ways (Kamrlová, Varhaníková, 2011) show significant increase in mathematical competence.

5.2 Subjects

As far as my data goes, there are two main groups of participants – third graders and eighth graders from eight elementary schools located in western Slovakia. The data was obtained in collaboration with Centre for Educational Research and Innovation (CERI) in OECD (Organisation for Economic Co–operation and development). OECD also carries out different tests in the field of education. Two of these, mentioned below are the source of data for this study. Data obtained for this thesis were a part of the international OECD testing. This testing included eighth and third grade students of elementary school. The students of these two particular age groups were selected based on several theoretical and practical reasons (they are not in transitory grades between different levels of education, there is no other large-scale testing scheduled in these grades in participatng countries, etc.).

In this study, results of 356 eighth grade students (age 12–14) were used. Out of these, 221 students took only science and mathematics or only arts and music testing, which means the relationship between these two fields was not possible to observe. From the remaining 135 students 42 students did not fill sufficient amount of data in tests. The final relevant sample consisted of 81 eighth grade students.

Regarding the third grade students (age7–9), all 302 of them participated in both science & mathematics and arts & music testing. The tasks were in form of TIMSS testing, also mentioned below. Unfortunatelly, 34 did not participate in one of the tests and from the resulting 268 only 162 were able to fill in relevant amount of data.

5.3 Methods

This whole thesis is built upon the larger project called Assessing progression in creative and critical thinking skills in education by CERI (Centre for Educational Research and Innovation). Panel of experts from this organization along with experts from participating countries, which are part of OECD (the Organization for Economic Co-operation and Development) created tests for this project. Namely the academic knowledge tests STEM (Science, Technology, Engineering and Mathematics) and artistic and music knowledge VAM (Visual Art and Music). STEM testing puts emphasis on ability to solve problems that arise in these fields and it takes inspiration from PISA testing. VAM testing was used to extract useful information about the musical knowledge of the children and the relevant testing involves listening to 3 audio records and extracting relevant data which are referred to in the questions. The test also includes crucial information for this work and that is the relation to music and active music engagement. The project engages in 15 countries, focusing on 2 levels of education – primary, students aged 8-9 and secondary, students aged 12-13.

The form of these particular tests was uniform – a questionnaire with different types of options, including multiple choice, open answer or linear scale. The STEM test (Science, Technology, Engineering and Mathematics) consisted of 24 questions for eight–graders and 21 questions for third–graders in both forms, focused on academic and mathematics knowledge. These tests include arithmetic and logic tasks, mental rotation, verbal tasks and graphical representation. The VAM test (Visual Arts and Music) consisted of 14 questions for eight–graders and also for third–graders.

EPoC (Evaluation of Potential Creativity) testing comes from HOGREFE association, originally conceived with a group of French elementary and middle school students. This series of tests focuses on observing creative potential in elementary school students (Barbot, Besançon, Lubart, 2011) and their productivity while engaging creative process in a meaningful task. The students are tested in two lines of approach. Divergent – exploratory task, which observes fluency factor, which highly correlates with originality and Convergent – integrative, which observes the ability of integrating several elements in a creative synthesis. The divergent tasks are focused on generating as many possible answers as possible, while during the convergent task, one complex answer is assessed on its originality. Two tasks were carried out, each focusing on different approach. The combinations resulted in four scores: divergent numbers, divergent figures, convergent numbers and convergent figures, all restricted to 10 minutes time limit. Participant has an option to get accustomed with a similar task in training phase (see Appendix A).

Divergent numbers test consisted of graphical representation of calculator (consisting of numbers 0-9) and space, where subsequent correct answers are displayed. Participants were supposed to create a math problem which results in randomly pregenerated number. The rules for the task were as follows:

- One must use all four basic operators (+ , - , * , /)
- It is not possible to create larger than one-digit number
- It is not possible to create or count with negative numbers

Divergent figures test consisted of grid, were the participant is to create a shape. To create this shape, 3 types of basic shapes (square and 2 kinds of triangles) are available, each in amount of 5. The task is to create as many shapes as possible. Here is the list of the rules:

- The final shape must consist of exactly 5 basic shapes
- These basic shapes must be connected with at least 1 side
- The rotation of the final shape doesn't matter

Convergent numbers test observes how many numbers and operators (both are the same as for divergent numbers testing) can a participant group together to get a result (again randomly pregenerated number) while obeying the following rules:

- All digits must be used at least once
- All operators must be used at least once
- It is not possible to create larger than one-digit number
- It is not possible to create or count with negative numbers

The aim in the convergent figures test is to create one big shape with as many sides as possible. Two basic shapes (square and rectangle) are at disposal. The amount of both is 10. The graphical interface is similar to the one of the divergent figures task. The rules are simple: only those shapes are included in the sum of sides, which are in contact with at least 2 sides with other objects.

5.4 Procedure

Two series of testing were conducted, pre- and post-test. The difficulty levels were different with regards to the age of the participants. More specifically, the eighth grade students were given STEM tests based on PISA tests, while the STEM tests for third-graders was based on tasks from TIMMS tests. Students of both grades were also tested in visual arts and music (VAM). Both groups also attended psychometric testing of creativity (by EPoC tests). The testing was conducted in eights schools in Nitra county by teachers who applied to participate in this research. Contextual data were also collected about schools, teachers and their classes. 356 eighth-graders and 302 third-graders were split into experimental and control groups. A proposed methodological rubric was introduced to the teachers at schools. Further they were expected to come uo withs excercises and curricula that would put emhasis on creativity. A twelve week long inervention in form of this alternative tuition took place between the two series of testing.

6 Results

From the whole STEM testing, regarding the eight–graders, 18 questions were relevant for this research. In the tests of third–graders, 20 questions were relevant for this research. From VAM tests, 6 questions (41 including subquestions) were used in further analyses of eight and 6 (35 including subquestions) of third grade students. Regarding EPoC, both figures and numbers tests were joined to give comprehensive scores for divergent and convergent tasks. Children from both grades were to respond to how often they are to use knowledge from different subjects in the class on the scale A - never to D - on every class (for the whole scale see Appendix C 1). The results, coded numerally (A = 0 to D = 3) sadly confirmed, that transfer of knowledge is used only occasionally in the classes of third-graders and at best very rarely in the case of eighth-graders (Figure 21).

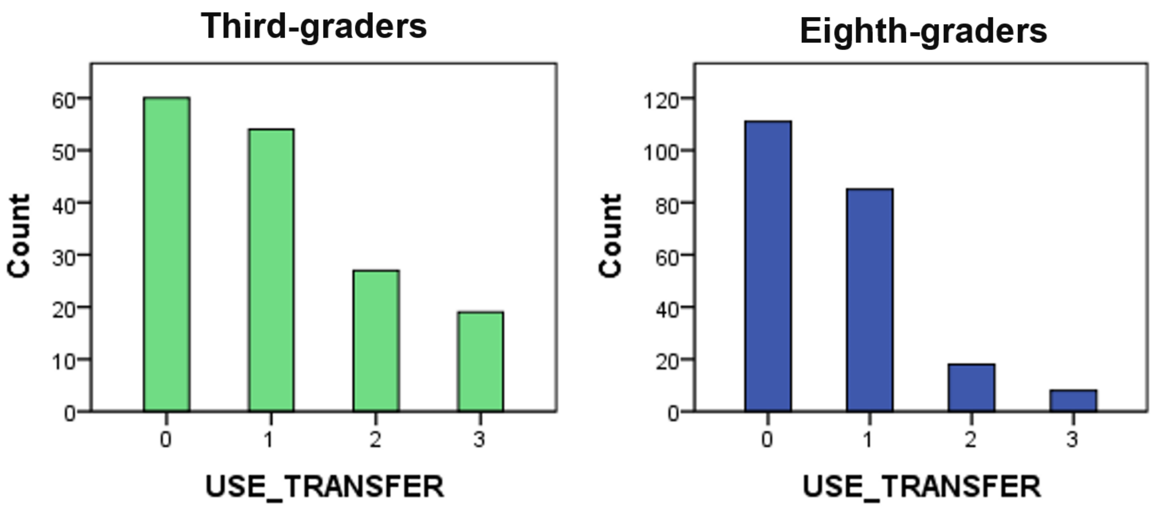

Figure 21: Number of students with regards to the transfer use in classes of third and eighth-graders.

6.1 Sample characteristics

As the first steps, Z –scores were calculated from VAM and STEM test results. EPoC test results were evaluated and summed into two categories. Z-scores of divergent tasks results and Z-scores of convergent tasks results. From VAM tests, two new categories were structured based on the engagement rate of the students: occurrence of active engagement in music, including music lessons (Music Lesson Active Engagement – MLAE) and music lesson activities without active engagement (Music Lesson Standard – MLS). Means and standard deviations of the precursor data can be seen below (Table 8).

Tests of normality were conducted on both groups in form of Shapiro-Wilk test (Razali, Wah, 2011) and visual evaluation of histograms and normal Q-Q plots (Table 9).

	3rd graders (N = 162)		8th graders (N = 81)	
	M	SD	M	SD
STEM	11.73	3.39	7.51	3.10
VAM	17.89	2.82	24.67	3.16
MLAE	2.21	2.35	7.79	2.84
MLS	2.90	2.30	11.22	3.55
DivNum	14.33	7.71	20.77	8.88
DivFig	21.02	9.5	30.39	14.50
ConNum	3.41	1.43	3.88	1.33
ConFig	4.25	1.40	4.35	1.54

Table 8: Performance of all participants showing amount of correct questions. DivNum and DivFig represent scores from divergent figure and numbers scores, the same goes for ConNum and ConFig, where Con stands for convergent tasks.

NORMALITY; Shapiro-Wilk											
Z_STEM		Z_VAM		Z_EPoC_DIV		Z_EPoC_CON		ML_ActiveEng		ML_Passive	
Grade 3	Grade 8	Grade 3	Grade 8	Grade 3	Grade 8	Grade 3	Grade 8	Grade 3	Grade 8	Grade 3	Grade 8
0.105	0.079	0.014	0.285	0.571	0.635	0	0	0	0	0	0

Table 9: Results for Shapiro - Wilk normality tests on both groups and all tasks.

Z-scores for skewness and kurtosis have also shown approximate normality except for z-scores from VAM (third-graders) which is bimodal and platykurtic, EPoC convergent tasks (both groups) which are negatively skewed and Music lesson active engagement (both groups, both levels of engagement) being positively skewed according to the table above. In the STEM tasks, the skewness was -0.492 (SE = 0.191) for third-graders and 1.269 (SE = 0.267) for eight-graders and Kurtosis was -1.029 (SE = .379) and -0.735 (SE = 0.529), respectivelly. In the VAM tasks skewness was -0.591 (SE = 0.191), 0.52 (SE = 0.267), respectivelly and kurtosis was -1.66 (SE = 0.379) for third-graders and 0.13 (SE = 0.529) for eighth-graders. In EPoC tasks only Z-scores from divergent tasks came out normal, which is also confirmed by skewness being 0.628 (SE =0.191) and -0.602 (SE = 0.267) and kurtosis being -0.543 (SE = 0.379) and 0.035 (SE = 0.529). None of these exceeded the value 1.69 or -1.69 (Cramer,1998). Kolmogoro-Smirnov test also has not shown any indication of exponential data distribution.

6.2 Correlations

Correlations have been explored as first indicators in order to engage possible relationship between the variables, that have been observed for third-graders and eighth-graders separatelly. All of the tested correlations can be seen in the diagrams below (Figure 22) (the values of correlations can be seen in Appendix C 2,3). The correlation elements were divided into two main categories. Music and Mathematical group. Correlations were examined between all elements from one group and all elements from the other one. Both parametric and non-parametric correlation methods have been chosen due to the different types of samples distribution. Pearson's r was used to measure linear correlation between groups with normally distributed data while Kendall's tau and Spearman's rho were used to explore non-linear non-parametric correlations. For each grade nine correlations were tested.

Regarding the eight grade students, three significant correlations were discovered. Surprisingly no positive correlation has been discovered, instead, two negative correlations have been found. For these two correlations a set of non-parametrical tests must have been used, because of non-normal distribution of data. The first one ($\tau = -0.187$; $p < 0.05$ and $r_s = -0.251$; $p < 0.05$) is a weak negative monotonic correlation between music lesson active engagement and STEM knowledge and the second also weak negative and monotonic correlation this time between music lesson standard is ($\tau = -0.265$; $p < 0.01$ and $r_s = -0.355$; $p < 0.01$).

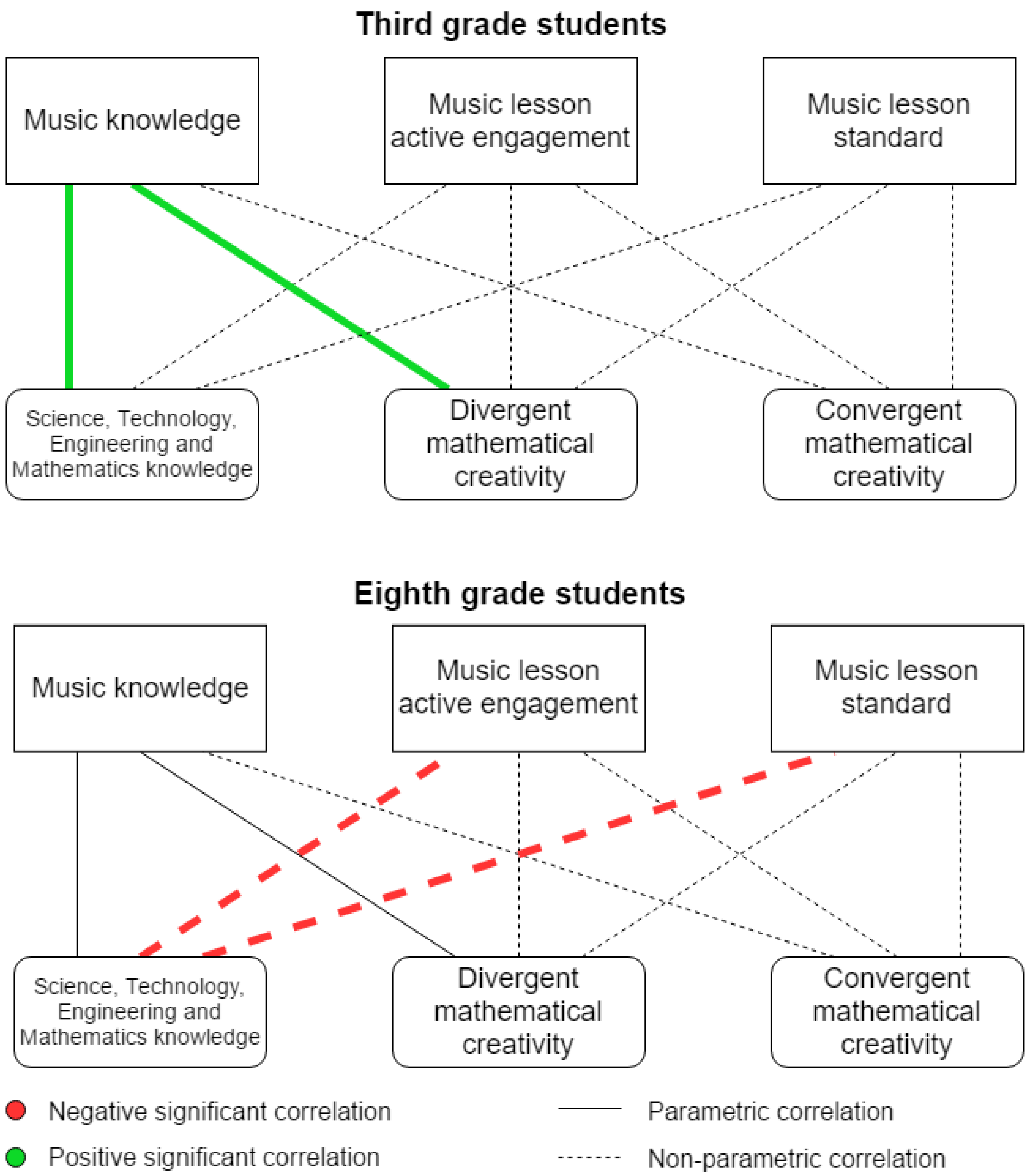

Figure 22: All examined correlations between the explored elements for both grades.

From all nine correlations only two have exhibited significance on third-graders data. Correlation between music knowledge and STEM knowledge is significant ($p < 0.01$) positive, linear and weak ($r = 0.227$). Another positive linear correlation emerged ($r = 0.184$; $p < 0.05$) between music knowledge and ivergent musical creativity. No other significant correlation was found.

6.3 Regression analysis

Significant outliers of dependent variables have been searched for using interquartile range rule (IQR) with the multiplier g = 2.2 (Hoaglin, Iglewicz, 1987). No outliers were found in STEM data. The results of linear regression show very high variance ($R^2 = 0.051$), yet the regression model shows a significant trend ($p < 0.05$) and analysis of variance confirmed the significance ($p < 0.01$). The final regression equation is:

$$Z\_STEM = -0.30 + 0.22 * Z\_VAM$$

The relationship between Music knowledge and divergent mathematical creativity also didn't manifest any outliers. Linear regression showed again high variance ($R^2 = 0.034$) while still being significant ($p < 0.05$). ANOVA model on this connection evaluated the relationship to be significant ($p < 0.05$). The regression equation for response (in this case divergent mathematical creativity) prediciton by music knowledge is:

$$Z\_EpoC\_Div = -0.09 + 0.128 * Z\_VAM$$

The correlations that emerged in case of eighth-graders are not linear. Therefore linear regression could not have been applied. Due to non-positive values in Z-scores of STEM tests, power, exponential and logistic models could not be applied. Two approaches have been applied. Firstly, encoding the dependent variable into positive-only values. This was done very simply, *Z_STEM_positive = Z_STEM + 3* so it was possible to explore all models. Secondly, regular quadratic and logarithmic regression fit were applied on the untransformed data. Results of variance and significance have been compared to chose the best fit.

The regression between STEM results and MLS was tested. And while quadratic regression on untransformed data shown no significant regression at all with $p > 0.05$, the logarithmic model produced significant results ($R^2 = 0.136$; $p < 0.01$). The exploration of transformed data was also a succsessful method. In addition to logarithmic, three more potential models were evaluated and compared (Figure 23), with the logarithmic remaining the most fitting one. The resulting function that describes the trend in this relationship is following:

*Z_STEM = 2,406 - 1,067 * log(MLS)*

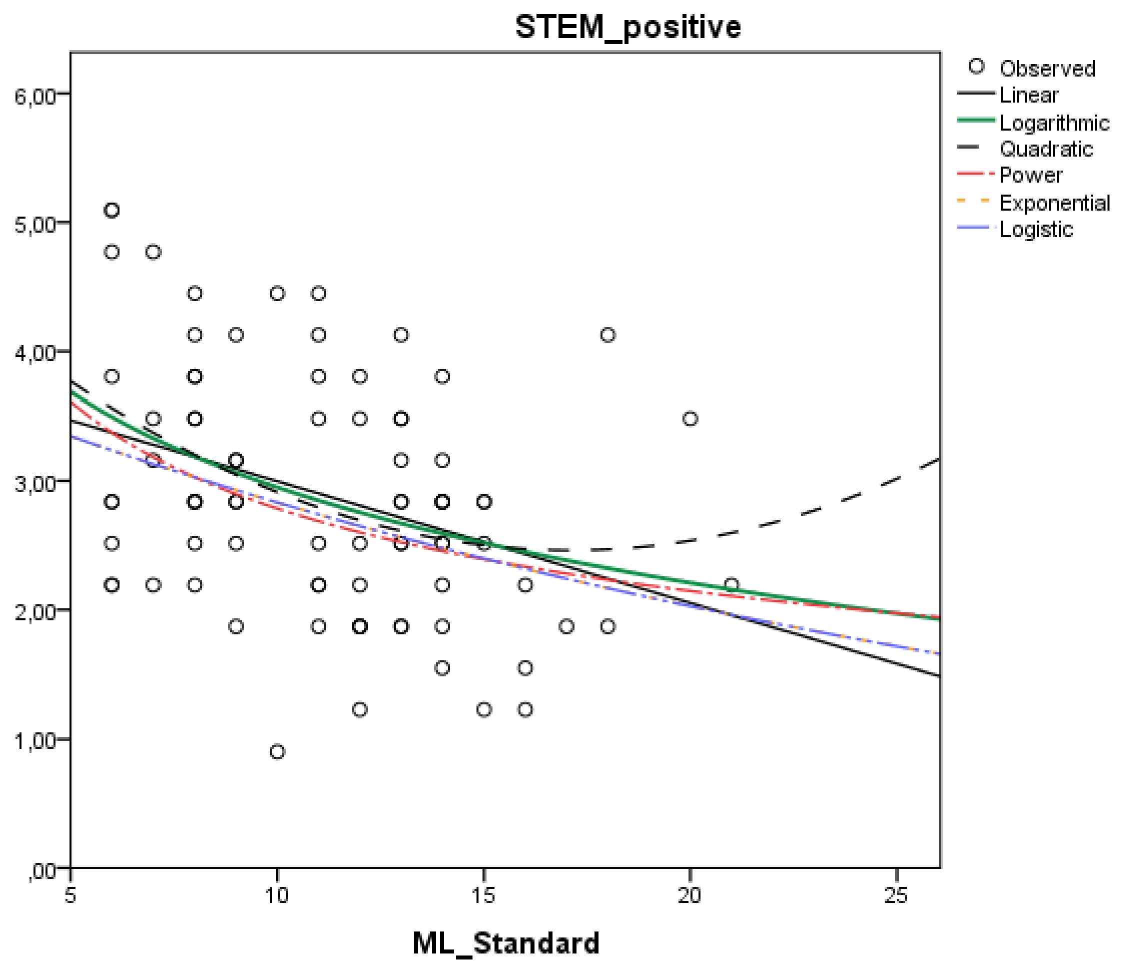

Figure 23: Nonlinear regresion models between modified STEM and ML_Standard (MLS). All except quadratic produced significant fitting functions, with logarithmic (green) being the best fit.

Regarding the second assumed regression, between STEM scores and MLAE, the sequence was the same as in previous case. The results in the case of unmodified data were similar to the previous tested regression. Again, quadratic regression didn't result in any meaningful outcome and the logarithmic model pointed to a significant trend in data ($R^2 = 0.073$; $p < 0.05$). The nonlinear regression on transformed data resulted in four significant models (Figure 24).

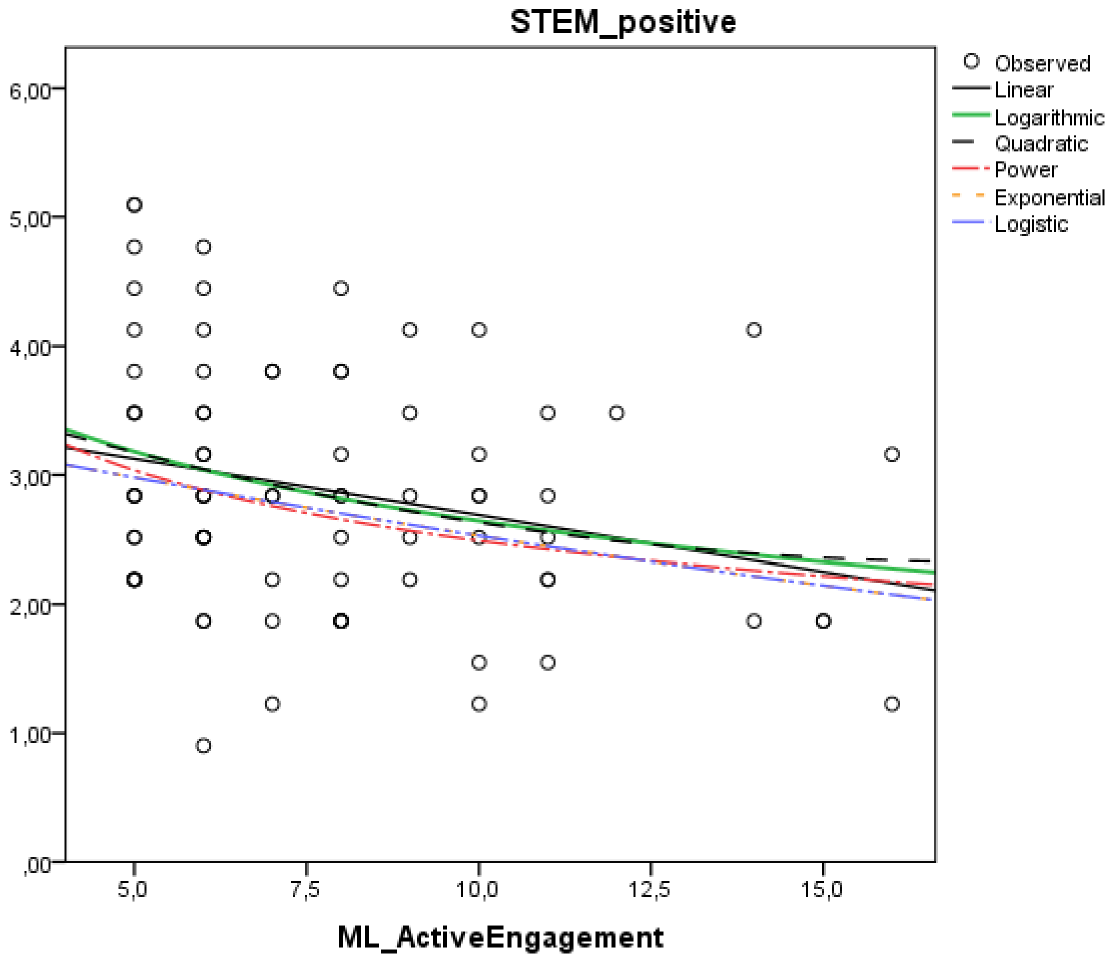

Figure 24: Four out of five nonlinear regresion models between modified STEM and ML_ActiveEngagement (MLAE) exhibit trend, with logarithmic, marked as green producing the best fit function.

The logarithmic, was again evaluated as the most fitting for the data, taking into account the variance and significance. The fitting function for this relationship is:

$$Z\_STEM = 1{,}431 - 0{,}777 * \log(MLAE)$$

7 Discussion

This study explored the proposed relationship between academic and musical abilities (Chobert, 2014, Graziano, 2016, Rauscher, Shaw, Ky, 1993, 1995). This connection was the base ground for the whole idea and the formation of the hypotheses.

Four main hypotheses were tested, which are, due to the strong variance of the results, difficult to evaluate. Regarding the first expectation (H_1), while there is a significant positive correlation between the scores from musical testing and results from academic testing of third grade students, eighth-graders did not exhibit this connection. The second hypothesis (H_2) encountered the same situation, specifically the significant positive correlation of third-graders' results in musical testing and divergent mathematical creativity did occur, no such correlation was found in the data of eight-graders. The third claim (H_3) that there is a positive correlation between the level of active musical engagement and results from academic testing of third and/or eighth grade students resulted in reverse. While no such relationship occured in third-graders, the eighth-graders exhibited negative correlation between the two observed elements regrading both active engagement and standard activity in class. The last hypothesis (H_4) has not been confirmed.

The results show that in the case of third-grade students there really seems to be, even though only weak, positive correlation, particularly between the scores of STEM and VAM tests, adapted from OECD TIMSS tests ($p < 0.01$). With also linear regression analysis showing a significant trend Linear regression analysis ($p < 0.05$) exhibited a significant trend in this relationship. Another interesting relationship was found between the music knowledge and divergent mathematical creativity ($p < 0.05$). The results of ANOVA ($p < 0.01$ in the first case, $p < 0.05$ in the second) confirmed that these relationships are not just a sampling error.

These results support the proposal (An, Capraro, TIllman, 2013, An, Tillman, 2015, Graziano, Peterson, Shaw, 1999) of actual existence of the relationship between these two fields of education in elementary school and also reinforce our assumption of actual utilization of this connection as a potential tool for interdisciplinary planning (Sicherl-Kafol, Denac, 2010). Not enough though to claim causality, the suggestion is that this may be the stepping stone for further investigation in this topic. On the other hand, the group of eighth grade students did not indicate any signs of positive correlation in case of STEM and VAM scores, in fact no correlation whatsoever between the two. Levitin (2009) suggests that the 5 years old children have already evolved the full system to analyse music continuity and musical syntax and with the time passed, one gets overflown with the data and noise, which effectively leads to eventual weakening of this ability. By doing so, we suggest that younger children (in this case the third graders) are more able to understand music in sort of subconscious level, which may directly correspond to their interest in it. Also this whole testing was set to cover general international standards, which include difficulty levels. Throughout the last years, our students sadly score very poorly in these tests, which may also indicate poor preparation for such a test, and/or possible low understanding of tasks, influenced by lower cognitive abilities. Another factor that supposedly might have influenced the difference between the grades is higher effect of math anxiety in eight-graders (Wigfield, Meece, 1988) and thus lower motivation for correctly and responsibly approaching the testing as these tests were in no way a part of students' final grading in their schools.

The results of the data analysis on eighth-graders were rather contra-intuitive. The negative effect of musical activity on mathematical knowledge is indeed difficult to interpret and the only assumption is as follows. The difference between the contexts (Sicherl-Kafol, Denac, 2010) of the music and mathematics lesson. Mathematics education in general is considered to be rigidly approached by the teachers and strongly affected by many external factors (An, Capraro, Tillman, 2013, Ashcraft, Ridley, 2005, Tine, Gotleib, 2013), e.g. anxiety connected with the particular subject, stereotype threats and socioeconomic status, which we assume negatively affected the results. On the other hand, the explored both actual musical engagement and interactivity on music lesson, necessary build on the right prerequisites, which the teacher creates. It infers openness and self-presentation of students, and other aspects which are in contradiction to the above mentioned factors that influence mathematics lesson. Therefore we propose a bold assumption that there might be a relation between the children's openness and active engagement in the music lesson and the extent of negative factors that influence the mathematical scores or the approach to math lesson at all (Ashcraft, Ridley, 2005). Furthermore there is one evident marker in this case, which is productive time throughout the day, when the child would invest more time into practicing with the musical instrument, rather than solving mathematic problems.

The absence of expected connection between music and mathematics where it has been examined, that is 14 cases out of 18 altogether for third and eighth grade students, is inclining to the rejection of the relationship in general as proposed by some studies (Nantais, Schellenberg, 1999, McKelvie, Low, 2002, Steele, Bass, Crook, 1999).

At last, no causal relationship can be proposed from this study due to the limitations below and inability to control all the possible factors that could influence the results in tests (Cranmore, Tunks, 2015, Ridley, 2005, Tine, Gotleib, 2013).

7.1 Limitations

Unfortunately, there is quite a lot of drawbacks to this work, which could (and some of them definitely did) influence this research and results.

First of all, the OECD CERI testing was not set to examine the phenomenon of transfer of learning. Therefore lots of data collected were not transformable into usable material. Furthermore it was really broad and complex, which means that a lot more time, manpower and preparation was needed than it was available. This resulted in many issues that we discuss below.

There was to begin with, lack of time to properly train and instruct the assistants and project workers who were to test these children and subsequently the teachers, who should establish the intervention. This has led to unclear instruction of children during the testing phase as some of the questions or answers in the answer sheets were rather unclear (we will get to this later). Due to the lack of time, preparation and great quantity of tests, teachers did not have enough time to distribute the time for tests appropriately, which in the end resulted in children not having enough time to fill the tests. Lots of test results had to be discarded due to lack of filled questions.

After the testing, only manual data processing was available. This was taken care of by different people, resulting in different encoding of the answers (which was eventually resolvable with enough effort) and in worse case, input errors (Appendix C 4), which again led to losing data. The final result of these drawbacks is a strong decrease of relevant data. Out of 658, only 243 final participants were suitable for this research.

Another issue regarding the original tests is the formulation of some questions, unclear assignment, instructions for results or even didn't contain a correct result in scoring table. 12 questions suffered from this issue (see the list of these questions in Appendix C 5).

Another significant issue are the scores themselves. The questions, focusing on some phenomenon by asking on a technical term, which requires higher musical knowledge, exhibits signs of random answer patterns (e.g. VAM test for eighth-graders, question 2e). There are two possible explanations. Either these musical terms were taught, yet the students failed to learn their meanings, or these terms were not taught at all. Both of these results intuitively refer to the level of music education. Yet it is not possible to carry out any general inference without further investigation. Therefore we propose this investigation of music education in various classes all around the country to determine, whether there really is any meaning of testing the relationship between music and mathematics in elementary school at all.

8 Conclusion

To answer the research question, there is a not very apparent relationship between the two fields at least to the degree, to which the results of this work are convincing. What is not so evident is the nature of this relationship. There are way too many factors that might have influenced the data obtained and from the position of only data analysis, there is no telling to what extent these factors did affect the results of the individual tests. The results are varying based on the grades, therefore it's very difficult to generalize. What can be provided though, are the actual individual relationships, evaluation of possible problems and ideas for future improvement.

From these results, many suggestions can be implied, including the existence of the relationship between the natural sciences and music in elementary education, but care must be taken, when implying such statement, because there are many other factors that also contribute to the results. These may be both internal and external as explained in the limitations sections. Either way, there is lot to explore and observe in the field of transfer of learning, including the course of school lesson, approach to solving tasks that are not typical for the school's curriculum, teacher's ability to handle the encumbrance of these additional tests on children and more. We have learned from this work, that phenomenon such as transfer of learning is not easily observable and examined and that the time an manpower for conducting a test like CERI team did are crucial for such research and it is vital not to exploit and decrease the scale and complexity of the research. The final suggestion regarding the data collection is that before the exploration of transfer, it is necessary to carry out studies on the samples to figure out the extent of different factors, which influence the student's performance in school for both music and natural sciences and how to deal with these factors.

The question that arises regarding the connection between VAM and STEM scores is, where the more successful children obtained the musical knowledge from. As indicated by the results of these tests, they did not fare very well in the musical test itself, from which an assumption is made about their low level of musical education in the school. Did the successful children attend additional extracurricular musical education, or did they spend additional time at home to prepare for music lessons at school? The results of different correlations between third and eighth-graders opens the question, why there were no analogical relations. The most important step in solving this is to investigate deeper in different levels of the educational approach from the individual student, through teachers' competencies to what emphasis is put into proper teaching of these two subjects in the particular school in general. The amount of limitations had a strong effect on this study, which resulted in poor significance, in our opinion. And while the expectations based on previous research have not been met, it is vital to emphasize the importance of these vague results as this study might refer to add to detachment of transfer of learning, if even this phenomenon really exists, from all other factors that influence it and also all setbacks and limitations that have been encountered may serve for the next research as a valuable resource in a way of highlighting the potential issues connected with such research.

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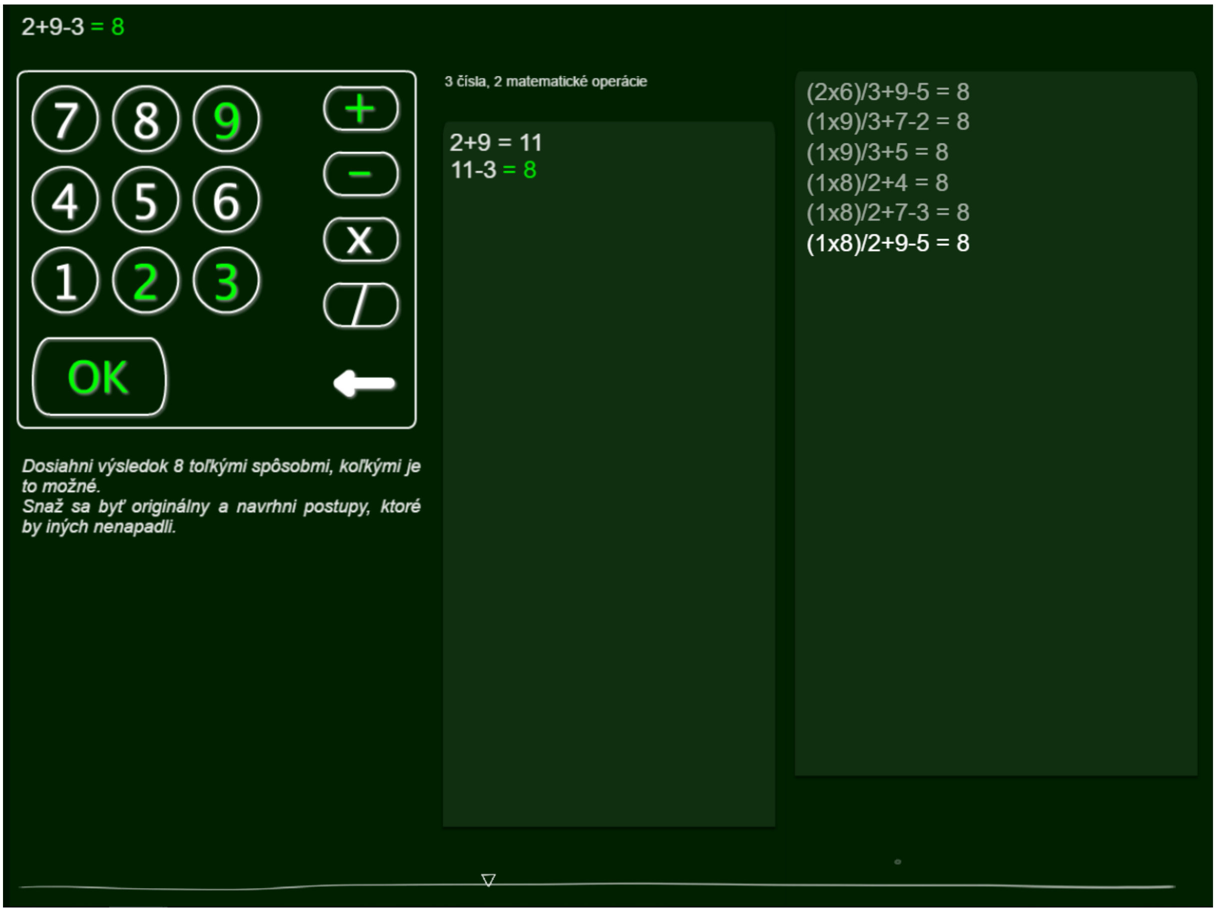
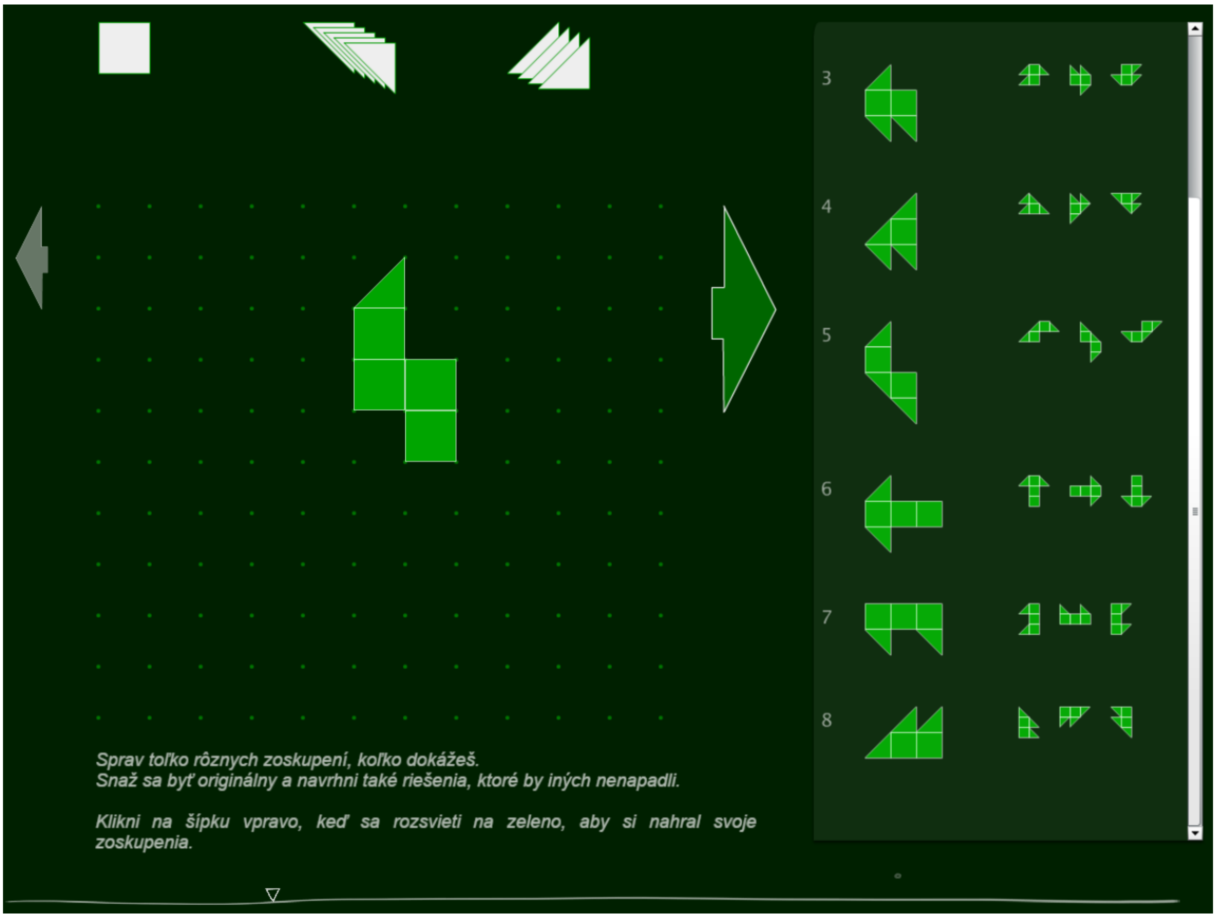
10 Appendix

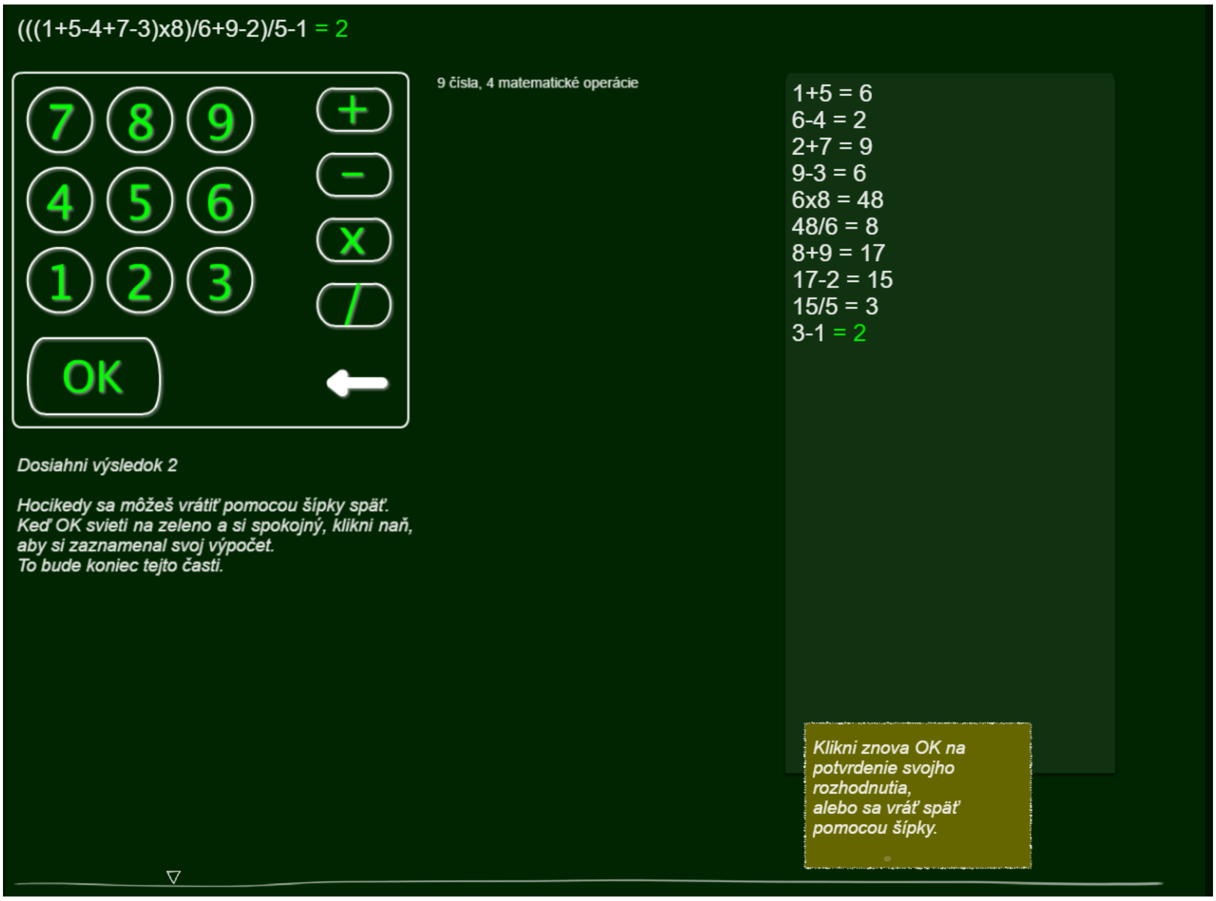
A: Screenshots from EPoC tests



Appendix A 1: Example of EpoC divergent number test.



Appendix A 2: Example of EPoC divergent figures test.



Appendix A 3: Example of EPoC convergent numbers test.

Appendix B: Examples of STEM and VAM tests and answer sheets

Otázka 6: CYKLISTKA HELENA PM957Q02

Helena prešla 6 km ku domu svojej tety. Tachometer jej ukázal, že mala počas celej jazdy priemernú rýchlosť 18 km/h.

Ktoré z nasledujúcich tvrdení, je pravdivé?

Ⓐ Helene trvalo 20 minút dostať sa do tetinho domu.

Ⓑ Helene trvalo 30 minút dostať sa do tetinho domu.

Ⓒ Helene trvalo 3 hodiny dostať sa do tetinho domu.

Ⓓ Nie je možné povedať, ako dlho Helene trvalo dostať sa do tetinho domu.

Otázka 7: CYKLISTKA HELENA PM957Q03

Helena išla na bicykli od domu k rieke, ktorá je vzdialená od domu 4 km. Trvalo jej to 9 minút. Domov išla kratšou cestou, ktorá mala 3 km. To jej trvalo len 6 minút.

Aká bola Helenina priemerná rýchlosť (v km/h) počas celého výletu k rieke a nazad?

Priemerná rýchlosť počas výletu: .... km/h

Appendix B 1: STEM test for 8-graders, form A

Otázka 1: ÚLOHA NA POČÚVANIE 1

LIST1A_ G3A_VAM

Ktorý nástroj je hraný v skladbe?

Ⓐ Xylofón

Ⓑ Gitara

Ⓒ Klavír

Ⓓ Bicie

Otázka 2: ÚLOHA NA POČÚVANIE 1

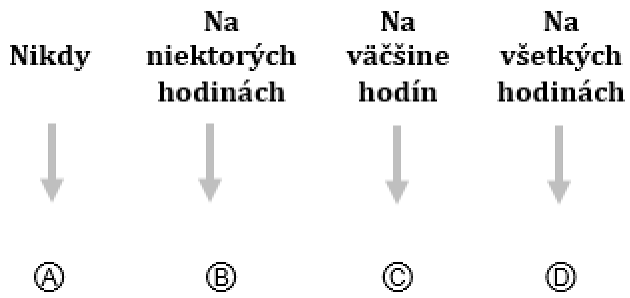
LIST1B_ G3A_VAM

Sú nasledujúce výroky o hudbe pravdivé alebo nie?

		Pravda	Nepravda
2.a)	V skladbe je silný prvok opakovania	Ⓐ	Ⓑ
2.b)	V skladbe sa objavujú rôzne výšky tónov	Ⓐ	Ⓑ
2.c)	Hudba pôsobí dojmom, že sa stále zrýchľuje	Ⓐ	Ⓑ
2.d)	Niektoré časti melódie sú akoby ozvenou iných častí	Ⓐ	Ⓑ
2.e)	Hlasitosť hudby sa neustálene zvyšuje	Ⓐ	Ⓑ
2.f)	Je to energická a nervózna melódia	Ⓐ	Ⓑ
2.g)	Je to nežná a romantická melódia	Ⓐ	Ⓑ
2.h	Je to uspávanka	Ⓐ	Ⓑ
2.i)	V melódii sú niektoré tóny veľmi zdôraznené	Ⓐ	Ⓑ
2.j)	Hudba hrá veľmi nízko a veľmi vysoko	Ⓐ	Ⓑ

Appendix B 2: VAM test for third-graders, form B

Appendix C: Miscelaneouss



Appendix C 1: Scale for evaluating, how often the children use knowledge from other subjects in the class.

Correlations

		Z_VAM	Z_STEM	ML_ActiveEngagement	ML_Standard	Z_EPoC_Div	Z_EPoC_Conv
Z_VAM	Pearson Correlation	1	,227**	-,109	-,106	,184*	-,053
	Sig. (2-tailed)		,004	,166	,177	,019	,502
	N	162	162	162	162	162	162
Z_STEM	Pearson Correlation	,227**	1	-,088	-,064	,308**	,014
	Sig. (2-tailed)	,004		,268	,416	,000	,861
	N	162	162	162	162	162	162
ML_ActiveEngagement	Pearson Correlation	-,109	-,088	1	,571**	,102	,121
	Sig. (2-tailed)	,166	,268		,000	,197	,125
	N	162	162	162	162	162	162
ML_Standard	Pearson Correlation	-,106	-,064	,571**	1	,005	,036
	Sig. (2-tailed)	,177	,416	,000		,952	,652
	N	162	162	162	162	162	162
Z_EPoC_Div	Pearson Correlation	,184*	,308**	,102	,005	1	,168*
	Sig. (2-tailed)	,019	,000	,197	,952		,033
	N	162	162	162	162	162	162
Z_EPoC_Conv	Pearson Correlation	-,053	,014	,121	,036	,168*	1
	Sig. (2-tailed)	,502	,861	,125	,652	,033	
	N	162	162	162	162	162	162

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix C 2: Third-graders. Parametric, linear correlation table. Green scores are significant.

Correlations

			Z_VAM	Z_STEM	ML_ActiveEngagement	ML_Standard	Z_EPoC_Div	Z_EPoC_Conv
Kendall's tau_b	Z_VAM	Correlation Coefficient	1,000	-,014	-,017	-,082	,147	-,017
		Sig. (2-tailed)	.	,865	,838	,319	,063	,835
		N	81	81	81	81	81	81
	Z_STEM	Correlation Coefficient	-,014	1,000	-,187*	-,265**	,135	,120
		Sig. (2-tailed)	,865	.	,026	,001	,086	,145
		N	81	81	81	81	81	81
	ML_ActiveEngagement	Correlation Coefficient	-,017	-,187*	1,000	,623**	-,105	,038
		Sig. (2-tailed)	,838	,026	.	,000	,193	,655
		N	81	81	81	81	81	81
	ML_Standard	Correlation Coefficient	-,082	-,265**	,623**	1,000	-,099	-,044
		Sig. (2-tailed)	,319	,001	,000	.	,208	,596
		N	81	81	81	81	81	81
	Z_EPoC_Div	Correlation Coefficient	,147	,135	-,105	-,099	1,000	,120
		Sig. (2-tailed)	,063	,086	,193	,208	.	,128
		N	81	81	81	81	81	81
	Z_EPoC_Conv	Correlation Coefficient	-,017	,120	,038	-,044	,120	1,000
		Sig. (2-tailed)	,835	,145	,655	,596	,128	.
		N	81	81	81	81	81	81
Spearman's rho	Z_VAM	Correlation Coefficient	1,000	-,024	-,032	-,114	,213	-,030
		Sig. (2-tailed)	.	,835	,776	,311	,056	,790
		N	81	81	81	81	81	81
	Z_STEM	Correlation Coefficient	-,024	1,000	-,251*	-,355**	,197	,165
		Sig. (2-tailed)	,835	.	,024	,001	,078	,140
		N	81	81	81	81	81	81
	ML_ActiveEngagement	Correlation Coefficient	-,032	-,251*	1,000	,759**	-,147	,067
		Sig. (2-tailed)	,776	,024	.	,000	,190	,554
		N	81	81	81	81	81	81
	ML_Standard	Correlation Coefficient	-,114	-,355**	,759**	1,000	-,156	-,059
		Sig. (2-tailed)	,311	,001	,000	.	,165	,599
		N	81	81	81	81	81	81
	Z_EPoC_Div	Correlation Coefficient	,213	,197	-,147	-,156	1,000	,169
		Sig. (2-tailed)	,056	,078	,190	,165	.	,132
		N	81	81	81	81	81	81
	Z_EPoC_Conv	Correlation Coefficient	-,030	,165	,067	-,059	,169	1,000
		Sig. (2-tailed)	,790	,140	,554	,599	,132	.
		N	81	81	81	81	81	81

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix C 3: Eighth-graders. Non-parametric correlations (in this case only negative) are marked red.

Q20a	Q20b	Q
4	6	
1	8	
2	4	
7	4	
2	6	
9	12	
6	9	
4	7	
8	5	
99	99	
8	6	
6	4	
10	13	

Otázka 20: JAZDA AUTOM

ATTAG8M2

Platia tieto výroky o matematike aj na teba?

V každom riadku vyplň len jeden krúžok

Otázka	Toto som celý ja	Toto je takmer ako ja	Toto je len trochu ako ja	Toto nie je vôbec ako ja
a) Matematiku je treba, aby svet fungoval	Ⓐ	Ⓑ	Ⓒ	Ⓓ
b) Na matematike nie je nič tvorivé; je to len o pamätaní si vzorcov a vecí.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
c) Komunikovanie so spolužiakmi mi pomáha zlepšiť si postoj k matematike	Ⓐ	Ⓑ	Ⓒ	Ⓓ

Appendix C 4: To the left, 13 students, which responded to STEM test, form A, questions Q20a and b. The possible answers in answer sheet were A to D as seen on right (coded 1 to 4 respectively). 99 represents „did not answer“. Every other number can not be evaluated.

STEM_3_A: 10a

STEM_3_B: 4, 7, 8a

STEM_8_A: 3a, 7

STEM_8_B: 10,

VAM_3_A: 6e

VAM_3_B: 4, 6e

VAM_8_A: 4a

VAM_8_B: 8

Appendix C 5: list of particular questions that suffered from unclear assignment, unclear result form. Questions STEM_3_B_Q8A, VAM_3_B_Q4 do not even contain the correct solution in the scroing table.