STEM4MATH

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Abstract

The purpose of this 3-year Erasmus+ project was to tackle difficult math concepts by using an integrated STEM-approach which is characterized by learning from action using meaningful contexts that are relevant for children. The outputs of the project are a didactic model with two key elements (integration and process) and 20 STEM-good practices with a focus on math which are presented on the web platform www.stem4math.eu. Pilot teachers from the five participating countries were trained, tested the activities and shared experiences during joint staff training events.

Questionnaires were used to examine children attitudes towards math before and after the activities. In general, the results of the survey showed that 9-12 and 6-8-year-old children have a positive attitude towards math. After completing the STEM4MATH activities, 9-12-year-old children find math more useful and important, in particular boys. On the other hand, 9-12-year-old children reported low scores of enjoyment for math. Different from the results of the 9-12-year-old, children of the age group 6-8 years old have a more positive attitude towards math and their class ambience after the activity. However, 6-8-year-old children didn't link the STEM4MATH-activity with the mathematics used in daily life. These results are in line with previous research results, indicating that attitudes towards mathematics decrease with age. Teachers should be aware of this shift and can have an important role in the attitudes of the children.

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1. Introduction

Children often experience difficulties in math learning. Of course math is one of the more abstract disciplines in primary education. In this project we pointed out the idea that STEM education can play an important role to learn the more difficult math concepts and so capture the potential of all children. This is because, an integrated STEM approach is characterized by learning from action within meaningful contexts which are relevant for children. It is sure that an integrated approach is a good way in order to improve the quality of education in math (Cotabish, Dailey, Robinson & Hughes, 2013). Studies have shown that an interdisciplinary approach foster positive attitudes towards STEM disciplines, motivation and problem solving skills and that these positive attitudes also result in an increase of interest in STEM-disciplines and a growth of being competitive in an ever-changing global economy (Moore & Smith, 2014). Without doubt, STEM skills are important in order to reach the 21st century skills.

But there is a threshold amongst teachers to really use the STEM didactics in the classroom in order to teach math. Furthermore, concerning math education, the potential for STEM integration in advancing mathematics learning is less apparent than for science, technology or even engineering. A challenge is then to achieve a better balance in which science, mathematics, engineering and technology become equally recognized. So in particular, mathematics is not well connected to STEM-activities nowadays because of the difficulties to contextualize math contents and let them encompass real world problem based learning. In this research we wanted to improve teaching mathematics through a STEM approach and this by exchanging, selecting and developing good practices in which especially math concepts are integrated in STEM in such a way that these concepts become attractive and more easy to learn for children.

2. Goals of the project

The project had three main goals: developing a didactic model for integrated STEM-education with a focus on math, developing 20 STEM-good practices and investigate the impact of the activities on the attitudes of the pupils.

2.1. Didactic model

The first goal was to develop a **didactic model** for integrated STEM-education strengthening the learning of math in elementary school. A strong emphasis in the model was on key elements of effective STEM-education in order to learn math concepts in particular, such as inquiry-based learning within contexts that are relevant for the children, learning by action (e.g. by using scaffolding techniques), stimulating reflection and interaction, guiding design and inquiry through a systematic process (Van De Keere & Vervaet, 2013). This didactic model was the guideline for selecting and developing good practices and contained criteria necessary to set up successfully integrated STEM-activities with a clear incorporation of mathematics.

2.2. 20 STEM-good practices

The second goal of the project was to develop **20 STEM-good practices** with a focus on math. Our good practices offered teachers a wide range of opportunities to organize math in their classrooms as part of a broader STEM-education objective. For each age group (6-8 years and 9-12 years old) 10 activities were developed.

2.3. Effects on attitudes of the children

The third goal of the project was to assess the attitudes of the children for math and to assess the effect of the STEM-activities on the attitudes of the children. STEM-activities were tested in the age group of 9-12 years old and in the age group of 6-9 years old. Attitudes towards STEM and math were measured before the activity and after the activity. The hypothesis was that children found math more meaningful, that they more enjoyed math and that they perceived themselves better to perform math after the activity.

3. Method

3.1. Design

During the project the 'educational design research' methodology was used as described by McKenney & Reeves (2012).

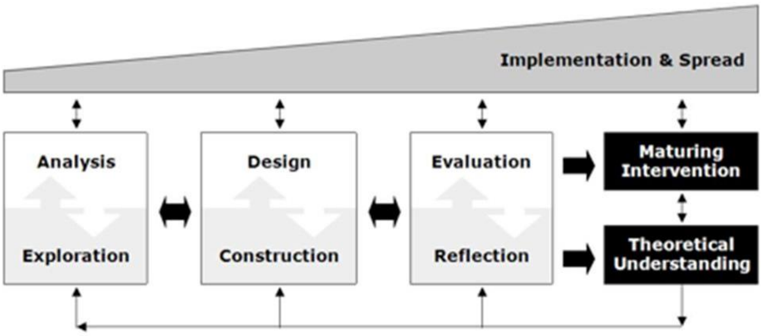

Figure 1. educational design research (McKenny & Reeves, 2012)

First *a need analysis* was made to define the problem. An analysis of the local situation in each partner country was made by conducting a needs assessment concerning STEM-education at the level of the teacher in a selection of 2 schools in each partner country. An in-depth interview took place at each school with at least 2 teachers to get a clear view on the needs for implementing integrated STEM regarding math in the curriculum. Based on the needs analysis *a literature study* took place to review previous national and EU-projects as well as academic studies on integrated STEM-education and its impact on attitudinal and cognitive development of children, in particular for math. A protocol was used to conduct a systematic literature study, e.g. with criteria to select literature (such as search terms in the research question (e.g. learning math concepts through an integrated STEM-approach; De Meyere, Sokolowska, Folmer, Rovsek, Peeters, 2013). Based on the need analysis and the literature study, a didactical model was formed consisting of an interdisciplinary approach of the 4 STEM disciplines with a clear integration of mathematics.

A *collection of existing STEM-activities* was made by searching in existing tutorials, manuals, and also (inter)national literature. The didactic model was a guideline for selecting the activities that enable an integrated STEM-approach with a clear incorporation of math in elementary school. This process led to a list of selected activities and for each activity a template was made revealing its opportunities. Based on the template, 4 integrated STEM4MATH-activities were developed by each partner, so that we have a total of *20 good examples of STEM-activities* with a focus on the implementation of math (= 10 for each age group).

To implement these STEM4MATH-activities in the partner countries, minimum 2 *teachers* from each partner country and each age group were involved in the testing of the activities (10 teachers for each age group). The training (2 days) was on a national level, but the pilot team were also involved in video conferences to meet each other and exchange expertise. For each age group all 10 activities were divided among the pilot teachers. Each activity was implemented twice by different teachers.

During a *joint staff training event* for each age group, the pilot team shared results. They learned from each other and gave feedback to optimize the tested activities. The methodology of focus groups was used to acquire a variety of suggestions, barriers,... An iterative evaluation of the intervention (here: implementation of STEM-activities) took place to gather information about what worked (or not) (here: regarding math learning) and about the constraints to carry out interventions successfully (Reason & Bradbury, 2001). Based on the evaluation, the STEM4MATH-activities were optimized to 20 good practices enabling math learning through an integrated STEM-approach (see www.stem4math.eu)

A quantitative study was conducted to measure the impact of the STEM4MATH-activities on children's attitude to math and STEM in general. Therefore, the pilot groups (both age groups) were assessed before and after the activity.

For the age group of 9-12 years old, the questionnaire consisted of 18 items and was divided in three subscales: enjoyment of math, mathematical self-perception and perceived usefulness of mathematics. The total questionnaire has a reliability of $\alpha = 0.93$. The subscale 'enjoyment of math' consisted of 6 items and measured the degree to which the pupils take pleasure in doing and learning mathematics (e.g. 'I look forward to the mathematics lessons', 'I'm interested in math'; $\alpha = 0.94$). The subscale 'mathematical self-perception' had 8 items and measured the perception of the pupils as a mathematical learner including beliefs about his or her ability to learn and to perform well in mathematics (e.g. 'I'm learning quickly for math', 'I find tasks for math easy'; $\alpha = 0.87$). The last subscale 'perceived usefulness of mathematics', had 4 items and measured the pupil's beliefs about the practical use and applicability of mathematics in daily life (e.g. 'Mathematics are important', 'I need math in everyday life'; $\alpha = 0.69$). A 5 point-Likert scale was used (from 0 = I disagree to 4 = I agree).

The questionnaire for the younger age group (6-8 years) consisted of 5 items in the pretest and 6 items in the posttest. Statements about the class climate and about math lessons were filled in by the pupils (e.g. 'In class we talk about what we have learnt', 'I need math outside of the math lessons. (e.g. at the supermarket, during sports, …)'). The level of agreement was represented by 4 stars from small to big. The bigger the star the more the pupil agree. Cronbach's α for the questionnaire is 0.70.

Simple T-tests, paired sample T-tests and ANOVA for repeated measures were used for testing for the quantitative research.

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3.2. Participants

Following schools participated in the STEM4MATH-project: Agrupamento de Escolas de Oliveira do Hospital (Portugal), Agrupamento de Escolas de Castro Daire (Portugal), Agrupamento de Escolas Viseu Norte (Portugal), Agrupamento de Escolas de Búzio - Vale de Cambra (Portugal), Agrupamento de Escolas de Ílhavo (Portugal), Agrupamento de Escolas de Esgueira (Portugal), Escola Profissional de Agricultura e Desenvolvimento Rural de Vagos (Portugal), Laude Fontenebro School (Spain), Co-operative Alcázar (Spain), C.E.I.P. Fray Juan de la Cruz (Spain), C.E.I.P. San José (Spain), C.E.I.P. Domingo de Soto (Spain), C.R.A. Los Almendros (Spain), C.E.I.P. La Pradera (Spain), C.R.A. Obispo Fray Sebastián (Spain), C.E.I.P. Arcipreste de Hita (Spain), Colegio San Agustín (Valladolid) (Spain), Colegio Niño Jesús (Spain), Vendelsömalmsskolan (Sweden), Spanjeschool (Belgium), GO! Ter Elzen (Belgium), Kummun koulu Outokummun kaupunki (Finland)

1. Pilot teachers

For each age group there was a pilot teacher team. Per age group, minimum 2 teachers per country were involved (so 20 teachers in total). The training of the teachers took place on a national level. These teachers tested the activities that were selected and developed by the partnership in order to optimize them. This testing gave the opportunity to the partnership to obtain good practices. During a joint learning event of 5 days the pilot team of each age group was brought together to learn from each other and to exchange experiences about the implementation of the developed STEM-activities.

2. Pupils

Pupils who participated in the project did one or more STEM4MATH-activity in class. In the age group of 9-12 years old, 561 children participated (46% girls, 54% boys; mean age= 11,2). In the age group of 6-8 years old, 267 children participated (48% girls, 52% boys; mean age= 8,1).

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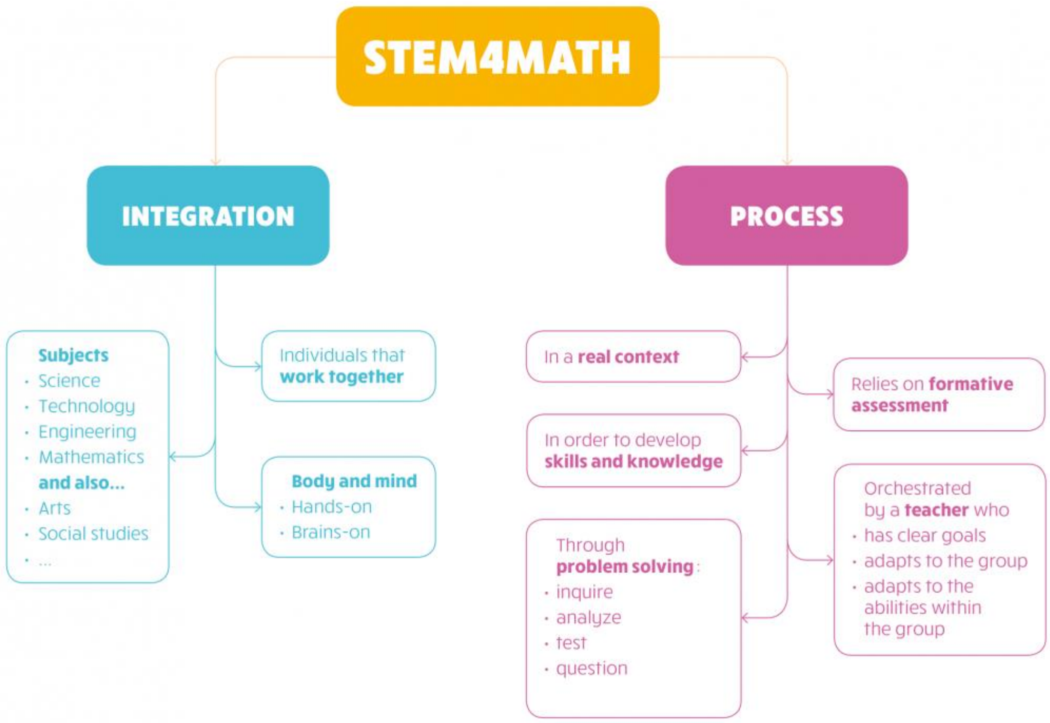
4. Results

4.1. Didactic model



In the didactic model of STEM4MATH there are 2 key elements: **integration** and **process**. Working in STEM means **integrating** the work in all four subjects: Science, Technology, Engineering and Math. We have to approach all four topics as a single one where skills are acquired in a unified way and connections among them are evident (Stohlmann, Moore, & Roehrig, 2012). Working in STEM means integrating the hands-on experiences with the mind's work (Zemelman, Daniels, & Hyde, 2005). Working in STEM means facing challenges that usually need team-work. Collaborative-learning is naturally ingrained in STEM (Zemelman, Daniels, & Hyde, 2005) and allows each team-member to provide the group with a different ability.

The second key element is **process**. The problem that needs to be tackled should always include elements that the children did not know before starting the work. We have to keep in mind that we're aiming at improving their inquiry skills, their ability to formulate questions and test their own hypothesis as well as analyzing and questioning their own results (Asghar, Ellington, Rice, Johnson, & Prime, 2012). On the other hand, the unknown elements should have the right level of difficulty that will let them be able to learn with very little or no help from the teacher (Dejonckheere, Vervaet, & Van De Keere, 2016).

While the student should be the main character in his own learning, the teacher has the critical role of orchestrating each child's learning process (Crawford, 2000). The teacher's questions should provoque deeper thinking and make new questions arise (Mant, Wilson & Coates, 2007). In fact, he should avoid giving closed answers that might transform the work of the children into a search of the "right" answer that the teacher already knows (Dejonckheere, Vervaet, & Van De Keere, 2016).

All throughout the process, both the teacher and the students need to keep in mind the importance of assessment (Hodgson & Pyle, 2010). Self-evaluation through rubrics help students understand what they are learning and achieving. Peer-evaluation allows them to reflect on their teams' work, but also on their own performance. On the other hand, the teacher –who has become a coach- can (and should) dedicate to observe the children and give them feedback on their work. The teacher should talk with the children in order to both test and improve their understanding of the concepts they are acquiring, as well as the skills that they are developing (Zemelman, Daniels, & Hyde, 2005).

4.2. 20 STEM-activities

Based on the didactic model 20 good practices of integrated STEM-education with a clear integration of math were developed. The activities were tested by a team of pilot teachers. There's a total of 20 good examples of STEM-activities with a focus on the implementation of math (10 in each age group). These activities can be found at www.stem4math.eu The web platform is also a learning platform consisting of teaching guidelines to strengthen the didactical competences of teachers with regard to integrated STEM education.

4.3. Effects on attitudes of the children

9-12 years old

General

The questionnaire results indicated that children had positive attitudes towards math. According to table 1, descriptive statistics (mean, standard deviation) and one sample t-test were adopted to investigate children's attitudes before and after participating in the STEM4MATH-activity. One sample t-test analysis was used to compare the learning attitudes of children with an answer of "2", the neutral point on the five-point Likert scale. In general, the results showed that children's attitudes towards math were positive and significant (M =2.47, *SD* = 0.82, *t* = 8.12, *p* <0.001). Children's scores towards self-perception and perceived usefulness were positive and significant. In particular children had the highest score for perceived usefulness at both pre- and posttest. The scores towards enjoyment were significant for the pretest but not for the posttest (table 1).

Table 1: Analysis of one-sample t test regarding children's attitudes towards math

	Pretest			Posttest		
	Mean	SD	t	Mean	SD	t
Enjoyment	2.15	1.05	2.19*	2.13	1.17	1.57
Selfperception	2.60	0.72	12.56***	2.54	0.78	9.77***
Perceived uselfuness	2.79	0.81	14.60***	2.86	0.89	13.51***
Total score	2.49	0.73	10.21***	2.47	0.82	8.12***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Changes in attitudes

A paired simple T-test was adapted to measure the change of children's attitude towards math. The results indicated that children had only significant change in the perceived usefulness scale (t(187) = -2.2, p=0.028). In regard to the subscales of enjoyment and self-perception, children's attitudes didn't change significantly. The results suggest that the activity can change the perception of usefulness and the importance of math in daily life of children (table 2).

Table 2: The difference between the children pretest and posttest attitudes (N=188; *df*= 187)

Subscale	Paired differences	t
	M(SD)	
Enjoyment	0.14 (0.72)	0.27
Selfperception	0.07 (0.61)	1.63
Perceived uselfuness	-0.13 (0.82)	-2.22*
Total score	0.01 (0.52)	0.23

* $p < 0.05$

Gender

For the scores on the perceived usefulness scale for the pretest, girls score significant higher than boys ($t(221)=2.64$, $p=0.009$). Before the activity girls find math more meaningful and important than boys. No statistically significant differences were found between girls and boys for the subscales 'enjoyment' and 'self-perception' (table 3).

If we only look at the boys, we see a pre-posttest effect for the perceived usefulness scale (table 4). Boys have higher scores on the scale after the activity than before the activity. They find math more meaningful and important after performing the activity than before (see figure 2).

Table 3:

	Girl		Boy		difference	
	M	SD	M	SD	M	t
Enjoyment (pretest)	2,14	1,00	2,16	1,09	-0,20	-0.18
Enjoyment (posttest)	2,13	1,13	2,13	1,21	0.001	0.01
Selfperception (pretest)	2,60	0,70	2,61	0,74	-0.01	-0.8
Selfperception (posttest)	2,54	0,84	2,54	0,73	0.01	0.07
Perceived Uselfulness (pretest)	2,94	0,66	2,66	0,91	0.28	2.64**
Perceived Uselfulness (posttest)	2,99	0,83	2,76	0,94	0.23	1.80
Total (pretest)	2.52	0.68	2.47	0.77	0.05	0.50
Total (posttest)	2.47	0.83	2.45	0.82	0.05	0.46

** $p < 0.01$

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Table 4: Differences pre-and posttest for girls and boys

	Paired differences			
	Girl (n=87)		Boy (n=100)	
	M(SD)	t	M(SD)	t
Enjoyment (pre-post)	-0.004 (0.65)	-0.06	0.03 (0.78)	0.39
Selfperception (pre-post)	0.07 (0.61)	1.04	0.08 (0.61)	1.25
Perceived usefulness (pre-post)	-0.07 (0.76)	-0.85	-0.19 (0.87)	-2.17*
Total (pre-post)	0.01 (0.50)	0.28	0.003 (0.55)	0.06

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

For the scale of perceived usefulness, an ANOVA repeated measures analysis was made. There's no interaction effect between time and gender $F(1,186)=0.95$, $p=0.33$. There's a main effect of time $F(1,186) = 4.58$, $p=0.034$, as mentioned before.

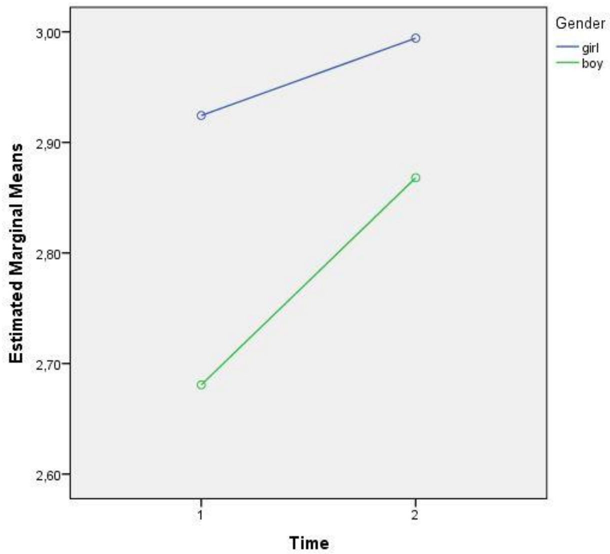

Figure 2: Gender effect for scale 'perceived usefulness'

6-8 years old

General

The questionnaire results indicated that children had positive attitudes towards their class climate and math. Table X shows the descriptive statistics (mean, standard deviation) and results of the one sample t-test that were adopted to investigated children's attitudes after participating in the STEM4MATH-activity. One sample t-test analysis was used to compare the learning attitudes of children with an answer of "1,5", the mean of the scale. In general, the results showed that children's attitudes towards class climate and math were positive and significant. In particular, children had the highest score for the item 'I understand what the teacher wants me to achieve' at both pre- and posttest. For the posttest, the item 'I like mathematics' was the highest for the math-items (table 5).

Table 5: Analysis of one-sample t test regarding children's attitudes towards class climate and math

	Pretest			Posttest		
	Mean	SD	t	Mean	SD	t
In class we talk about what we have learnt.	1.75	1.06	3.56***	2.42	0.79	17.44***
I understand what the teacher wants me to achieve.	2.45	0.72	20.99***	2.59	0.65	25.45***
I like mathematics.	2.18	1.03	10.16***	2.43	0.91	15.49***
Learning math is easier when I can work together.	2.07	1.03	8.51***	2.30	0.95	12.62***
I need math outside of the math lessons.	2.21	1.08	10.00***	2.19	1.06	9.81***
I have used math in the project xxx.				2.24	1.02	10.88***

* p < 0.05, ** p < 0.01, *** p < 0.001

Changes in attitudes

A paired simple T-test was adapted to measure the change of children's attitude towards the class climate and math. The results indicated that children had significant changes for all items except for the item 'I need math outside of the math lessons'. The results suggest that the activity had a positive impact on the attitudes towards class climate and math (table 6).

Table 6: The difference between pretest and posttest attitudes (6-9 years old)

	Paired differences	
	M(SD)	t
In class we talk about what we have learnt.	-0.65 (1.12)	-8.11***
I understand what the teacher wants me to achieve.	-0.16 (0.71)	-3.12**
I like mathematics.	-0.31 (1.21)	-3.82***
Learning math is easier when I can work together.	-0.32 (1.22)	-3.61***
I need math outside of the math lessons.	-0.09 (1.30)	-1.00
Total questionnaire	-0.30 (0.68)	-6.12***

* p < 0.05, ** p < 0.01, *** p < 0.001

Gender

For the questionnaire of the 6-9 years old, no interaction effect was found between gender and time for the different items. For both boys and girls, there's main effect of time for the items 'In class we talk about what we have learnt', 'I like mathematics' and 'Learning math is easier when I can work together'. For girls, there is a significant effect of time for the item 'I understand what the teacher wants me to achieve' (p=0.002). This result indicates that especially girls understand more what the teacher wants them to achieve, after the activity than before.

Post-item 'I have used math in the project'

In the posttest there was an additional item that investigated if children were aware of the fact that they were doing mathematics in the project (item 'I have used math in the project'). 77,63% of the children reported the third or fourth star that indicates that about ¾ of the children was aware that they were doing math. There's no significant difference between girls and boys (p=0.56).

5. Conclusion

In this research project we pointed out the idea that STEM education can play an important role to learn the more difficult math concepts. This is because, an integrated STEM approach is characterized by learning from action within meaningful contexts which are relevant for children. Using meaningful STEM-context in order to tackle more abstract mathematical concepts ensure that children understand mathematics better.

We wanted to improve teaching mathematics through a STEM approach by exchanging, selecting and developing good practices in which especially math concepts are integrated in STEM in such a way that these concepts become attractive and more easy to learn for children. In the project 20 STEM good practices with a focus on math were developed. In the activities all the elements of the didactical model were integrated. Pilot teachers were trained and tested the activities. In joint staff training events experiences were shared and teachers learned from each other. This coaching trajectory emphasizes the role of the teachers in STEM-education.

On the web platform www.stem4math.eu the didactical model and good practices are available. The web platform also offers concrete teaching guidelines for implementing good practices into the classroom practice.

For the 9-12 years old we find evidence that children perceive math more useful after the activity than before. The activity had a positive effect on the perceived usefulness of mathematics, especially with boys. From this study we can conclude that 9-12 years old children understand better the role of mathematics in daily life after participating a STEM4MATH-activity. On the other hand, children report low scores in enjoyment of mathematics. Children aren't interested in learning math, don't look forward to the mathematics lesson… For the 6-8 years old, we find slightly different results. Children like mathematics more after the activity than before and they report more that learning math is easier when they can work together. In line with previous research, we see a shift in attitudes towards mathematics when children getting older (Morrell & Lederman, 1998; Barmby, Kind & Jones, 2008). Attitudes towards math are decreasing with age. We put forward from this study the need to concentrate on improving children's experience of math in school. Teachers must be aware of this shift and have an important role in enthusing pupils in mathematics (Osborne, Simon & Collins, 2003).

For usefulness of mathematics in everyday life for the 6-8 years old children, there is no difference after the activity. 6-8 years old children don't connect the STEM4MATH-activity with the use of math in daily life. In both age groups, children are not always aware that they are doing mathematics in the STEM4MATH-activities. It is the role of the teacher to point this out to the children. In daily life, you need mathematics so it's important that children make the link with their everyday life. Previous research indicates that children of 8-9 years old are unable to make connections between mathematics in class and its practical uses in daily life (Ashby, 2009). This research also points out that teachers have an important role to explain this link. Though, understanding the usefulness of mathematics doesn't imply that children like mathematics. Teachers can also have an impact there and help children to improve their love for math.

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