REPORT

DEFINING A GOOD PRACTICE IN STEM EDUCATION WITHIN A FRAMEWORK OF MARCH PROJECT

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SUMMARY

Europe faces a challenge of skilled personnel in STEM, which is a consequence of interest in science studies by secondary education graduates. Drawing on the project MARCH, which seeks to address a number of educational challenges that are linked to perceptions on science and existing science education methods and practices in secondary schools across Europe, insights this report is providing an analysis of good practices in secondary STEM education. Combining internal statistical and analytic generalization report reveals the very core features of good practice. Furthermore, a set of recommendations for STEM education in four areas: values, teachers' professional development, cooperation and formal education is provided.

KEY CONCLUSIONS

The features of STEM good practice address current concerns in STEM education: the need of modern pedagogical ideas, the need of effective education methods, and the need to link educational content to “real” life. Therefore, if we are aiming to foster students’ attraction to STEM, we should go back to few important insights:

- Good practices target 14–18 age group. This is a group of particular interest for tertiary education institutions and labor market. It is a target group for PISA surveys as well. Taking into consideration the fact that teaching impact becomes tangible in the long-term, we should think how to reach broader age groups in STEM education, i.e. from the earlier age.

- Although STEM good practices tend to develop few intellect types, we should consider how to develop various intellect types in STEM. For example, although spatial thinking is indispensable in STEM, visual-spatial intellect type was not very dominant in selected examples. Moreover, if we are approaching STEM through higher level of integration, development of various intellect types is even more reasonable.

- Good practices communicate the idea of developing an individual, who participates in society through creative application of STEM knowledge. Therefore, it implies the need for more complex level of integration in STEM education and even incorporation of other disciplines (i.e. transition from STEM to STEAM). In addition, it implies on a peculiar value system, which considers the common good in STEM education, i.e. it is reaching out for scientific knowledge responsibility.

The last observation is particularly important, because it fits in the context of sustainability and innovations. As responsible scientific knowledge (responsible research and innovations) is at the core to realize sustainable development, the idea articulated in good practices indicates that we have positive examples in STEM education, which are addressing global challenges through secondary education.

KEY RECOMMENDATIONS

We propose recommendations in four areas: values, teachers' professional development, cooperation and formal education for teachers, policy-makers and education related institutions and stakeholders how to make science more attractive at schools.

Recommendations for teachers:

- To communicate about the values in STEM, i.e. STEM responsibility and participation in society through STEM results' dissemination to community.
- To involve students in STEM learning planning, expand the use of teaching methods tailored to more various intellect types' development.
- To involve community in STEM activities.

Recommendations for policy makers:

- To initiate discussions on the need to include an aspect of virtues in STEM education curricula and think of STEAM as means to transmit values in STEM.
- To support teachers' professional development in STEM through purposive programmes and/or initiatives.
- To create more favorable conditions for STEM activities in formal education.
- To support cooperation with community, institutions and organizations for STEM education.

Recommendations for education related institutions and stakeholders:

- To share out-of-school knowledge and institutional support for students and participate in a dialogue on aspect of virtues in STEM education curricula and the relevance of STEAM by providing justified expertise on this issue.
- To organize teachers' professional development activities with a focus on STEM education methodology (including complexities of integration, variety of plausible methods in STEM teaching, participation of students in learning planning).
- To communicate a clear message to schools about the openness and possibilities for cooperation.

INTRODUCTION

We are living in a world of intellectual, human and material flows, constant technological advancement driven by the rules of global competition. States' involvement in this game contribute to the quest for creative local and global problem solving, which is a crucial prerequisite for innovations, and to development of societies. Meanwhile the countries, whose involvement in global competition is limited or unsuccessful due to various internal and external factors, hamper their own prospects for innovations and participation in global reality and therefore sustains uneven development.[2]

Such gap creates a big challenge in times of sustainability paradigm. On 25 September 2015 United Nations members adopted Sustainable Development Goals (SDG) to address global issues like poverty, the need to protect the planet, and ensure prosperity for all[3]. All these issues are effects of global competition and states' part in it. The emphasis of agenda on such issues forms a clear demand for innovations, especially those from STEM (*Science, technologies, engineering and mathematics)* fields.

Indeed, a very recent European Commission report emphasizes the importance of science in understanding the world, managing risks, guiding technological development and planning the future[4]. Needless to say, there is a need for human capital, which is competent and capable to involve in science "industry".

However, Europe faces a challenge of skilled personnel in STEM. The challenge lies in growing demand and insufficient supply. The question of supply is particularly related to tertiary education institutions, which play a pivotal role when it comes to transition to labor market[5]. Their ability to provide high quality training is significant for a smooth graduates' transition. Obviously various education institutions across European countries and even within the same country differ from each other by the quality of training. This contributes to the problem of insufficient supply of STEM personnel, because low quality training is incapable to prepare skilled graduates.

[2] No robust, published research found to address the statements in this paragraph.

[3] United Nations (2015) Transforming our world: the 2030 Agenda for Sustainable Development, Resolution 70/1.

[4] European Commission (2015) "Science education for responsible citizenship", Luxembourg: Publications office of the European Union, p. 15.

[5] *Katsomitros, A. (UNDATED) "The Global Race for STEM Skills", The Observatory on Borderless Higher Education, Available online: http://www.obhe.ac.uk/newsletters/borderless_report_january_2013/global_race_for_stem_skills [Accessed 20th July, 2016]*

Nevertheless, a bigger issue is declining interest in science studies and related careers *per se*[6]. Even though tertiary education institutions might demonstrate a full training capacity, if there is no interest in joining the institution for training, it will not be able to form a critical mass of graduates for STEM labor market.

Thus, we are obliged to focus our attention to secondary education institutions as a key to unlock STEM potential and we should ask questions about the state of, the challenges to STEM education. And more importantly, to look: a) how do we approach STEM in practice; b) which best practices in STEM can we offer.

Taking into consideration everything discussed, this report is relevant and timely as it is linked to the current issues and aims to address the questions related to STEM practice in secondary education. The report sheds a light by looking at European experiences from 7 countries, which were collected during MARCH (*MAke science Real in sCHools*) project. Building on these experiences, recommendations on how to implement and make the most of them are proposed.

1. STATE OF AND CHALLENGES TO STEM EDUCATION

The state of STEM education across Europe could be described as diverse in terms of their performance in science. Eurydice report highlights, that the rate of low achievers was about 15 per cent in a number of European countries, like Germany, Ireland, Latvia, Hungary, the Netherlands, Slovenia, the UK and Liechtenstein. However, Bulgarian and Romanian experience in science performance is radically opposite – about 40 per cent of students in those countries did not reach the proficiency Level 2[7]. Such proportions testify divergent trends in science education within Europe and calls for a closer look at secondary education.

Previous analysis suggests important challenges arising to STEM education. Firstly, it is more focused on theory than on "hands-on" practices. Secondly, the use of modern methodologies, like out of school science-related "hands-on" activities, for attracting students to STEM is limited. Thirdly, secondary schools are more closely linked to education and science-based organizations than to industry[8]. These tendencies are related to a broader set of problems like provision of critical mass of students attracted to STEM field and aiming for involvement in scientific industry, but current tendencies in STEM education are setting a path incapable to address the latter problems. Thus, it is a strong impetus to

[6] European Commission (2015) "Science education for responsible citizenship", Luxembourg: Publications office of the European Union, p. 18.

[7] European Commission (2011) "Science education in Europe: national policies, practices and research", Brussels: Education, Audiovisual and Culture Executive Agency.

[8] Galev T. (2015) "The State of the Art in Science Education: Results of MA.R.CH. Empirical studies", Sofia: Bulgarian Academy of Sciences.

rethink current practices in STEM education and think of innovative ways to approach it, i.e. to develop modern pedagogical ideas; to implement effective education methods; to search links to "real" life in educational content.

2. MARCH PROJECT OVERVIEW

MARCH project is an international 3-year project supported by the Lifelong Learning Programme of the European Commission, which involves partners from 7 European countries: the UK, Greece, Germany, Serbia, Lithuania, Bulgaria and Portugal. Altogether, partners form a network, which brings together key players in the field of science education, science communication and relevant policies, who share a common concern with science education and motivation to improve it.

MARCH project seeks to address a number of educational challenges that are linked to perceptions on science and existing science education methods and practices in secondary schools across Europe: lack of effective educational methods; shortage of well-qualified science teachers capable of providing a positive experience with learning science in schools; need for linking science educational content to 'real' life; need for a joint European approach.

In the context of these challenges, the project aims to:

1. provide an overview of Science Education in secondary schools through scoping and comparative analysis and promote the development of needs analysis;

2. assist in the networking and content support of projects and network that are thematically related and funded by Lifelong Learning Programme of the European Commission;

3. promote the implementation of innovative methodologies, insights and best practices in science education that allow dynamic interaction between teachers, young people, researchers and other experts in science education and science communication.

The current report is concerned with the third objective: more specifically, with good practices in STEM education in secondary education across 7 European countries.

Within a framework of MARCH project participating countries aimed to identify good practices, exchange of ideas on these practices with key actors in local and international Innovation Swap Workshops and building on the insights from international Innovation Swap Workshops set a solid ground for the pilot in secondary schools.

In total, 7 local workshops (LW) were carried out in each project country: Lithuania, Germany, Portugal, Serbia, Greece, the UK and Bulgaria to bring teachers, pupils and researchers together to focus on methodologies and educational content that could make science teaching exciting and attractive to young people (e.g. digital content, social aspects of science, researchers as role models, arts and science).

Upon conclusion of each local workshop, 3 international Innovation Swap Workshops (ISW) took place in Lithuania, Portugal and Bulgaria. In Lithuania, innovative practices tested in Lithuania and Germany were presented and discussed, in Portugal it was practices tested in Portugal and the UK, and lastly in Bulgaria, the focus was on practices tested in Bulgaria, Greece and Serbia.

During the period February 2015–October 2015, when LW and ISW took place, 22 good practices in STEM education[9] were presented and discussed among teachers, pupils, researchers and other stakeholders.

19th February 2015	20th February 2015	6th March (GR, PT) and 6th–7th March (RS) 2015	24–25th March 2015	17th April 2015	8th May 2015	19th May 2015	6th October 2015
LW Lithuania	LW Germany	LW Greece, Portugal, Serbia	ISW Lithuania	LW UK	ISW Portugal	LW Bulgaria	ISW Portugal

The constellation of these examples across project countries forms a picture of good practice as a whole and perfectly captures the issue of effective educational methods. The empirical knowledge, which is accumulated from international experiences, allows us to think of recurrent commonalities and to develop a good practice recipe for implementation. If we are building on 22 cases, this leads to several methodological questions: how to conceptualize, collect and analyze those cases?

[9] QR codes to 22 good practices are provided in annex.

FRAMEWORK

Since this report is intended to showcase good practices in STEM education in 7 countries: the UK, Greece, Germany, Serbia, Lithuania, Bulgaria and Portugal and using comparative methodology to present international experiences and distill common features to define a good practice, we should take a brief look at procedural logic behind.

1. CONCEPTUALIZATION AND COLLECTION OF GOOD PRACTICES IN STEM EDUCATION

MARCH partners are sharing a common vision to discover what a good practice in STEM education actually is and what really works with students in secondary schools and makes it attractive. In order to uncover the veil of the unknown, each MARCH partner collected a set of 3 good practice examples (except Germany, which provided 4 examples) from their countries, to form a basis for the definition of good practice in STEM education across MARCH partners. Each set of 3 good practices was chosen based on its attractiveness to students. Partners applied various selection procedures such as: self-selection, purposive selection, competitive selection or combination of few usually followed by education expert evaluations.

In Lithuania, emerging practices using innovative technologies or innovative pedagogic approaches were selected to be tested by pupils and teachers. The process was observed and evaluated by researchers, which has led to leaving the most prospective practices. Germany has a wide range of good practices – therefore the most innovative, popular practices were selected by partners. Greece has followed a combination of self-selection and expert evaluation selection procedure: innovative, creative, learner-centered and attractive methodologies submitted by teachers were evaluated and shortlisted by education experts. Partners from Portugal selected best practices submitted by educators from schools involved in the project "Sustainable City" and teachers experienced in innovative STEM teaching approaches. Serbia organized competitive selection procedure and have chosen practices that have scored the best across criteria: innovativeness, level of interactivity with students, balance between cost and impact of proposed practices, the possibility to be implemented in other EU partner countries. UK used a purposeful sampling approach and selected project based practices fitting in with the sustainable cities topic. Bulgaria shortlisted good innovative practices from those provided by teachers already contacted during MARCH previous activities and by national non-governmental science education and communication organizations. A more detailed selection procedure and supporting evidence for each country is provided in annex (table 10).

2. ANALYSIS OF GOOD PRACTICES IN STEM EDUCATION

We designed the framework for cases as an open-ended form each partner had to fill in electronically and circulate back to coordinating institution (Education development centre, Lithuania). We asked partners to:

- briefly describe selected good practice;
- indicate targeted level (or age group);
- specify advantages: why is it innovative/attractive to students;
- provide teacher's opinion on good practices;
- provide student's opinion on good practices;
- specify difficulties for implementation.

All answers were supposed to give a general picture on the practice itself and provide a brief evaluation from a perspective of both actors - teachers and students - involved in educational process. Further, we used the content provided by partners for analysis. It combined analytic generalization with internal statistical generalization[10]. Such combination allowed us to make inferences on extracted information within MARCH project framework and to validate how selected cases 'fit' with general constructs in education.

For the purposes of the analysis, we focused on 4 major "blocks": 1) students' perceived advantages of selected good practice (internal statistical generalization); 2) teachers' perceived advantages of selected good practice (internal statistical generalization); 3) theoretic foundations of good practice (analytic generalization) and 4) educational outcomes (analytic generalization).

For the first 2 "blocks" we identified emerging advantages in practices, made a list and did a double validation to check if codes were assigned correctly. After looking carefully at the final list, we did the secondary coding to identify the plausible advantages, which were not mentioned but could be theoretically inferred from the whole description. Thus, we got a mosaic of empirical evidence and theoretic implications characterizing good practice.

For the third "block" we focused on 3 dimensions: 1) learning theory[11], 2) type of intellect (according to Gardner) and 3) type of integration. Each of 22 practices was assessed and double validated to identify how the case fits in with each dimension. Learning theory was chosen, because it covers and allows

[10] Onwuegbuzie A. J., Leech N. L. (2007) "Sampling Designs in Qualitative Research: Making the Sampling Process More Public", The Qualitative Report 12-2, p. 240-2.

[11] Summary of learning theories: Ashworth F. et al. (2004) "Learning Theories and Higher-Education", Level 3, Issue 2.

revealing the fundamentals of the practice: how it understands the purpose of education and how it pictures the learner. Type of intellect was chosen with an intention to identify which learner it is tailored to on the one hand and what impact on intelligence does it aim for on the other hand. Finally, the type of integration was chosen as a very important aspect in relation to STEM education, because it is at the core of research and policy in this field. I.e. we can approach STEM as separate disciplines or we can approach thereof through the efforts of integration to foster the learning and motivation[12]. The table 1 below summarizes the dimensions and their components.

Table 1. Dimensions and components of good practice theoretic foundations.

<table>
<tr><th>LEARNING THEORY</th><th>TYPE OF INTELLECT (GARDNER)</th><th>TYPE OF INTEGRATION</th><th>COMPETENCES</th></tr>
<tr><td rowspan="2">BEHAVIORISM</td><td>Musical-Rhythmic</td><td>Subject</td><td rowspan="3">Mathematical competence and basic competences in science and technology; Digital competence</td></tr>
<tr><td>Bodily-Kinesthetic</td><td>Parallel</td></tr>
<tr><td rowspan="2">COGNITIVISM</td><td>Logical-Mathematical</td><td>Multidisciplinary</td></tr>
<tr><td>Verbal-Linguistic</td><td rowspan="2">Interdisciplinary</td><td>Creativity</td></tr>
<tr><td rowspan="2">CONSTRUCTIVISM</td><td>Visual-Spatial</td><td rowspan="2">Social and civic competences</td></tr>
<tr><td>Interpersonal</td><td rowspan="2">Integrated day</td></tr>
<tr><td>HUMANISM</td><td>Intrapersonal</td><td>Communication</td></tr>
</table>

For the fourth “block” we focused on educational outcomes the good practice is generating. We chose to define outcomes through competences, which are being developed by good practice. To identify the impact on competences development, we assessed lists of advantages identified by students and teachers (the first and the second analysis block) and assigned which competence it is related to. The European Reference Framework of Key Competences defined in the Recommendation on key competences for lifelong learning and competence definitions served as a benchmark for assessment[13].

[12] Committee on Integrated STEM Education (2014) “STEM Integration in K-12 Education: Status, Prospects and an Agenda for Research”, Honey M. et al. (ed.), The National Academies Press: Washington, D. C., p. 143-4.

[13] Definitions of key competences: *http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV%3Ac11090*

GOOD PRACTICE RECIPE

Collection of good practices in STEM education allowed to get a very real glimpse into the state of good practice affairs in STEM education in secondary schools and revealed recurrent features. This allowed us to answer key questions: what does STEM practice aim for? Who does it target? How does it approach STEM in practical contexts? How is it being assessed by teachers and students?

In this section of the report we will take a brief look at good practices from each country, provide the results of the analysis and discuss how we could approach a good practice in STEM education for implementation.

1. THE CONSTELLATION OF GOOD PRACTICES IN STEM EDUCATION

Experiences of good practice in each of 7 MARCH countries vary from those based on combination of classical learning theories to those of recent learning theories; from those of narrowing a scope to few intellect types to those of targeting almost all intellect types; from those of simplified integration to those of more complex integration (for each practice description see QR codes in the annex).

Selected examples from Lithuania are: *Robotics, 3D printers* and *Theatre Sports*. These practices combine constructivism and humanism. Basically it means that education process is directed towards the acquisition of knowledge through individual empirical experiences. However, if humanistic orientation is taken into account, the knowledge is not a means to an end, but rather a facilitator in a quest of individual's potential fulfillment. Lithuanian good practice cases show that on the practical level it is realized through interdisciplinary integration and development of logical-mathematical, visual-spatial and interpersonal intellect. The development of these intellect types are reflected in students' assessment: the possibility to create, design, model and improve makes these practices attractive to students. Whilst teachers focus on constructivist advantages: new and STEM knowledge.

The set of good practices from Germany include: *Flip the Classroom, Nature Inspires - Bionics, Junior Science Cafe, and Big Bang Theory*. Unlike in Lithuanian set, behaviorism and cognitivism are behind these examples. Therefore, education process is driven by an aim to help the learner to learn. In this context behaviorism approach contributes through instruments to modify behavior towards the desired end - effective learning. German cases reveal that it best works if STEM is being taught through subject integration and develops logical-mathematical intellect. It is reflected in student's tendency to rationalize learning advantages (for example, meeting scientists, closeness to industry and real life) by making connections with practical side of education process. Teachers mostly highlight attitudinal, motivation changes related to implementation of selected good practice in STEM education.

Portugal identified *Learning outside the classroom (Woodlands), Internship programme for young students, Inquiry-based learning (school activities under the topic Sustainable Cities)*. These good practices in STEM education strongly link constructivism and humanism. In this case the success lies in facilitation of empirical experiences to fulfill individual potential of each student. Since the center of attention in education process is a unique learner, it requires organizing teaching in complex way. Interdisciplinary way of integration when approaching STEM is used in Portugal examples. These learning experiences develop logical-mathematical, verbal-linguistic, interpersonal intellects. For students they are attractive, because of unconventional and innovative elements embedded in selected good practices: going out, work in different way or with new equipment. Teachers observe the impact on each student's learning and motivation, attitudes to science.

The UK selected good practices are: *National Science Learning Centre, CHREST Awards and STEM Ambassadors*. These practices build on behaviorism, aiming for transformative change in behavior towards interest in STEM. At the very core of this change are educators and role models from STEM fields, who facilitate interest through subject integration and develop verbal-linguistic and musical-rhythmic types of intellect. Teachers outline attitudinal changes towards science and career choices as main advantages of selected good practices. Students consider these practices as useful for high-achievers in science. Thus, both opinions wrap-up STEM learning based on behaviorism in a very nice way.

Bulgarian set of good practices in STEM education consists of: *Electronic Platform for Science Education in Secondary Schools, Use of Online and Remote Labs, Learning by Doing Using ICT*. The strong online character of these good practices is mainly based on ideas of behavioral learning theories. Again, as in other partner countries, who are focusing on behavioral approach in STEM teaching, Bulgarian examples testify for transformative action towards learners. STEM teaching appears here through subject integration emphasizing logical-mathematical intellect development. Selected good practices are attractive for students, because of fun, novelty and modernity it brings into learning process, for this reason they distinguish such aspects as: use of ICT, work in different way or with new equipment, overall coolness. Teachers outline the empowering behavioral aspect of good practices, i.e. encouragement of students, creativity, learning to learn.

School Lab, *Light Pollution*, *Make Energy Real @ Education (MERE)* are identified as good practices in STEM education in Greece. The overall objective they focus on is constructivism's idea of facilitating experiential learning. This is reflected by the fact, that selected good practices acknowledge the diversity of experiences and information processing. Therefore, they are targeting various types of intellect like: verbal-linguistic, interpersonal, logical-mathematical and visual-spatial. STEM teaching is organized through higher level of integration - multidisciplinary and interdisciplinary. It is attractive for students, because it allows experiencing learning through hands-on activities working in a team. The main advantages of good practices stressed by teachers are those related to new knowledge construction through creativity and inquiry, which later on transcends to students' motivation and attitudes towards science.

Finally, the collection of 22 good practices in STEM education is completed with 3 Serbian good practices: *Physics Winter Camp, Flipped (Biology) Classroom* and *Magic Village,* which are building on constructivism like in Greece. Again, experiential learning as the main purpose of STEM education is being realized through several intellects development: logical-mathematical, verbal-linguistic and interpersonal. Selected STEM good practices from Serbia are aims to provide conditions for knowledge construction through integrated day (the highest level of integration among all countries cases), which provides a whole bunch of experiences for the learner. Consequently, students find these good practices rewarding as they bring innovative and fun aspects to the whole learning experience through teamwork and hand-on activities. Meanwhile teachers outline empowering aspects of selected good practices such as: encouragement of students and promotion of their responsibilities through communication.

2. OVERARCHING INGREDIENTS OF GOOD PRACTICE IN STEM EDUCATION

A close look at each country set of good practices allowed us to understand the variety of each component. Intuitively some overlapping elements and recurrent themes across the countries might be noticed. For this reason, we can argue that it indicates some recurrent patterns of what is working in STEM education and what makes STEM learning attractive for students.

If we look into theoretic foundations which could be identified from empirical evidence (blue color in the table 2) and inferred by coders (green color in the table 2), the variance across theoretic approaches on teaching is evident. Good practices cluster around humanism and constructivism approach. The clustering around more recent learning theories means a strong focus of good practices on active learner. The learner, who is recognized as individual human being and participates in construction of new knowledge and new meaning through a process enabling to have a very unique experience.

The focus on and acknowledgement of individual uniqueness correlates with the learner these good practices are tailored for. Each good practice develops 1–5 types of intellect with logical-mathematical, verbal-linguistic and interpersonal intellect types the most common among all intellect types developed. Such scope still indicates the recognition of learners' diversity. Meanwhile the types being developed in good practices provide a framework to form a logical-mathematical individual capable to work and communicate with others.

The experience of 7 countries reveals a tendency towards more difficult integration in STEM teaching, although subject integration strongly persists. This is a bit counterintuitive to the fact that inquiry-based and creative teaching methods (a basis to sustain individual activity) dominate among good practices. A strong persistence on subject integration might show a lack of understanding of STEM as a whole, which is being advocated for in recent European Commission report "Science education for responsible citizenship".

Table 2. Theoretical foundations of MARCH good practice.

THEORETICAL FOUNDATIONS OF MARCH GOOD PRACTICE
TYPE OF INTELLECT TO BE DEVELOPED
Musical-Rhythmic
Bodily-Kinesthetic
Logical-Mathematical
Verbal-Linguistic
Visual-Spatial
Interpersonal
Intrapersonal
TYPE OF INTEGRATION IN GOOD PRACTICE
Subject
Parallel
Multidisciplinary
Interdisciplinary
Integrated day
LEARNING THEORIES
Behaviorism
Cognitivism
Constructivism
Humanism

Students' narrative (table 3, where blue – empirical evidence, green – inferred) about attractiveness of good practices reveal three major trends: STEM content, process and STEM purpose related. Students across the countries find the content connection to real life and the possibility to choose the topic of their interest as very appealing. The fact that STEM learning within selected cases is being approached in unconventional, fun, interesting way and allow students to work differently than usual is another important factor. They perceive the whole experience as rewarding with the possibility to learn something new and put a great value to acquisition of skills needed for science. Therefore, it implies that demystifying STEM and loosening formalized approach to STEM teaching in selected good practices are the most important key components from students' point of view.

We consider it is worthwhile to mention the domain of good practice as well. Informal education dominates among good practices. Thus, it seems formal education systems and culture is too inflexible to accommodate the teaching logic behind the good practices.

Table 3. Advantages of good practice according to students.

ADVANTAGES OF GOOD PRACTICE ACCORDING TO STUDENTS
Testing in practice
Creating
Designing
Modeling
Improving
Teamwork
Break stereotypes
Combines nature & Technology
Close to industry
Choosing topics
Meeting scientists
Connection with real life
Learning something new
Work in different way
Making presentations
Hands – on
Make own experiments
Work with new equipment
Skills needed for science
Supply for high achievers
Independent overview
Fun, interesting, "cool way"
Going out
Use of ICT

GOOD PRACTICE DOMAIN																						
Formal education																						
Informal education																						

Teachers' assessment of good practices across 7 countries (table 4, where blue – empirical evidence, green – inferred) highlight impacts on the learner. On the one hand, good practices broaden the knowledge of learners. On the other hand, they change learners' perspective on science, facilitate their active involvement and empower them to engage in communication on STEM topics. These observations of teachers provide important evidence for active learner-centered approach in good practices.

Table 4. Advantages of good practice according to teachers.

ADVANTAGES OF GOOD PRACTICE ACCORDING TO TEACHERS																						
STEaM Integration																						
STEM knowledge																						
New knowledge																						
Local problem solving																						
Environment changes																						
Initiative																						
Creativity																						
Collaborative problem solving																						
Teamwork																						
Communication																						
Inquiry-based																						
Improvisation skills																						
Links with formal curriculum																						
Students responsibilities																						
Motivation / attitudes to science																						
Encouraging students																						
Learning to learn																						
Career choices																						
Role models																						
Experiments in virtual labs																						
Each students learning																						

Students and teachers' narrative on good practice advantages reveals an impact on competence development. Those of actually experienced by students (table 5) and those identified by teachers (table 6). Both cover areas of creativity, communication, STMD competences and social and civic competences. Students articulate practice advantages through impact on STMD competences and creativity, whereas teachers communicate impacts on basic, social and civic competences. The combination of both viewpoints gives an important insight about the purpose of STEM education. STMD competence relates to field specific knowledge and its application. Creativity might be interpreted in procedural terms as it can sustain different use of field specific knowledge. Civic and social competence relates to the value system and what the knowledge could be used for. Therefore, competences developed by good practices in STEM are actually developing an individual, who aims participation in society through creative application of STEM knowledge.

Table 5. Advantages of good practice according to students and impacts on competence development.

Advantages of good practice according to students	Competences		
Testing in practice	STMD competences		
Creating	Creativity		
Designing	Creativity		
Modelling	Creativity		
Improving	Creativity		
Teamwork	Social and civic competences	Communication	
Break stereotypes	Creativity	Social and civic competences	
Combines nature & Technology	Creativity	Social and civic competences	
Close to industry	STMD competences		
Choosing topics	STMD competences		
Meeting scientists	STMD competences	Social and civic competences	Communication
Connection with real life	STMD competences	Social and civic competences	
Learning something new	STMD competences		
Work in different way	Creativity	Social and civic competences	
Making presentations	Communication	Social and civic competences	
Hands – on	STMD competences		
Make own experiments	Creativity	STMD competences	
Work with new equipment	STMD competences		
Skills needed for science	STMD competences		

Supply for high achievers	STMD competences	
Independent overview	Communication	Social and civic competences
Fun, interesting, "cool way"	Communication	STMD competences
Going out	Creativity	STMD competences
Use of ICT	STMD competences	

Table 6. Advantages of good practice according to teachers and impacts on competence development.

Advantages of good practice according to teachers	Competences		
STEaM Integration	STMD competences		
STEM knowledge	STMD competences		
New knowledge	STMD competences		
Local problem solving	Social and civic competences	STMD competences	Creativity
Environment changes	Social and civic competences	STMD competences	
Initiative	Social and civic competences	Communication	
Creativity	Creativity		
Collaborative problem solving	Social and civic competences	Communication	
Teamwork	Social and civic competences	Communication	
Communication	Communication		
Inquiry-based	STMD competences		
Improvisation skills	Creativity		
Links with formal curriculum	STMD competences		
Students responsibilities	Social and civic competences		
Motivation / attitudes to science	Social and civic competences		
Encouraging students	Social and civic competences		
Learning to learn	Social and civic competences	STMD competences	
Career choices	Social and civic competences	STMD competences	
Role models	Social and civic competences	STMD competences	Creativity
Experiments in virtual labs	STMD competences		
Each students learning	STMD competences		

To sum up, the findings from 22 examples in STEM education collected by MARCH partners, the definition of good practice in STEM education within MARCH project framework could be proposed. The good practice in STEM education has a set of following features:

- combines constructivism and humanism;
- develops logical-mathematical, verbal-linguistic and interpersonal intellect types;
- aims for higher level of integration;
- combines creative and inquiry-based methods;
- targets 14-18 age group at informal education;
- is performed in school setting.[14]

STEM education within a framework of MARCH project is oriented towards an individual, who aims participation in society through creative application of STEM knowledge in relation to SDG adopted by UN.

3. APPROACHING A GOOD PRACTICE IN STEM EDUCATION FOR IMPLEMENTATION

The general definition of good practice in STEM education provides a very general recipe of what is working in practical education settings. However, to proceed with good practice implementation on the basis of the collection of 22 good practices, one should choose a way of approaching those practices. Selecting and piloting good practice in MARCH project is one of the most important activities. We will propose four possible ways, how to select good practice for implementation:

1. Selecting on a basis of *good practice according to students*. This strategy could be used if we want to put a maximum emphasis on students' needs, expectations and desires in STEM. The characteristics of good practice outlined by students in 7 countries could be used in discussions with students, who will participate in piloting, to set the most important characteristics. These characteristics could be used as guideline to select a good practice of interest from the whole collection.

2. Selecting on a basis of *good practice according to teachers*. This strategy could be used if we want to put a maximum emphasis to teachers' objectives in STEM education. Like in previous strategy, the characteristics of good practice outlined by teachers in 7 countries could be used in discussions with teachers, who will participate in piloting, to set the most important characteristics. These

[14] No robust, published research found to address the statements in this paragraph.

characteristics could be used as guideline to select a good practice of interest from the whole collection.

3. Selecting on *theoretical foundations of good practice*. This strategy could be used if we want to put a maximum emphasis to sophisticated, scientifically based STEM education and links to national education policies. Theoretical foundations of good practice in 7 countries could be used in discussions with relevant players, who will participate in coordinating the piloting, to decide on most important characteristics. These characteristics could be used as a guideline to select a good practice of interest from the whole collection.

4. Selection on basis of *theoretical foundations, students' and teachers' insights*. This strategy could be used if we want to put a maximum emphasis to participatory process of decision-making. Theoretical foundations, students' and teachers' insights on good practice in 7 countries could form a solid background in discussions with interest groups, who will provide necessary support, coordinate and participate in piloting, to decide on most important characteristics. These characteristics could be used as guideline to select a good practice of interest from the whole collection.

Each of these ways is plausible and is good in its own ways. We proposed the choice on one or on three analytical blocks. It is possible to select on two analytical blocks as well. However, one should take in mind, that the choice will largely depend which actors it will be focused on. Nevertheless, each of these selection strategies could still aim to reflect a very core of the whole MARCH good practice discourse that is: STEM education within a framework of MARCH project is oriented towards an individual, who aims participation in society through creative application of STEM knowledge in relation to SDG adopted by UN.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of all good practices in STEM education revealed that practical examples from 7 countries are very diverse indeed. Nevertheless, despite the differences, we identified recurrent elements of these practices and which form a basis to define a good practice in STEM education within a framework of MARCH project.

The good practice in MARCH is very oriented towards empowerment of active learner as it combines constructivism with humanism. It acknowledges different ways of learning process through development of logical-mathematical, verbal-linguistic and interpersonal intellect types. It also aims to provide diverse learning experience and grasp the complexity of STEM through higher level of integration. This appears to be a MARCH recipe to attract students to STEM.

Putting the summarized features of STEM good practice into more global context, we should note that it addresses current concerns in STEM education: the need of modern pedagogical ideas, the need of effective education methods, and the need to link educational content to "real" life. Therefore, if we are aiming to foster students' attraction to STEM, we should go back to few important insights.

Good practices target 14-18 age group. This is a group of particular interest for tertiary education institutions and labor market. It is a target group for PISA surveys as well. Taking into consideration the fact that teaching impact becomes tangible in the long-term, we should think how to reach broader age groups in STEM education, i.e. from the earlier age.

Although STEM good practices tend to develop few intellect types, we should consider how to develop various intellect types in STEM. For example, Visual-Spatial, which appeared to be not very dominant in selected examples, although spatial thinking is indispensable in STEM. Moreover, if we are approaching STEM through higher level of integration, development of various intellect types is even more reasonable.

Good practices in MARCH communicate the idea of developing an individual, who participates in society through creative application of STEM knowledge. Therefore, it implies the need for more complex level of integration in STEM education and even incorporation of other disciplines besides science, technologies, engineering and mathematics (i.e. transition from STEM to STEAM). In addition, it implies on a peculiar value system, which considers the common good in STEM education, i.e. it is reaching out for scientific knowledge responsibility.

This last observation is particularly important, because it fits in the context of sustainability and innovations. As responsible scientific knowledge (responsible research and innovations) is at the core to realize sustainable development, the idea articulated in MARCH good practices indicates that we have positive examples in STEM education, which are addressing global challenges through secondary education.

Taking into consideration everything discussed, we propose the following recommendations for teachers, policy-makers and education related institutions and stakeholders how to make science more attractive at schools (table 7).

Table 7. General recommendations.

Area of recommendations	Recommendations for teachers	Recommendations for policy makers	Recommendations for education related institutions and stakeholders
Values in STEM education	To communicate about the values in STEM, i.e. STEM responsibility and participation in society through STEM results' dissemination to community.	To support students' innovation and participatory activities in STEM. To initiate discussions on the need to include an aspect of virtues in STEM education curricula and think of STEAM as means to transmit values in STEM.	To share out-of-school knowledge and institutional support for students. To participate in a dialogue on aspect of virtues in STEM education curricula and the relevance of STEAM by providing justified expertise on this issue.
Teachers' professional development in STEM education	To expand the use of teaching methods tailored to more various intellect types' development. To involve students in STEM learning planning.	To support teachers' professional development in STEM through purposive programmes and/or initiatives.	To organize teachers' professional development activities with a focus on STEM education methodology (including complexities of integration, variety of plausible methods in STEM teaching, participation of students in learning planning).
STEM in formal education	To organize more" hands-on" STEM activities.	To create more favorable conditions for STEM activities in formal education.	To review existing education curricula with a purpose of creating niche for more "hands-on" activities.
Cooperation in STEM education	To involve community in STEM activities.	To support cooperation with community, institutions and organizations for STEM education.	To communicate a clear message to schools about the openness and possibilities for cooperation.

RECOMMENDATIONS FOR THE PILOTING

22 best practices of seven European countries in STEAM education were selected and success factors described by teachers, students and researchers for the implementation encourages grass-roots discussion on science and sustainability issues and allows opportunities for policy-makers to share best practice with international counterparts.

The web resource of best practices provides basis for the open discussion and brings dynamic for STEAM educators, pupils and scientists to talk about the science, research, its impact on society for communicating with public audiences.

Picture 1. Recommendations for the piloting. Pilot implementation phases under the theme of Sustainable cities.

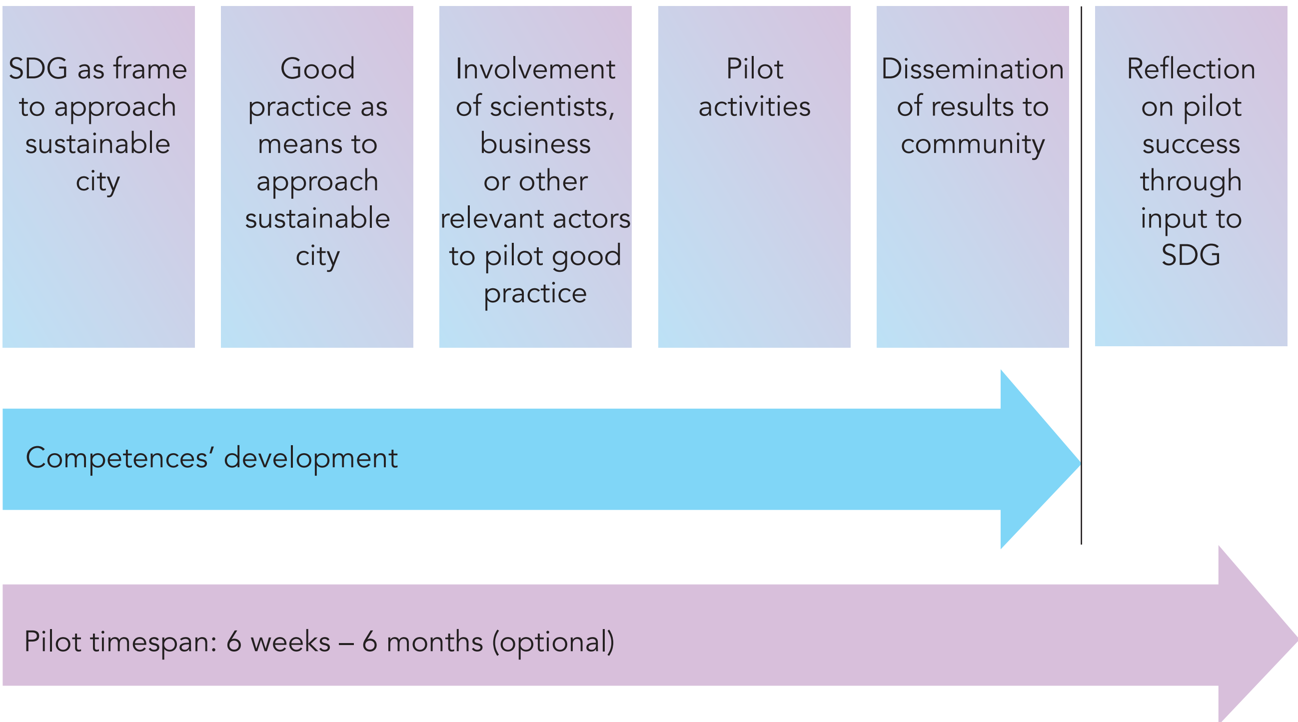

Table 8. Recommendations for piloting. Sustainable development goals.

SDG (Sustainable development goals)	
Goal 1	End poverty in all its forms everywhere
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3	Ensure healthy lives and promote well-being for all at all ages
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5	Achieve gender equality and empower all women and girls
Goal 6	Ensure availability and sustainable management of water and sanitation for all
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10	Reduce inequality within and among countries
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12	Ensure sustainable consumption and production patterns
Goal 13	Take urgent action to combat climate change and its impacts
Goal 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Table 9. Recommendations for the piloting. Competences developed through attractive activities for students.

Competences	Attractive activities for students	Description of the activities / Piloting details
STMD competencesw	Testing in practice	
	Close to industry	
	Choosing topics	
	Meeting scientists	
	Connection with real life	
	Learning something new	
	"Hands – on" experience	
	Make own experiments	
	Work with new equipment	
	Skills needed for science	
	Supply for high achievers	
	Fun, interesting, "cool way"	
	Going out	
	Use of ICT	
Social and civic competences	Teamwork	
	Break stereotypes	
	Combines nature & Technology	
	Meeting scientists	
	Connection with real life	
	Work in different way	
	Making presentations	
	Independent overview	

Competences	Attractive activities for students	Description of the activities / Piloting details
Creativity	Creating	
	Designing	
	Modelling	
	Improving	
	Break stereotypes	
	Combines nature & Technology	
	Work in different way	
	Make own experiments	
	Going out	
Communication	Teamwork	
	Meeting scientists	
	Making presentations	
	Independent overview	
	Fun, interesting, “cool way”	

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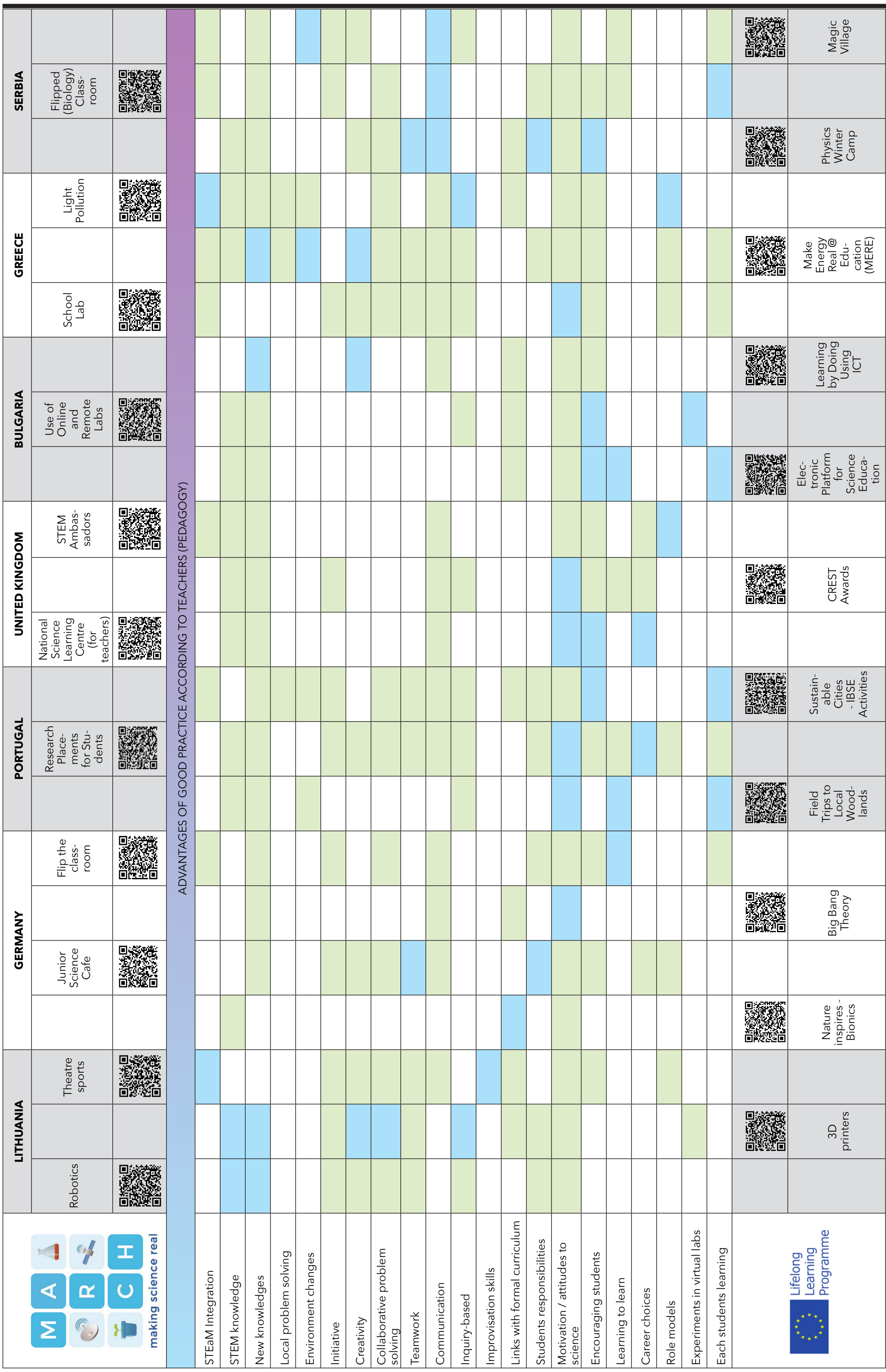
ANNEX

Picture 2. Advantages of good practice according to students and QR codes of good practices.

	LITHUANIA			GERMANY				PORTUGAL			UNITED KINGDOM			BULGARIA			GREECE			SERBIA		
MARCH making science real	Robotics	3D printers	Theatre sports	Nature inspires - Bionics	Junior Science Cafe	Big Bang Theory	Flip the classroom	Field Trips to Local Woodlands	Research Placements for Students	Sustainable Cities - IBSE Activities	National Science Learning Centre (for teachers)	CREST Awards	STEM Ambassadors	Electronic Platform for Science Education	Use of Online and Remote Labs	Learning by Doing Using ICT	School Lab	Make Energy Real@Education (MERE)	Light Pollution	Physics Winter Camp	Flipped (Biology) Classroom	Magic Village
ADVANTAGES OF GOOD PRACTICE ACCORDING TO STUDENTS (SKILLS AND COMPETENCES)																						
Testing in practice																						
Creating																						
Designing																						
Modelling																						
Improving																						
Teamwork																						
Break stereotypes																						
Combines nature & Technology																						
Close to industry																						
Choosing topics																						
Meeting scientists																						
Connection with real life																						
Learning something new																						
Work in different way																						
Making presentations																						
Hands - on																						
Make own experiments																						
Work with new equipment																						
Skills needed for science																						
Supply for high achievers																						
Independent overview																						
Fun, interesting, "cool way"																						
Going out																						
Use of ICT																						
GOOD PRACTICE DOMAIN																						
Formal education																						
Informal education																						

Lifelong Learning Programme

Picture 3. Advantages of good practice according to teachers and QR codes of good practices.



Picture 4. Theoretical foundations of good practice and QR codes of good practices.

MARCH making science real	LITHUANIA			GERMANY				PORTUGAL			UNITED KINGDOM			BULGARIA			GREECE			SERBIA		
	Robotics	3D printers	Theatre sports	Nature inspires - Bionics	Junior Science Cafe	Big Bang Theory	Flip the class-room	Field Trips to Local Wood-lands	Research Place-ments for Students	Sustai-nable Cities-IBSE Activities	National Science Learning Centre (for teachers)	CREST Awards	STEM Ambas-sadors	Elec-tronic Platform for Science Educa-tion	Use of Online and Remote Labs	Learning by Doing Using ICT	School Lab	Make Energy Real@ Educa-tion (MERE)	Light Pollution	Physics Winter Camp	Flipped (Biology) Class-room	Magic Village
THEORETICAL FOUNDATIONS OF MARCH GOOD PRACTICE																						
ADVANTAGES OF GOOD PRACTICE ACCORDING TO TEACHERS (PEDAGOGY)																						
Musical-Rhytmic																						
Bodily-Kinestetic																						
Logical-Mathematical																						
Verbal-Linguistic																						
Visual-Spatial																						
Interpersonal																						
Intrapersonal																						
TYPE OF INTEGRATION IN GOOD PRACTICE																						
Subject																						
Parallel																						
Multidisciplinary																						
Interdisciplinary																						
Integrated day																						
LEARNING THEORIES																						
Behaviorism																						
Cognitivism																						
Constructivism																						
Humanism																						
Role models																						
Experiments in virtual labs																						
Each students learning																						
Lifelong Learning Programme																						

Table 10. Good practices.

COUNTRY	SELECTION OF GOOD PRACTICE	GOOD PRACTICE	QR CODE	SUPPORTING EVIDENCE/MATERIAL
Lithuania	It was important for us to select activities to be led by business partners (as the report outlined a particular need to connect business and schools). When selecting partners, we aimed to ensure a variety of technologies and activities related to STEM disciplines. Supplementing selection criterions were: • the possibility to have a hands-on experience with technology; • possibility for teachers and pupils to participate in activities together; • innovativeness. All activities were evaluated by teachers and students in the survey. In addition to that, we invited researchers to observe participants and the whole process of experience and evaluate it in open-ended questionnaires. Later on, an expert focus group was organized to reflect upon the effectiveness and future potential of observed activities. Best evaluated activities were selected to put in MARCH list.	*Robotics*		**Other evidence:** Robotics in Education & Education in Robotics: Shifting Focus from Technology to Pedagogy: *http://edumotiva.eu/edumotiva/images/files/alimisis_RIE2012_paper.pdf* Evaluating the impact of robotics in education on pupils' skills and attitudes: *http://www.terecop.eu/TRTWR-RIE2014/files/00_WFr1/00_WFr1_13.pdf* *These proposed practices are fully supported by the following study (University of Warwick team):* *Sullivan, F. R. (2007) ,Robotics and Science Literacy: Thinking Skills, Science Process Skills and Systems Understanding', Journal of Research in Science Teaching, Vol. 45, No. 3, pp. 373-394*[15] *These proposed practices are moderately supported by the following study, but it focuses more on inspiring students through the running of the class as opposed to the development of actual STEM skills (University of Warwick team):* *Nemiro, J., Larriva, C. and Jawaharlal, M. (2015) 'Developing Creative Behaviour in Eliementary School Students with Robotics', The Journal of Creative Behaviour, Vol. 0, No. 0, pp. 1-28*[16] *Study offers partial support but focus is more on altering student attitudes rather than the development of STEM skills (University of Warwick team):* *Welch, A. and Huffman, D. (2011) 'The Effects of Robotics Competitions on High School Students' Attitudes Toward Science', School, Science and Mathematics, Vol. 111, No. 8, pp. 416-424*[17]
		3D printers		**Other evidence:** 3D printers in schools: uses in the curriculum. Enriching the teaching of STEM and design subjects report: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251439/3D_printers_in_schools.pdf* An Educational Framework for Digital Manufacturing in Schools: *http://online.liebertpub.com/doi/pdfplus/10.1089/3dp.2015.0009* *Offers full support but focus is on the use of 3D printers (discusses the use of 3D printers as a way of demonstrating and visualizing chemical structures), not research into how effective they are in STEM based learning (University of Warwick team):* Blauch, D. N. and Carroll, F. A. (2014) '3D Printers Can Provide an Added Dimension for Teaching Structure–Energy Relationships', *Journal of Chemical Education*, Vol. 91, pp. 1254–1256[18]

		Theatre sports		**Other evidence:** Integrating Art and Science in Undergraduate Education: *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3582565/* Theatre Sports and Competitive Dramatic Improvisation: *http://www.interactiveimprov.com/tspwb1hist.html* Science and theatre education: A cross-disciplinary approach of scientific ideas addressed to student teachers of early childhood education: *http://www.artsedsearch.org/summaries/science-and-theatre-education-a-cross-disciplinary-approach-of-scientific-ideas-addressed-to-student-teachers-of-early-childhood-education#sthash.Q0XMqrld.dpuf* *The following study by Peleg& Baram-Tsabari (2011) only offers partial support for this proposed good practice, while Rajan (2016) offers full support (University of Warwick team):* Peleg, R. and Baram-Tsabari, A. (2011) 'Atom Surprise: Using Theatre in Primary Science Education', *Journal of Science Education and Technology*, Vol. 20, pp. 508–524[19] Rajan, R. (2016) 'Beyond Broadway: Connecting Musical Theater and Academic Learning', *Childhood Education*, Vol. 92, No. 2, pp. 118-125[20] Bertacchini, F., Bilotta, E., Pantano P. and Tavernise, A. (2012) 'Motivating the learning of science topics in secondary school: A constructivist edutainment setting for studying Chaos', *Computers & Education*, Vol. 59, No. 4, pp.1377-1386[21] Kerby, H. W., Cantor, J., Weiland, M., Babiarz, C. and Kerby, A. W. (2010) 'Fusion Science Theatre Presents The Amazing Chemical Circus - a New Model of Out-reach uses Theatre to Engage Children', *Journal of Chemical Education,* Vol. 87, No. 10, pp. 1024-1030[22]

GERMANY	Our selection process was based on desktop research on good practices. Indicators we were looking for were: • awards and other acknowledgements the methodologies received; • great interest on the side of schools/teachers/students, numbers of participants/users; • research material on the methodologies; • positive feedback from experts and/or teachers & students using it, evaluations. We presented best practices at the local workshop, collected further best practices, discussed them with the participants and then decided on which best practices would make it on our MARCH list.	*Nature inspires - Bionics*		Award: MINT von morgen Schulpreis Supported by the Joachim Herz Foundation & the initiative MINT Zukunft schaffen # evaluation by the University of Bremen Cooperation with the EU project PROFILES: *http://www.chemiedidaktik.uni-bremen.de/profiles/* **Other evidence:** *Bioinspiration Education at Zoological Institutions: An Optomistic Approach for Innovation Leading to Biodiversity Conservation: http://onlinelibrary.wiley.com/doi/10.1111/izy.12123/epdf* [23]
		Junior Science Cafe		40 schools participating across school years and very actively, contributing to the project blog etc. Supported by Telekom Foundation & Wissenschaft im Dialog Positive feedback: *http://juniorsciencecafe.de/projekt/#mitdenker* Supported by the Ministry of Culture **Other evidence:** *The following two studies are full supportive of this proposed good practice, but not in the context of school-based education.* *(University of Warwick team):* Ahmed, S., DeFino, M. C., Connors, E. R., Kissack, A. And Franco, Z. (2014) 'Science Cafés: Engaging Scientists and Community through Health and Science Dialogue', *Clinical and Translational Science*, Vol. 7, No. 3, pp. 196-200[24] Peterman, K., Fleischer, D. And Goodman, I. (2005) *NOVA scienceNOW: Final Season One Report, Programs One and Two*, Available online: *http://www.informalscience.org/sites/default/files/report_266.PDF* [25] *The following study discusses difficulties of engaging with scientists in order to run a science café (University of Warwick team):* Mizumachi, E., Matsuda, K., Kano, K., Kawakami, M. And Kato, K. (2011) 'Scientisits' attitudes toward a dialogue with the public: a study using "science cafés"', *Journal of Science Communication*, Vol. 4, No. 4, pp. 1-11[26]
		Big Bang Theory		Award: Georg-Kerschensteiner-Preis 500.000 online visitors per month Questionnaire (6278 participants): *http://www.leifiphysik.de/sites/default/files/medien/leifi_ergebnisse_umfrage2014.pdf* **Other evidence:** Dhingra, K. (2006) 'Science on Television: Storytelling, Learning and Citizenship', *Studies in Science Education*, Vol. 42, No. 1, pp. 89-123[27] Espinoza, F. (2009) 'Using Project-Based Data in Physics to Examine Television Viewing in Relation to Student Performance in Science', *Journal of Science Education and Technology*, Vol. 18, No. 5, pp. 458-465[28]

		Flip the classroom		Awards: MINT von morgen Schulpreis & ars-legendi-Preis Recommendation by an independent teachers' platform:*http://www.lehrer-online.de/flipped-classroom.php*; Positive media mentions: *http://www.flippedmathe.de/presse/* Cooperation between teachers, university professors, a big educational publishing house **Other evidence:** Herreid, C. F. and Schiller, N. A. (2013) 'Case Studies and the Flipped Classroom', *Journal of College Science Teaching,* Vol. 42, No. 5, pp. 62-66[29] *The following study offers full support for the flipped learning approach, but highlights the importance of implementing the practice properly as it will otherwise be ineffective (University of Warwick team):* Khanova, J., Roth, M. T., Rodgers, J. E. and McLaughlin, J. E. (2015) 'Student Experiences Across Multiple Flipped Courses in a Single Curriculum', *Medical Education,* Vol. 49, pp.1039-1048[30] *The following study offers largely supportive results for this practice, however it considers success in terms of student opinions and thinking. It offers no evidence of students' grades in STEM subjects improving when taking part in flipped classroom learning. Also, it does discuss possible limitations of the flipped classroom approach (University of Warwick team):* Swart, W. And Wuensch, K. L. (2016) 'Flipping Quantitative Classes: A Triple Win', *Decision Sciences Journal of Innovative Education*, Vol. 14, No. 1, pp. 67-89[31] *Study offers full support for the practice, both in terms of student opinions/engagement and in academic achievement (University of Warwick team):* Choa, C-Y., Chen Y-T. and Chuang, K-Y. (2015) 'Exploring Students' Learning Attitude and Achievement in Flipped Learning Supported Computer Aided Design Curriculum: A Study in High School Engineering Education', *Computer Applications in Engineering Education*, Vol. 23, No. 4, pp. 514-536[32] *Following study provides full support for the flipped learning approach but in the context of adult medical professional as the students. It also highlights some issues with the flipped classroom approach such as time constraints which, although not written in the context of school based learning, are reiterated in other studies such as those above. (University of Warwick team):* Tan, E., Brainard, A. and Larkin, G. L. (2015) 'Acceptability of the Flipped Classroom Approach for In-House Teaching in Emergency Medicine', *Emergency Medicine Australasia,* Vol. 27, pp. 453-459[33]

PORTUGAL	We selected best practices submitted by educators from schools involved in the project "Sustainable City" and teachers experienced in innovative STEM teaching approaches. Selected practices had these features: • integrates activities carried in the classroom and outside, in the local community; • involves students while contributing to their well-being; • builds bridges between theory and reality, schools and local communities and makes learning more engaging and relevant; • influences students' career choices and their interest in STEM topics; • promote the development of inquiry based skills.	*Learning outside the classroom (Woodlands)*		**Other evidence:** Out-of-Classroom Learning. Practical information and guidance for schools and teachers: *https://www.rgs.org/NR/rdonlyres/3D0B3905-8CFB-4D95-B25D-0B8818B9CA71/0/OoCLweb_pdf.pdf* What is learning Outside the classroom: *http://www.lotc.org.uk/what-is-lotc/* Learning Outside the Classroom Curriculum Planning: *http://www.lotc.org.uk/wp-content/uploads/2010/12/LOtC-within-the-school-curriculum_2011.pdf* *Orion, N. and Hofstein, A. (1994)* 'Factors that Influence Learning during a Science Field Trip in a Natural Environment', *Journal of Research in Science Teaching*, Vol. 31, No. 10, pp. 1097-1119.[34] *Following studies offer full support to field trips but the first study below (Whitesell 2016) only found a small and statistically insignificant link (University of Warwick team):* Whitesell, E. R. (2016) 'A Day at the Museum: The Impact of Field Trips on Middle School Science Achievement', *Journal of Research in Science Teaching*, Vol. 0, No. 0, pp. 1-19.[35] Manzanal, R. F., Rodríguez Barreiro, L. M. and Casal Jiménez, M. (1999) 'Relationship between Ecology Fieldwork and Student Attitudes Toward Environmental Protection', *Journal of Research in Science Teaching*, Vol. 36, No. 4, pp. 431-453[36]
		Internship programme for young students		**Other evidence:** Internships for young people in laboratories: *http://www.cienciaviva.pt/ocjf/?accao=change-lang&lang=en* Learning Science Through Work Experience: Ciencia Viva Internships Program for Secondary School Students: *http://www.cienciaviva.pt/img/upload/LSWE_IJSS.pdf* *Following studies offer full support to this proposed good practice (University of Warwick team):* Kapon, S. (2016) 'Doing Research in School: Physics Inquiry in the Zone of Proximal Development', *Journal of Research in Science Teaching*, Vol. 0, No. 0, pp. 1-26[36] Scholz, R. W., Steiner, R. And Hansmann, R. (2004) 'Role of Internship in Higher Education in Environmental Science', *Journal of Research in Science Teaching*, Vol. 41, No. 1, pp. 24-46[38]

		Inquiry-based learning (school activities under the topic of Sustainable Cities)		What Is Inquiry-Based Instruction: *https://edis.ifas.ufl.edu/wc075* **Other evidence:** Inquiry based science education - outcomes from establish: *http://www.pdst.ie/sites/default/files/AMGEN%20TEACH_ESTABLISH%26SAILS_18OCT2014%20%281%29.pdf* Inquiry based science education, SCIENTIX: *http://www.scientix.eu/web/scientix-cop-02/ibse* *Following studies offer full (Berlan et al. 2015) and only partial (Wallace & Brooks 2014) support to this good practice respectively (University of Warwick team):* *Berlan, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S. and Reiser, B. J. (2015) 'Epistemologies in Practice: Making Scientific Practices Meaningful for Students', Journal of Research in Science Teaching, Vol. 0, No. 0, pp. 1-31*[39] Wallace, C. S. And Brooks, L. (2014) 'Learning to Teach Elementary Science in an Experimental, Informal Context: Culture, Learning and Identity', *Science Education*, Vol. 99, No. 1, pp. 174-198[40] Minner, D. D., Levy, A. J. and Century, J. (2009) 'Inquiry-Based Science Instruction - What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002', *Journal of Research in Science Teaching*, Vol. 47, No. 4, pp. 474-496[41]
UK	We identified activities and organisations who were already doing well evaluated STEM enrichment work that could be considered as best practice (e.g. CREST). We invited teachers involved in these programs who had done activities related to sustainable cities to come and present at the workshop. Therefore, only teachers involved in these already evaluated activities received invites to the workshop. Then participants voted for the best activities to share. The STEM Ambassadors best practice was something that support a number of the activities that were identified.	*National Science Learning Centre (for teachers)*		**Other evidence:** Evaluation of the Impact of National Science Learning Network CPD on Schools: *https://www.stem.org.uk/sites/default/files/pages/downloads/Super%20users%20evaluation%20final%20report.pdf* *Following studies offer a mix of partial (Wallace & Brooks 2014) and full support (Lowery 2010; Herman et al. 2013) to this proposed good practice (University of Warwick team):* Wallace, C. S. And Brooks, L. (2014) 'Learning to Teach Elementary Science in an Experimental, Informal Context: Culture, Learning and Identity', *Science Education*, Vol. 99, No. 1, pp. 174-198[42] Lowery, N. V. (2010) 'Construction of Teacher Knowledge in Context: Preparing Elementary Teachers to Teach Mathematics and Science', *School of Science and Mathematics*, Vol. 102, No. 2, pp. 68-83[43] Herman, B. C., Clough, M. P. And Olson, J. K. (2013) 'Teachers' Nature of Science Implementation Practices 2-5 Years After Having Completed an Intensive Science Education Program', *Science Education*, Vol. 97, No. 2, pp. 271-309[44]

	CREST Awards		CREST Awards and employability skills. A project for the British Science Association report The CREST Silver report: http://www.britishscienceassociation.org/crestsilver-report A summary of CREST evaluation: http://www.britishscienceassociation.org/crest-evaluation **Other evidence:** *Following study provides full empirical support to this proposed good practice (University of Warwick team):* Kapon, S. (2016) 'Doing Research in School: Physics Inquiry in the Zone of Proximal Development', *Journal of Research in Science Teaching*, Vol. 0, No. 0, pp. 1-26[45]
	STEM Ambassadors		NfER report on STEM Ambassadors: http://www.stemnet.org.uk/about-us/the-impact-of-stemnets-programmes/ **Other evidence:** *Following study (Butt 2013) offers only partial support to this proposed good practice (University of Warwick team):* Butt, M. (2013) 'The use of role models to improve engagement of ethnic minority students in secondary school science', *SSR*, Vol. 95, No. 350, pp. 110-118[46] Betz, D. E. and Sekaquaptewa, D. (2012) 'My Fair Physicist? Feminine Math and Science Role Models Demotivate Young Girls', *Social Psychological and Personality Science*, Vol. 3, No. 6, pp. 738-746[47] Buck, G. (2008) 'Science role models for adolescent girls', *Science Scope*, Vol. 32, No. 4, pp. 40-43[48]

BULGARIA	We shortlisted good innovative practices from those provided by teachers already contacted during MARCH previous activities and by national non-governmental science education and communication organizations. As a first step best teachers' practices presented at the national workshop were pre-selected by a jury, involving science communicators and researchers. As a second step the feedback received from the participants was collected and taken into account by the partners for the final selection. The selected practices are easy to be tested in different schools, easy to be multiplied in smaller schools in different regions and have potential for real practical application for students from different ages. Moreover, practices can be easily transferred and used in various science classes. The presented practices are innovative for the Bulgarian schools and have strong potential to encourage students' interest in the science classes.	*Electronic Platform for Science Education in Secondary Schools*		Technology In Schools: Education, ICT And The Knowledge Society: *Http://Siteresources.Worldbank.Org/EDUCATION/Resources/278200-1099079877269/547664-1099079947580/ICT_Report_Oct04a.Pdf* European Schoolnet Report On The Importance Of ICE In Education: *Http://Www.Eun.Org/Observatory/Country-Reports* Survey Of Schools: ICT In Education: *Https://Ec.Europa.Eu/Digital-Single-Market/Sites/Digital-Agenda/Files/KK-31-13-401-EN-N.Pdf* ICT Infrastructure And E-Readiness Assessment: *www.Arcfund.Net/Filesrc.Php?Id=1376* Implementation Of ICT-Based Teaching In Bulgarian Schools: *Http://Iict.Bas.Bg/Acomin/Docs/Sci-Forums/7-9-July-2014/Paper_2.Pdf* Darrah, M., Humbert, R., Finstein, J., Simon, M. and Hopkins, J. (2014) 'Are Virtual Labs as Effective as Hands-on Labs for Undergraduate Physics? A Comparative Study at Two Major Universities', *Journal of Science Education and Technology*, Vol. 23, No. 6, pp. 803-814[49] *Following studies offer a mix of limited support because the project evaluated in the study was unsuccessful (Waight 2011) and full support (Gebre et al. 2014; Meyer 2014) to this proposed good practice (University of Warwick team):* Gebre, E., Saroyan, A. and Bracewell, R. (2014) 'Students' Engagement in Technology Rich Classrooms and its Relationship to Professors' Conceptions of Effective Teaching', *British Journal of Education Technology*, Vol. 45, No. 1, pp. 83-96[50]
		Use of Online and Remote Labs		Waight, N. and Abd-El-Khalick, F. (2011) 'From Scientific Practice to High School Science Classrooms: Transfer of Scientific Technology and Realisations of Authentic Inquiry', *Journal of Research in Science Teaching*, Vol. 48, No. 1, pp. 37-70[51]
		Learning by Doing Using ICT		Meyer, K. A. (2014) 'Student Engagement in Online Learning: What Works and Why', *ASHE Highe Education Report*, Vol. 40, No. 6, pp. 1-114[52]

GREECE	We sent an open invitation call to all Directorates of Secondary Education in Greece asking them to forward it to all schools (both public and private) within their district). The Greek partners evaluated the practices submitted by teachers: • the criteria that were taken into consideration in the selection process of the practices were: the innovative and attractive aspect; • the creative and collaborative use of ICT; • the involvement of students in research; • the promotion of interdisciplinarity; • the promotion of "learning to learn"; • the adaptation to local community's needs; • the linkage to the concept of sustainable cities. The Greek partners created a list of invitee teachers to attend the workshop and present their teaching practice. During the workshop invitees presented their teaching practices, worked in teams to develop their teaching scenarios and discussed them with the rest of teachers. After the workshop teams reflected upon their teaching practices and submitted their final version of good practices via email.	*School Lab*		S.Papadimitriou, An.Andritsou, Th.Anadnostopoulos, An. Christodoulou B.Tsakarestou, The School Lab project: Communicating Science at the 7th International Conference in Open & Distance Learning - November 2013, Athens, Greece – PROCEEDINGS: *http://icodl.openet.gr/index.php/icodl/2013/paper/view/273* Sofia Papadimitriou, Educational Television – Ministry of Education, Greece: *http://www.media-and-learning.eu/2013/programme/friday.html* *http://www.media-and-learning.eu/2013/sites/default/files/presentations/ML_School_Lab_sofia.pdf* Creating Video at School-Lab – Awarded scenario by the Institute of Educational Policy _Ministry of Education: *http://aesop.iep.edu.gr/node/13278* **Ευρωπαϊκή οδηγία για την προώθηση της παιδείας στα Μέσα:** *http://europa.eu/rapid/press-release_IP-09-1244_el.htm* **Εκπαιδευτική Τηλεόραση 2.0: το Πείραμα της Ψηφιακής Μετάβασης**. Τσακαρέστου, Μ. & Παπαδημητρίου, Σ. (2011). Στο Λιοναράκης, Α. (Επιμ.) 6th International Conference in Open & Distance Learning - November 2011, PROCEEDINGS. Ανακτήθηκε 21 Μαρτίου, 2011 από from: *http://icodl.openet.gr/index.php/icodl/2011/paper/view/66* Creating video in school: A collaborative learning activity: *http://www.slideshare.net/sofipapadi/video-as-collaborativelearningactiv*... *Following study offers full support to this proposed good practice (University of Warwick team):* Polman, J. L. and Hop, J. M. G. (2014) 'Science News Stories as Bounary Objects Affecting Engagement with Science', *Journal of Research in Science Education,* Vol. 51 (3), pp. 315-341[53]
		Make Energy Real @ Education (MERE)		Inquiry Based Learning: *http://www.teachinquiry.com/index/Introduction.html* *https://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/C BS_InquiryBased.pdf* Teaching And Learning For A Sustainable Future Experiential Learning: *http://www.unesco.org/education/tlsf/mods/theme_d/mod20.html* Cooperative and Collaborative Learning in the Classroom: *http://study.com/academy/lesson/cooperative-and-collaborativelearning-in-the-classroom.htm* Minner, D. D., Levy, A. J. and Century, J. (2009) 'Inquiry-Based Science Instruction - What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002', *Journal of Research in Science Teaching*, Vol. 47, No. 4, pp. 474-496[54]

		Light Pollution		*No robust, published research available to address this proposed good practice. However, inquiry based learning research may be applicable (University of Warwick team):* Spanos S. and Xenakis, C. (2013). Learning Astronomy through Inquiry and by means of Self-Constructions. Published by Astronomy and Space Society & Ellinogermaniki Agogi, Athens pp 191.
		Science day		Authentic learning: *http://authenticlearning.weebly.com/* Six thinking hats: *http://apostolakakis.blogspot.gr/p/blog-page_3.html* *http://www.debonoforschools.com/asp/six_hats.asp* *Following study offers full support to this proposed good practice (University of Warwick team):* Birmingham, D. and Calabrese Barton, A. (2014) 'Putting on a Green Carnival: Youth Taking Educated Action on Socioscientific Issues', *Journal of Research in Science Education*, Vol. 51, No. 3, pp. 286-314[55]
SERBIA	We organized competitive selection procedure where teachers submitted their best practices. Then we have chosen practices that have scored the best across criteria: • innovativeness; • level of interactivity with students; • balance between cost and impact of proposed practices; • possibility to implement in other EU countries.	*Physics Winter Camp*		Six characteristics of a Great STEM lesson: *http://www.edweek.org/tm/articles/2014/06/17/ctq_jolly_stem.html* A New Strategy for Stem Education and Innovative Engineering Problem Solving: *http://web.mit.edu/sydneydo/www/ICED2012App/A%20New%20Strategy%20for%20Stem%20Education%20and%20Innovative%20Engineering%20Problem%20Solving%20rev%207.pdf* *Following study offers only limited support to this proposed good practice because it focuses more on the understanding of phenomena rather than the pros and cons of science camps. (University of Warwick team):* Rath, A. and Brown, D. E. (1996) 'Modes of Engagement in Science Inquiry: A Microanalysis of Elementary Students' Orientations Towards Phenomena at a Summer Science Camp', *Journal of Research in Science Teaching*, Vol. 33, No. 10, pp. 1083-1097[56]

		Flipped (Biology) Classroom		Flipped Classroom: *https://www.knewton.com/infographics/flipped-classroom/* Herreid, C. F. and Schiller, N. A. (2013) 'Case Studies and the Flipped Classroom', *Journal of College Science Teaching,* Vol. 42, No. 5, pp. 62-66[57] *Following studies largely indicate that this proposed good practice is effective. Full support is offered by Khanova et al. (2016), Choa et al. (2015) and Tan et al. (2015), although Khanova et al. stress the importance of implementing the practice properly as it will otherwise be ineffective. Choa et al. show the approach's effectiveness both in terms of student opinions / engagement and in academic achievement. However, Swart and Wuensch (2016) consider success in terms of student opinions and thought and offers no evidence of students grades in STEM subjects improving when taking part in flipped classroom learning. Also, Swart and Wuensch (2016) discuss possible limitations of the flipped classroom approach (University of Warwick team):* Khanova, J., Roth, M. T., Rodgers, J. E. and McLaughlin, J. E. (2015) 'Student Experiences Across Muliple Flipped Courses in a Single Curriculum', *Medical Education,* Vol. 49, pp.1039-1048[58] Swart, W. And Wuensch, K. L. (2016) 'Flipping Quantitative Classes: A Triple Win', *Decision Sciences Journal of Innovative Education*, Vol. 14, No. 1, pp. 67-89[59] Choa, C-Y., Chen Y-T. and Chuang, K-Y. (2015) 'Exploring Students' Learning Attitude and Achievement in Flipped Learning Supported Computer Aided Design Curriculum: A Study in High School Engineering Education', *Computer Applications in Engineering Education*, Vol. 23, No. 4, pp. 514-536[60] Tan, E., Brainard, A. and Larkin, G. L. (2015) 'Acceptability of the Flipped Classroom Approach for In-House Teaching in Emergency Medicine', *Emergency Medicine Australasia,* Vol. 27, pp. 453-459[61]
		Magic Village		Learning Outside the Classroom Manifesto: *http://www.lotc.org.uk/wp-content/uploads/2011/03/G1.-LOtC-Manifesto.pdf* *The following studies partially support the idea that this proposed good practice is effective. See footnotes for details (University of Warwick team):* Könings, K. D., Brand-Gruwel, S. and van Merriënboar, J. J. G. (2005) 'Towards More Powerful Learning Environments Through Combining the Perspectives of Designers, Teachers and Students', *British Journal of Educational Psychology*, Vol. 75, No. 4, pp. 645-660[62] Heilbronner, N. (2008) 'Science Safaris: Developing Bold Academic Explorers Outside the Science Classroom', *Science Scope*, Vol. 31 No. 7, pp. 23-27[63]

[15] Study into the relationship between students taking part in a robotics activity and their development of science literacy and valuable skill in STEM education. "The design of the robotics environment affords certain activities to be undertaken by students participating in robotics study including the use of manipulation and observation thinking skills, and the use of hypothesis generation, hypothesis testing, and evaluation of solution science process skills." pp. 387-388

[16] Research into the use of robotics-based lessons to inspire creativity and science learning in elementary school children as they are tasked with creating their own robots. "The findings revealed that the robotics classroom environment was characterized by a high degree of chaotic energy, one that encouraged self-directed student movement and natural control of student behavior within a non-traditional physical layout." pp. 2 *(University of Warwick team)*

[17] A statistical analysis into how participating in a robotics competition alters the views and attitudes of students towards science and science education. "The results imply that programs that engage students in authentic scientific problems can significantly improve students' attitudes and *views of science." pp. 423 (University of Warwick team)*

[18] This article discusses the use of 3D printers as a way of demonstrating and visualizing chemical structures. "Potential energy surface models prepared with 3D printers are likely to play a significant role in chemical education in future years. It is important for instructors to emphasize that any model is not the chemical system itself but is only a means to understand the chemical system. Thus, a 3D model of a potential energy surface should be presented as a representation of structure−energy relationships that complements textbook drawings and computer images. None of these models is complete by itself, but considering the models together can provide students with a more complete understanding of structure−energy relationships." pp. 1255-1256 *(University of Warwick team)*

[19] This article discusses the successes and weaknesses of an educational play "atom surprise" on children's learning of science. "In terms of affective outcomes, it seems the play could not significantly change children's views on science and scientists, but it did change their views of school science and in some cases their views of themselves as capable and interested science learners. Whilst it seems that the knowledge obtained from the play was forgotten over time, many elements of the play, such as certain scenes and the characters as well as many of the scientific words were remembered over time." pp. 522 *(University of Warwick team)*

[20] This article makes the case for integrating musical theatre into math, science, social studies, and language instruction. "A majority of the learning that takes place in science is built on students seeing, doing, and experimenting. Therefore, when connecting musical theatre to science, it is helpful to include a visual when possible, either through pictures, video clips, or, preferably, live performances." pp. 123 *(University of Warwick team)*

[21] This article discusses 'edutainment' - an amalgamation of the words 'education' and 'entertainment' - which has become an engaging way of supporting the educational process and the approach of young people to scientific topics. "Results enhance the great potentiality of the realized setting for science education and motivation. In particular, very positive results in learning, as well as an increase of motivation linked to interest/enjoyment and competence, have been demonstrated." pp. 1377 *(University of Warwick team)*

[22] This article discusses the success of a theatre performance "The Amazing Chemical Circus" on children's science learning. "As supported by the data, there is strong evidence that The Amazing Chemical Circus is educational as well as entertaining for children 2-14 years of age. This is a unique accomplishment in the discipline of chemical education outreach." pp. 1028 *(University of Warwick team)*

[23] Article discussing a similar project in Israel as a Zoological Centre has opened up an Educational Centre for the public, using bionics to encourage learning in other areas of science. "By inviting visitors to explore this new kind of learning, the aim is to tell them not only about nature but also about what can be learned from nature." pp. 113 *(University of Warwick team)*

[24] A study into the use of science cafes as and educational tool in the wider community. "The majority of the comments were positive, suggesting that attendees enjoyed the Café or had a good grasp of the information." pp. 199 *(University of Warwick team)*

[25] *An evaluative report on the science cafes run in the wider community by NOVA scienceNOW. "All attendees reported that they would attend another Science Café event. Over half reported they had completed an activity from* the Science Café handout and just over one third had plans to complete activities." pp. 17 *(University of Warwick team)*

[26] *A study into the reasons behind scientists' reluctance to engage with the community. "From these interviews, we identified five factors leading to their reluctance to participate in science cafes: 1) troublesome or time-consuming; 2) pressure to be an appropriate science representative; 3) outside the scope of their work; 4) could* not perceive any benefit; and 5) apprehension about dialogue with the public." p. 1 *(University of Warwick team)*

[27] This article is looks at science on television as a method of learning. "This review is concerned with science on television, understood as a significant component of the free-choice learning sector. It looks at the ways that science and scientists are depicted on television, and at what is known about the ways that science is learned from watching television." p.89 *(University of Warwick team)*

[28] This study discusses the relationship between viewing television and student performance in science, and argues there is "compelling evidence of the detrimental effect of watching an excessive amount of television on high school students' science performance resulting from studies containing large statistical analysis, and confirmed in this study by the use of an independent approach". p. 463 *(University of Warwick team)*

[29] This article discusses the "flipped" approach to teaching. It argues that this method has become particularly attractive because of the availability of internet resources including audio and video. It argues the approach seems to have an appeal to students, because in this electronic age young people engage a lot with online resources including podcasts and video. However, it also discusses some of the constraints of using the "flipped classroom" approach.*(University of Warwick team)*

[30] Research into the use of the flipped classroom approach across multiple courses within the curriculum. This study not only considers the success of the 'flipped classroom' as an educational tool but also considers the possible disadvantages such as increased workload and student engagement. "Challenges associated with ineffective course delivery can potentially erode the goals and perceived benefits of the flipped learning model." pp. 1044 *(University of Warwick team)*

[31] A study comparing the effectiveness of the flipped classroom approach to a traditional classroom approach to education. This article argues in favour of the flipped classroom. "Students feel they have learned more, have made better progress towards their learning goals, and are more satisfied with their experience in the flipped classroom than they think they would have been if they had taken the course in a traditional classroom." pp. 83 *(University of Warwick team)*

[32] Research into the impact of the flipped classroom approach on the pupils undertaking an engineering course at a high school in Taiwan. "[…] the flipped learning approach in this study further changed the learning culture to include active learning, exploration learning, collaborative learning such as sharing and discussing with peers." pp. 523 *(University of Warwick team)*

[33] Study into the use of the flipped classroom in teaching a departmental Emergency Medicine educational programme. "When we introduced a flipped classroom model to our departmental EM education programme, we received strong positive preferences for this approach […] from both faculty and resident learners." pp. 455 *(University of Warwick team)*

[34] A study into the different factors which make field trips more or less effective, in the context of a natural environment. "The variables influencing learning efficiency in the field fall into three groups: background, pre-field trip and field trip." pp. 1117 *(University of Warwick team)*

[35] Statistical analysis of the impact of attending field trips on science test scores. "I found small positive effects, suggesting that in addition to providing more enriching educational experiences, field trips can be an important contributor to students' academic achievement." pp. 2 *(University of Warwick team)*

[36] Research into the benefits of field trips in an eco-environment on students understanding of environment protection and science based knowledge. "The students who had visited the lagoon acquired a deeper, more solid understanding of the components of the ecosystem and the relationships within it […]" pp. 450 *(University of Warwick team)*

[37] Study into the benefits of applying and apprenticeship style model within a school laboratory. This case study focuses particularly on the benefit of the students working closely with a mentor (teacher/researcher) to carry out a physics based study. "The specific learning gains and features of engagement emerged not only because of the unique features of mentorship implemented by the advisor, but also because of the social infrastructure that fostered this mentorship." pp. 22 *(University of Warwick team)*

[38] Research into the benefits of environmental science-based internships for students in higher education. "Results indicated that internships enhance general abilities and key qualifications, such as communication skills, report writing, organization of work, information acquisition, and the ability to operate independently. This suggests that internships are of high value to professional education." pp. 24 *(University of Warwick team)*

[39] Article looks at the movement towards inquiry based learning and discusses the shift from learning about science ideas and towards learning by doing science. "[…] this article offers a framework the Epistemologies in Practice (EIP) framework for characterizing how students can engage meaningfully in scientific practices. This framework emphasizes two aspects of student engagement in scientific practices: (1) the students' epistemic goals for their knowledge construction work and (2) their epistemic understandings of how to engage in that work." pp. 1 *(University of Warwick team)*

[40] The case study of Alan within this article offers an example of inquiry-based learning in action. "Thus, early on, Allan expressed the perception of the teacher's role as a "guide" and letting the children "come to their own conclusions." […] this belief in allowing students to think, problem solve, and generate their own meanings for science, […]" pp. 188 *(University of Warwick team)*

[41] This paper examines the effectiveness of inquiry-based learning, by carrying out a synthesis of other studies' results. "Various findings across 138 analyzed studies indicate a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques, which are often necessary in the current standardized-assessment laden educational environment." pp. 474 *(University of Warwick team)*

[42] Case studies focusing on three preservice teachers and the importance of teacher training in preparation of teaching at a science camp. "In this study, we explored the culture of the learning context in the informal science setting, the development of science identities, and what the preservice teachers viewed as the most important understandings about science teaching that they took away from the course." pp. 175 *(University of Warwick team)*

[43] Research into the importance of effective training for preservice teachers. "These findings have implications for the preparation of teachers. Typical on-campus methods courses do not allow for immediate access to teaching elementary children in real-world situations. School-based methods courses allow preservice teachers immersion in authentic learning experiences and context." pp. 76 *(University of Warwick team)*

[44] Research assessing the success of an intensive science education program for preservice teachers. "This study raises important issues about achieving the goal of NOS [Nature of Science] instruction. Accurate and effective NOS instruction appears achievable, but may require far more effort than found in typical science teacher education programs." p. 271 *(University of Warwick team)*

[45] This study reveals the benefits of students carrying out their own research as part of their learning experience. "The study documented students' learning gains such as learning of scientific content and skills, internalization of scientific habits of thought as well as developing passion, interest, and agency with regard to science. It documented features of students' engagement that reflect deep involvement in the technical and epistemic aspects of the inquiry, and highlighted the specific features of mentorship, and the social infrastructure that fostered this learning and engagement. *(University of Warwick team)*

[46] This article describes an investigation into whether role models in science have an impact on ethnic minority engagement and aspirations. It discusses whether incorporating scientists from across the world into lessons could have a positive impact on ethnic minority and white pupils. "The majority of science staff hold the opinion that incorporating role model scientists from across the globe into science lessons will be beneficial for all pupils. In addition to this, all of the science staff at my school would like to use resources that include scientists from across the globe." p.118 *(University of Warwick team)*

[47] This article discusses how challenges to the stereotype of STEM subjects being "unfeminine", including using female STEM role models, may actually be "demotivating" particularly to young girls. "These studies offer evidence that feminine STEM role models can demotivate rather than inspire middle school girls. Study 1 showed that feminine STEM role models made middle school girls feel less capable and interested in math. Troublingly, feminine STEM role models also made STEM-disinterested girls feel less likely to study math in the future. This suggests that feminine STEM role models may most negatively impact girls who already disidentify with STEM, and who might benefit most from interventions that pique interest in these fields." p. 743 *(University of Warwick team)*

[48] This article describes conversations with secondary school girls about their role models in science and how they perceive them. It discussed how role models should engage with students by sharing. "[…] the girls' conception of a scientist had changed from a monolithic, emotionally detached white male to someone with whom they might be able to identify. They described scientists as normal people who know science and could be men or women of any ethnicity." p. 41 *(University of Warwick team)*

[49] This study looked at whether virtual labs were as effective for learning as doing the labs hands-on. It concluded that virtual labs were as effective as a learning tool. "This research was conducted with 224 students from two large universities and investigated the learning that occurred with students using the virtual labs either in a lab setting or as a supplement to hands-on labs versus a control group of students using the traditional hands-on labs only. Findings […] showed the virtual labs to be as effective as the traditional hands-on physics labs." p. 803 *(University of Warwick team)*

[50] This article supports the use of technology in STEM teaching classrooms and highlights the importance as the professors' role in ensuring an effective learning environment when using technology. "Principal component analysis with varimax rotation revealed four dimensions of student engagement: cognitive and applied engagement, social engagement, reflective engagement and goal clarity. Subsequent multivariate and univariate analyses of variance showed that the extent of students' cognitive and applied engagement and social engagement is related significantly to professors' conceptions of effective teaching." pp. 83 *(University of Warwick team)*

[51] This article discusses the effectiveness of the Biology Student Workbench (BSW), a web-based tool for students which is modelled on the Biology Workbench (BW). "Contrary to what often is advocated as a major benefit accruing from the integration of authentic scientific tools into precollege science teaching, classroom enactments of BSW lacked elements of inquiry and were teacher-centered with prescribed convergent activities." pp. 37 *(University of Warwick team)*

[52] This report takes a detailed look at the use of 'the online' in higher education and the importance of student engagement. Alongside this, it also discusses possible limitations which occur when a lack of student engagement is achieved. "engagement may be the critical key to making online learning an essential component of higher education and indispensable part of an institution's future." pp. 2 *(University of Warwick team)*

[53] Research study into students carrying out research and writing up a news article on a science topic of their choosing. "Through case studies, we describe how these boundary objects based on personally meaningful topics open opportunities for developing youth identities while fostering participation in critical thinking about science." p. 316 (University of Warwick team)

[54] This paper examines the effectiveness of inquiry-based learning, by carrying out a synthesis of other studies' results. "Various findings across 138 analyzed studies indicate a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques, which are often necessary in the current standardized-assessment laden educational environment." p. 474 *(University of Warwick team)*

[55] A study into an after-school science program designed to get students more involved in socioscience-based issues in their local community. Focus is also placed on the importance of informal learning in the 'real-world' when engaging in learning about science and the everyday. "We believe educated action on socioscientific issues is a responsibility of citizens in a democratic society and thus an important goal for science education. We see informal education as an avenue to provide opportunities for youth to take educated action today on relevant local issues and thus support their development as scientifically literate citizens." p. 311 *(University of Warwick team)*

[56] A study into students understanding of phenomena in a science summer camp. "Through microanalyses of videotape data of a summer science camp for elementary school children, we characterize students' orientations when exploring natural phenomena as modes of engagement. The six frequently observed orientations toward phenomena include exploration mode (to find out about the object and study its basic properties), engineering mode (a focus on making something happen), pet care mode (a personal connection focused on nurturing), procedural mode (an imitation and step-following orientation), performance mode (soliciting attention using the phenomenon as a prop), and fantasy mode (an imaginative play activity which builds on some aspect of the phenomena)." p. 1083 *(University of Warwick team)*

[57] This article talks about the "flipped" approach to teaching. It argues that this method has become particularly attractive because of the availability of internet resources including audio and video. It argues the approach seems to have an appeal to students, because in this electronic age young people engage a lot with online resources including podcasts and video. However, it also discusses some of the constraints of using the "flipped classroom" approach. *(University of Warwick team)*

[58] Research into the use of the flipped classroom approach across multiple courses within the curriculum. This study not only considers the success of the 'flipped classroom' as an educational tool but also considers the possible disadvantages such as increased workload and student engagement. "Challenges associated with ineffective course delivery can potentially erode the goals and perceived benefits of the flipped learning model." p. 1044 *(University of Warwick team)*

[59] A study comparing the effectiveness of the flipped classroom approach to a traditional classroom approach to education. This article argues in favour of the flipped classroom. "Students feel they have learned more, have made better progress towards their learning goals, and are more satisfied with their experience in the flipped classroom than they think they would have been if they had taken the course in a traditional classroom." p. 83 *(University of Warwick team)*

[60] Research into the impact of the flipped classroom approach on the pupils undertaking an engineering course at a high school in Taiwan. "[…] the flipped learning approach in this study further changed the learning culture to include active learning, exploration learning, collaborative learning such as sharing and discussing with peers." p. 523 *(University of Warwick team)*

[61] Study into the use of the flipped classroom in teaching a departmental Emergency Medicine educational programme. "When we introduced a flipped classroom model to our departmental EM education programme, we received strong positive preferences for this approach […] from both faculty and resident learners." p. 455 *(University of Warwick team)*

[62] This article discusses the optimal learning environment for students, drawing on the perspectives of both teachers and students. In doing so, it also discusses the importance of the four phases of active knowledge as a learning environment should: "First, prior knowledge and experiences of the student must be activated, in order to build new knowledge on pre-existing knowledge. Second, new skills or knowledge must be demonstrated to the student through modelling. Third, the student should have the opportunity to apply their new knowledge and skills. Fourth, the newly acquired skills and knowledge must be integrated into real-world activities of the student." p. 647 (*University of Warwick team*)

[63] This article discusses the benefits of taking science outside of the classroom by going on a trip. "The benefits of bringing real science back into the classroom were diverse. We had discussions about what we saw and how it might apply to the curriculum we were learning in class. Students became aware of the importance of science in the world around them, and in many cases, they came to see themselves as "explorers" of that world. Science became a pleasurable pursuit, with several students speaking of new ambitions to pursue a career in science. Perhaps equally importantly, Science Safaris brought us together as a group and helped us to bond with one another." p. 27 (*University of Warwick team*)