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HYBRID STEM INTERVENTION AS NEW POST-PANDEMIC APPROACH TO MOTIVATE STUDENTS TO STEM

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ABSTRACT

There has long been a struggle over how to increase student interest in careers in STEM and meet the labour market's need for specialised knowledge and skills. The long-standing debate at the EU level about the role of formal, informal, and non-formal education in meeting these challenges has not yet reached a clear conclusion. In the last decade, there has been a significant increase in the number of STEM programmes offered by various non-governmental organisations in Croatia. These interventions are often localised and have limited social impact, but there is a strong willingness to create an environment for their greater inclusion in the formal education system, triggered by comprehensive curriculum reform in Croatia. Motivation, especially intrinsic motivation, is a crucial driving force in our lives. In our pilot study, conducted with 6th grade elementary students, we aimed to explore the extent to which STEM interventions encourage students to learn more about the topic and whether it is possible to incorporate lessons learned from the pandemic into the design of future interventions. Our results show that there is no significant difference in student motivation after a 45-minute whole-class interactive intervention between face-to-face and virtual delivery. Although the intervention was entertaining, students perceived the science as interesting and useful rather than entertaining. Considering that students have positive attitudes toward Nature as a school subject, an early intervention with students at this age could be useful in maintaining their interest and preventing a decline in interest later in life. This finding is particularly important in the context of the transformation of the Croatian elementary school system into a "whole-day school", which provides room for incorporating this type of intervention into a regular school system.

KEY WORDS

STEM education, motivation, school, virtual, wow effect

CLASSIFICATION

APA: 2227, 2260, 2360, 3560
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INTRODUCTION

EU POLICY CONTEXT

The times we live in have changed the way we work, communicate and thrive. The ongoing double (digital and green) transition has been catalysed by the COVID-19 pandemic and the energy crisis. Learning and working in a digital (virtual) environment have become part of our routine in the last two years. The EU's transition to a resource-efficient, circular, digitised, and carbon-neutral economy and the widespread use of artificial intelligence and robotics are expected to create new jobs, while other jobs will change or even disappear [1]. In 2021, over 68 million people aged 25-64 were employed in science and technology in the EU, a 2,3 % increase from 2020. The EU Skills Agenda 2030 proposes 12 actions, including "Increasing STEM graduates, fostering entrepreneurial and transversal skills". People with high skills in STEM (science, technology, engineering, and math) are critical to driving the dual transition. However, only one in five young people in Europe complete higher education in STEM, which is less than two million STEM graduates each year [1]. On the other hand, the tests from PISA show that the percentage of low performance in basic mathematical skills is stagnating (22,9 % in 2020 compared to 22,7 % in 2010), while low performance in basic scientific skills is increasing at the EU-27 level (22,3 % in 2020 compared to 17,8 % in 2010). In Croatia, the trend is similar but the figures are higher (31,2 % in 2020 compared to 33,2 % in 2010 for mathematics and 25,4 % in 2020 compared to 18,5 % in 2010 for science) [2]. One of the EU recommendations to address this problem is: "Collaboration between formal, non-formal and informal educational providers, enterprise and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science and increase uptake of science studies and science-based careers to improve employability and competitiveness" [3].

CROATIAN CONTEXT

With more than 75 years of tradition, the Croatian Association for Technical Culture is the highest national institution in the field of technical culture in the Republic of Croatia. It is regulated by a special law and is financed directly from the state budget. Its mission is to stimulate and promote all activities in the field of technical culture and to harmonize the activities of national associations in the field of technical culture.

Since the early 2000s, there has been a growing number of activities in the field of science communication in other STEM disciplines in Croatia organized by public institutions. It all started with universities and research institutions organizing an "open day" and a Science Festival, followed by European Researchers Night projects, as well as numerous smaller initiatives (school visits, public lectures etc.).

In parallel, there is a growing nongovernmental organization (NGO) scene active in science communication and STEM educational activities, including workshops in their own premises, public events, visits to school activities, etc. These actions are often local and have limited social impact. Evaluation of these interventions is mostly internal, without longitudinal monitoring of participants or social impact.

Prior to 2020, there were limited opportunities for national funding of science communication and STEM education projects. From the background analysis of the European Social Fund (ESF) call for improving the capacity of civil society organizations in the field of STEM, it appears that in Croatia (at the end of 2019) only 1,15 % of all civil society organizations are registered for activities related to STEM and only 0,01 % of public funds allocated to civil society at the national level are used for them. In order to increase the impact of science communication and STEM education programs, it is important to map and evaluate the ongoing activities and establish some guidelines for future activities.

Comprehensive curricula reform of elementary and high school system in Croatia have started in 2018 with the implementation of an experimental program “School for Life”, followed by total implementation by 2021. One of the key goals of the reform is implementation of an approach based on educational outcomes, which are directed towards solving problems and critical thinking [4], which open the institutional system for novel approaches and interventions, especially in STEM. COVID-19 pandemics accelerate the implementation of novel teaching approaches, especially in a field of using digital learning tools and technology in general. The next step in the reform of the Croatian school system is the introduction of "whole-day school" [5] with a pilot phase (50 schools) planned for the 2023/24 school year, and with full implementation in 2027. This opens a new opportunity for cooperation between formal and informal education, especially in a variable part of the school day.

MOTIVATION MEASUREMENT

The impact of the intervention on students can be observed at different levels - overall satisfaction with the intervention, knowledge or skills acquired, attitude towards science or the subject STEM etc. Motivation is one of the most commonly used terms in evaluating interventions, and there are several theoretical concepts. Rosenzweigh and Wigfield evaluate the effectiveness of various motivational interventions in improving motivation in STEM through a review of the literature targeting middle and high school students. Overall, the results show that the interventions studied improve student motivation and various academic outcomes in STEM courses under certain circumstances. Intervention effect sizes varied widely, with researchers who implemented interventions reporting small to moderate effects on average. However, some researchers found large effects, while many others found mixed or no effects [6].

However, there are a number of aspects that should be considered to increase the motivational impact of the intervention. The study conducted in the USA and the Netherlands on students’ motivation and attitude towards STEM aimed to analyse motivation on two scales (controlled and autonomous motivation). It was found that the following characteristics of outreach activities were statistically significantly related to autonomous motivation and positive general attitude toward STEM: Workshop format, understanding of science, an out-of-school component [7]. Students prefer workshops to projects and lectures. Hands-on approaches at an early age when students are "doing the science" may be more affective compared to the "being a scientist" approach [8], with parents playing an important role in the process [9]. The wow effect is well known in marketing and is created by the perception of a memorable experience related to a product or service. Science communication and educational strategies from STEM try to achieve the same, especially with children. Although the wow effect is not a formal concept in educational theory, Kamstrupp has attempted to show its positive impact in teacher education in Denmark [10]. Some researchers are sceptical about the long-term impact on motivation for STEM, but the wow effect is the driving force of many social network challenges and could be useful in developing novel approaches to science communication and STEM education.

In the last decade, few studies have been conducted on STEM interventions in Croatia. Science competitions in STEM were for a long time only official activities for motivated students. Vinković and Potočnik analysed link between regional development index and student’s participation in the science fair competitions in biology, chemistry, physics, mathematics and astronomy. Students from the most developed regions of Croatia (Zagreb, Varaždin and Međimurje) participated more in science fair competitions (in all five monitored STEM subjects) on the national level compared to students from less developed regions. The authors stressed the importance of research of interest and motivation of the students and their mentors [11]. A qualitative analysis of data gathered during a four-year longitudinal study of relations between achievement, self-competence beliefs, and career interests among students of 16 Croatian elementary schools (JOBSTEM) suggest that the impact of intervention is related to previous STEM experience, as well as family and teachers support. For the maintaining of the interest, longer interventions focused to teamwork, autonomy in activities, learning through play and giving a sense of real-life usage is important. Moving towards younger age groups, especially with lower socioeconomic status and providing materials and resources for STEM activities at home are also suggested [12].

In our pilot study, we wanted to observe how "hidden motivators" affect student motivation and whether the wow effect motivates them to talk about it, explore more, and ultimately do it themselves. In addition, the COVID-19 pandemic has shifted many activities related to STEM to the virtual world. A deeper understanding of the triggers that move students to action could help science communicators and STEM educators design post-pandemic activities that combine virtual and face-to-face elements. Preliminary results already suggest that mixed STEM interventions may be more inclusive (especially for rural areas and/or students from lower socioeconomic backgrounds) and may encourage participants to be more open and participatory [13].

METHOD

INTERVENTION DESIGN

The intervention was designed in the form of a 45-minute workshop entitled "Water" The workshop was developed by chemistry student Maja Dugandžić, the first author of the manuscript, under the supervision of Marko Košiček, who holds a PhD in chemistry. All workshops were led by Maja Dugandžić.

The workshop consisted of theoretical and practical parts aimed at introducing scientific methods and scientific research and motivating students to conduct experiments themselves. During the workshop, "hidden motivators" were delivered. Simple experiments were presented, but some of them were explained without presentation and students were encouraged to try them at home.

Through the theme of water, many multidisciplinary topics were addressed, from chemical and physical concepts (density, solvent, heat capacity, surface tension, etc.) to ecology and biology. Water is simple, well known, safe to use and all experiments (presented or explained) can be easily repeated in any kitchen without special vessels or chemicals.

This activity was designed for 6^{th} grade Croatian elementary school students. 6^{th} graders were selected because they are already learning about nature and scientific methods, but do not yet have separate nature subjects (chemistry, physics and biology).

STUDY PARTICIPANTS AND DATA COLECTION

Elementary schools applied to an open call published for the Ruđer Bošković Institute Open day in spring 2021. The intervention was one of the offered activities during the virtual Open day without mentioning that this workshop is part of the research study. Teachers who chose to participate in the “water” workshop were contacted and informed about the study (without scientific details), and parents of students signed a written consent for data collection for this study.

Five schools participated in this study: elementary school Vladimir Nazor, Čepin; elementary school Miroslav Krleža, Čepin; elementary school Tordinci, Tordinci; elementary school Cvjetno, Briješće and elementary school Ivana pl. Matačića, Zagreb. Four of the five schools participated in the study with the next generation of sixth graders in the fall of 2021 (the school in Zagreb did not participate due to COVID -19). The intervention took place online in spring 2021 and face-to-face in fall 2021. The total number of 6^{th} graders who participated in this study was 187 (in the 2020/21 school year) and 141 (in the 2021/22 school year), giving a total sample size of 328.

Students were given two questionnaires, the first one a week before the intervention and the second one two weeks after the intervention. 154 students (47 %) responded to the first questionnaire and 124 students (38 %) responded to the second questionnaire. Responses were anonymous and passworded.

54 % of the paired responses were from students who had participated in the online intervention and 46 % were from students who had participated in the face-to-face intervention. There was no significant difference between the post-workshop questionnaire response rates between generations (online 36 %, face-to-face 40 %).

A total of 76 responses to the first and second questionnaires were paired beyond a reasonable doubt (61 % of the collected post-workshop responses and 23 % of all study participants). 68 % of the paired responses were from female students and 32 % from male students.

The first questionnaire was more comprehensive and included questions about attitudes toward school in general, academic achievement, socioeconomic patterns, hobbies, and interests. The second questionnaire was shorter and included control questions and questions about motivation and attitudes toward science.

ADDITIONAL DATA FOR COMPARISON AND DISCUSSION

To validate our results with other similar interventions, selected questions were included in other intervention series from our project partners at SCOPE (Virtual Arts and Culture Project). The interventions were 45-minute workshops conducted online. The topics were sound, water-earth-air, and cryptography.

The workshops took place in 22 elementary schools in 18 cities in Croatia, with more than 600 participants in 53 interventions. Responses from 3^{rd} grade (N = 54), 6^{th} grade (N = 53), and 7^{th} grade (N = 54) elementary school students were collected after the event.

DATA ANALYSIS

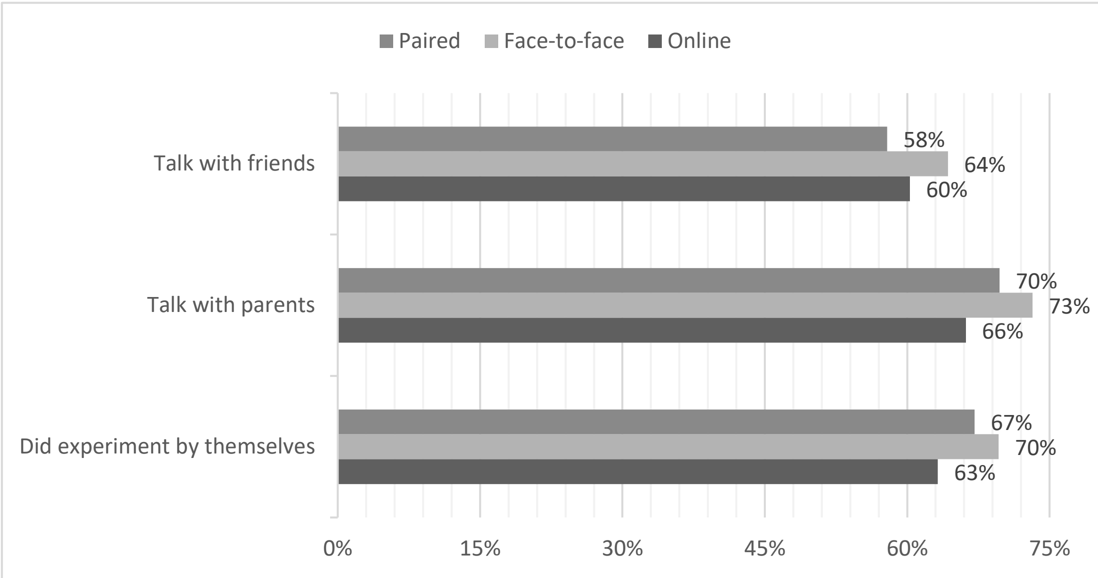
Statistical analysis was performed using difference test (difference between two proportions) and t-test for unpaired variables.

RESULTS

ONLINE AND FACE-TO-FACE INTERVENTION HAVE SIMILAR IMPACT ON STUDENT MOTIVATION

The COVID-19 pandemic has moved many activities into a virtual space. Science communication and educational activities that are interactive and personal addressed transformational issues. This study tested whether virtual interventions with a facilitator not physically present in the classroom differed from an face-to-face delivery of the same intervention in terms of student motivation. Student responses (68 online, 56 face-to-face, and 76 paired) to three questions about their post-intervention activities were compared (Fig. 1A).

A



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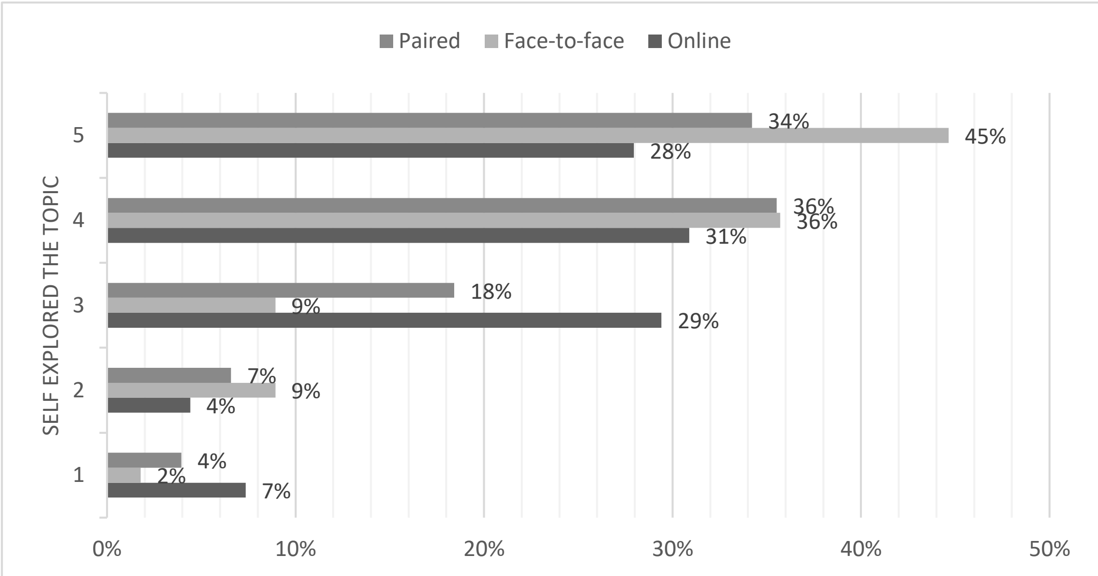

Figure 1. Activities after the intervention. **A**) there is no statistically significant difference between activities after online and face-to-face activities: did experiment by themselves (p = 0,414), talk with parents (p = 0,403), talk with friends (p = 0,649). **B**) Distribution of marks which show in which extent this intervention encourage students in research the topic by themselves moved to higher marks if intervention is done face-to-face (p = 0,024).

Because there were no significant differences in the three monitored motivational variables, a detailed analysis of the pairwise responses from the combined online and face-to-face interventions was conducted.

Students were also asked to rate their interest in the topic after the intervention by rating (1 strongly disagree – 5 strongly agree) the extent to which they agreed with the statement “This workshop encourages me to explore the topic”. Nearly 70 % of students rated this statement at the two highest levels, which is consistent with the previous three motivational variables (Fig. 1B). There is a statistically significant difference in marks distribution between the online (average 3,68) and face-to-face (average 4,13), p=0,024. This result suggests that personal contact during an intervention has a positive influence on the subjective opinion about the intervention, but not on the stimulation to concrete actions (e.g., to repeat the experiment themselves).

To validate our findings, we compared them to interventions delivered by our partners to sixth graders in the same school year by different facilitators on different topics. About 79 % of the students who responded to the questionnaire indicated that they tried to repeat the experiments at home. There is no statistically significant difference between frequency of this answer between our and this intervention Virtual Arts and Culture Projects (*p* = 0,138). Interestingly, motivation decreases sharply in 7th grade, where only 17 % of the students who answered the questionnaire indicated that they tried to repeat the experiments at home. This striking result should be investigated further (Fig. 2). Third graders are probably still too young to do the experiments themselves, so this activity depends on parents' time and willingness to participate.

The question about self-exploration of the topic was a yes/no question, so it is not possible to fully match it with our results, but about 1/5 of the participants indicated that they were exploring the topic themselves. Similar to the sixth graders' responses are the third graders' responses, but there is also a significant decrease in seventh grade, which is consistent with the previous question (Fig. 2).

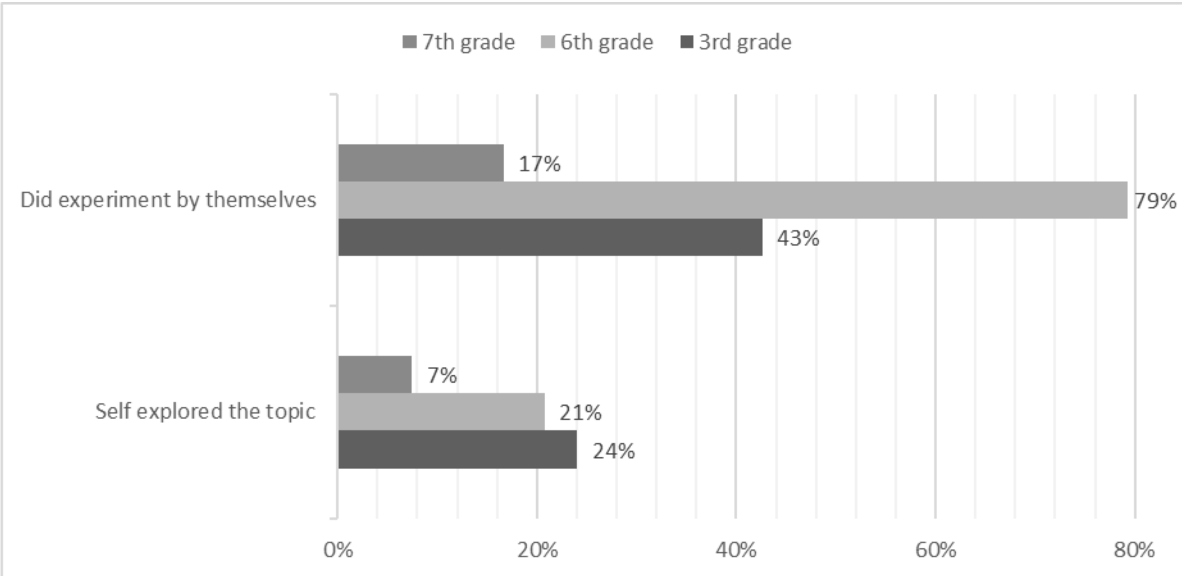

Figure 2. Data comparison with other intervention and age groups. 6th graders were the most active in experimenting at home (no statistically significant difference between frequency of this answer between our and this intervention (*p* = 0,138). Self-exploration of the topic was yes/no question, so it is not possible to fully adjust it with our result.

WOW EFFECT IS NOT JUST ENTERTAINMENT

In both questionnaires, students were given a set of five words from which to choose one that best described science. The distribution of responses is shown in Fig. 3. 32 students (42 %) chose different words in both questionnaires. There is a notable but not statistically significant decrease (*p* = 0,084) in the word "difficult" - 4 students change it to "useful" and 3 students to "interesting" after the intervention. Although there is an increase in "interesting" it is not statistically significant (*p* = 0,139). Only one student changed the selection from "useful" to "difficult" after the intervention. There was only one selection "boring" before the intervention, and it was replaced by "interesting" after the intervention.

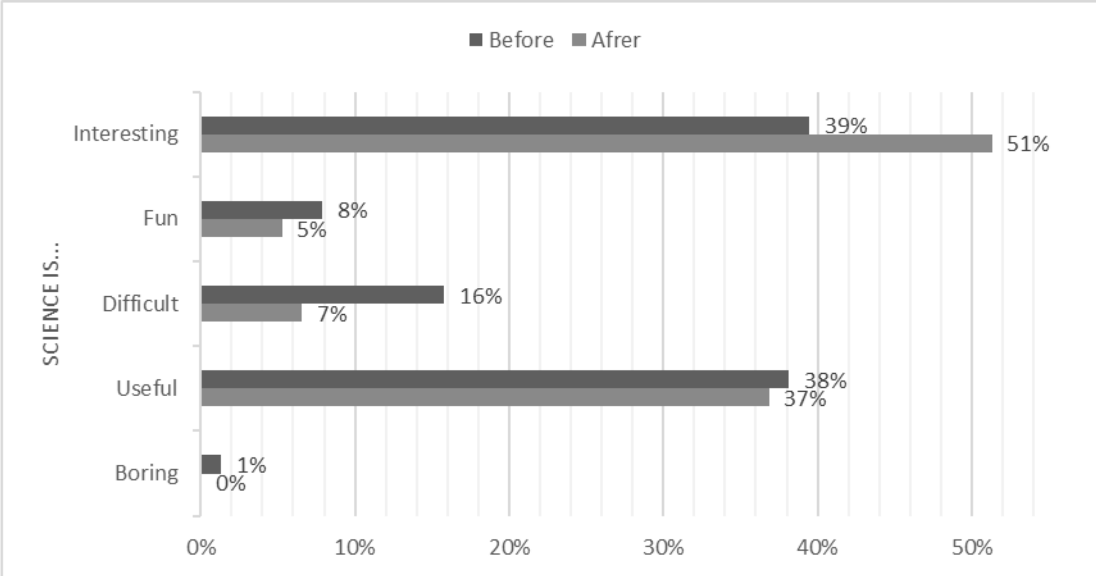

Figure 3. Distribution of selected words which best describe science before and after the intervention. There is no significant difference in the distribution of most selected words (interesting and useful), as well as for word difficult although the difference is notable (p=0,084).

Interestingly, the distribution of selected words did not change when we filtered out only the responses of students who indicated that they try to conduct experiments at home ($N = 51$) (Fig. 4). The students who described science as “difficult” also attempted to conduct experiments themselves. Next to the word “difficult”, the word “fun” was the second lowest selection, decreasing slightly after the intervention.

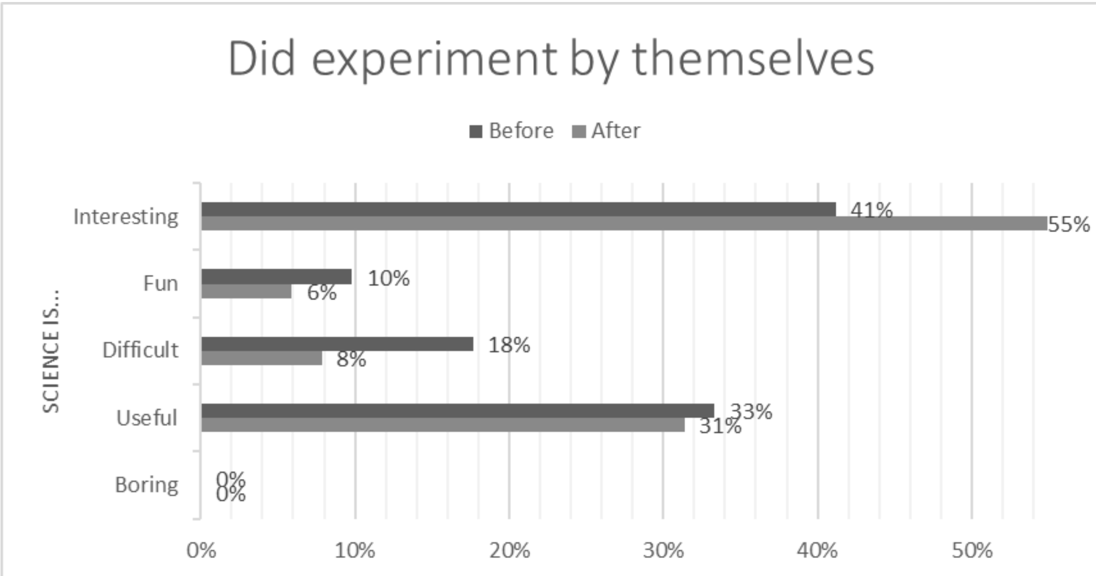

Figure 4. Selected word distribution among students which did experiment by themselves at home after the intervention. The distribution is similar to all answers presented in Figure 3.

Comparing this result with the responses collected after the partners’ interventions (Virtual Arts and Culture Project), the cumulative selection of the two most important words “interesting” and “useful” was similar, but with a different ratio (51 % “interesting” and 37 % “useful” vs. 32 % “interesting” and 47 % “useful”). This may be due to different topics that can be related to real life problems (useful) to different degrees. The seventh graders’ responses were consistent with the sixth graders’ responses. The distribution of the selected words among third graders varied widely. “Fun” was chosen more often in third grade than in sixth and seventh grade. At the same time, "boring" was chosen 6 % of the time, and “useful” was chosen much less frequently. The frequency of “difficult” is also increasing (Fig. 5).

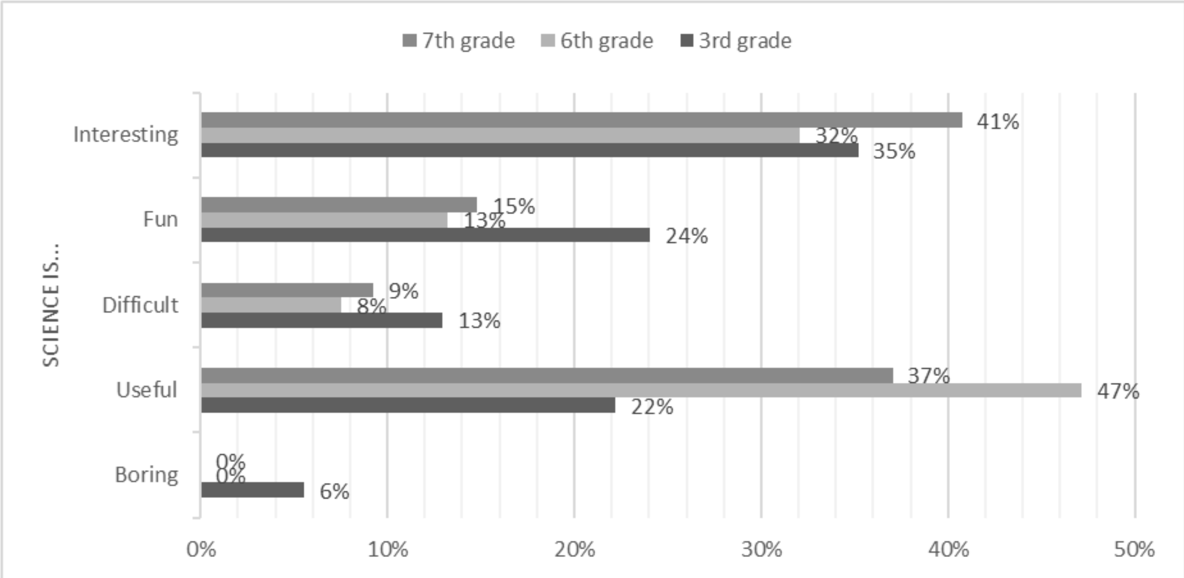

Figure 5. Distribution of selected word in partners’ interventions in three age groups. Distribution of the selected words in 3rd graders differ from 6th and 7th graders in the selection of the less frequent selections – “fun”, “difficult” and “boring”.

NATURE IS A ONE OF THE FAVOURITE SCHOOL SUBJECTS IN 6TH GRADE

Students in our cohort completed 5th grade with an average grade of “very good” (4,54, rank 3-5) and are equally distributed in general feeling about the school. In the statement “I like going to school” 38 % disagree, 33 % agree and 29 % have a neutral answer. On the other hand, 67 % of them say that it is easy for them to complete their schoolwork.

Overall, their favourite subjects are foreign languages, history, and nature, while technical culture, musical culture and mathematics are less popular (Fig. 6).

Mathematics is generally disliked. Mathematics is one of the least liked subjects in our study. 19 % of students like solving math problems, and 66 % of students say their classmates dislike math.

In contrast to math, nature is one of the top 3 subjects in school and students consider themselves good at the subject. 68 % of students say they like exploring new things, and 58 % of them say school makes them think and develop new ideas. Although these are indirect indicators of science education, students do not directly associate this with science. The statement “Science is taught in 7th grade” is disagreed with by 33 %, 36 % gave a neutral response, and 31 % agree with the statement. Slightly more of them agree with the statement “In school we learn about science and research” (15 % disagree, 34 % neutral, and 52 % agree). Students are also neutral about the statement “At school we often do experiments” (30 % disagree, 34 % neutral, 35 % agree).

The majority of students claim to be good at computer science (72 %) and nature (63 %), while only 42 % claim to be good at mathematics (Fig. 7).

Lower elementary students’ positive attitudes toward science (before they are formally taught chemistry, physics, and biology) provide room for more activities and interventions in students’ free time. In our study, only 2 of them report participating in STEM activities in their free time,

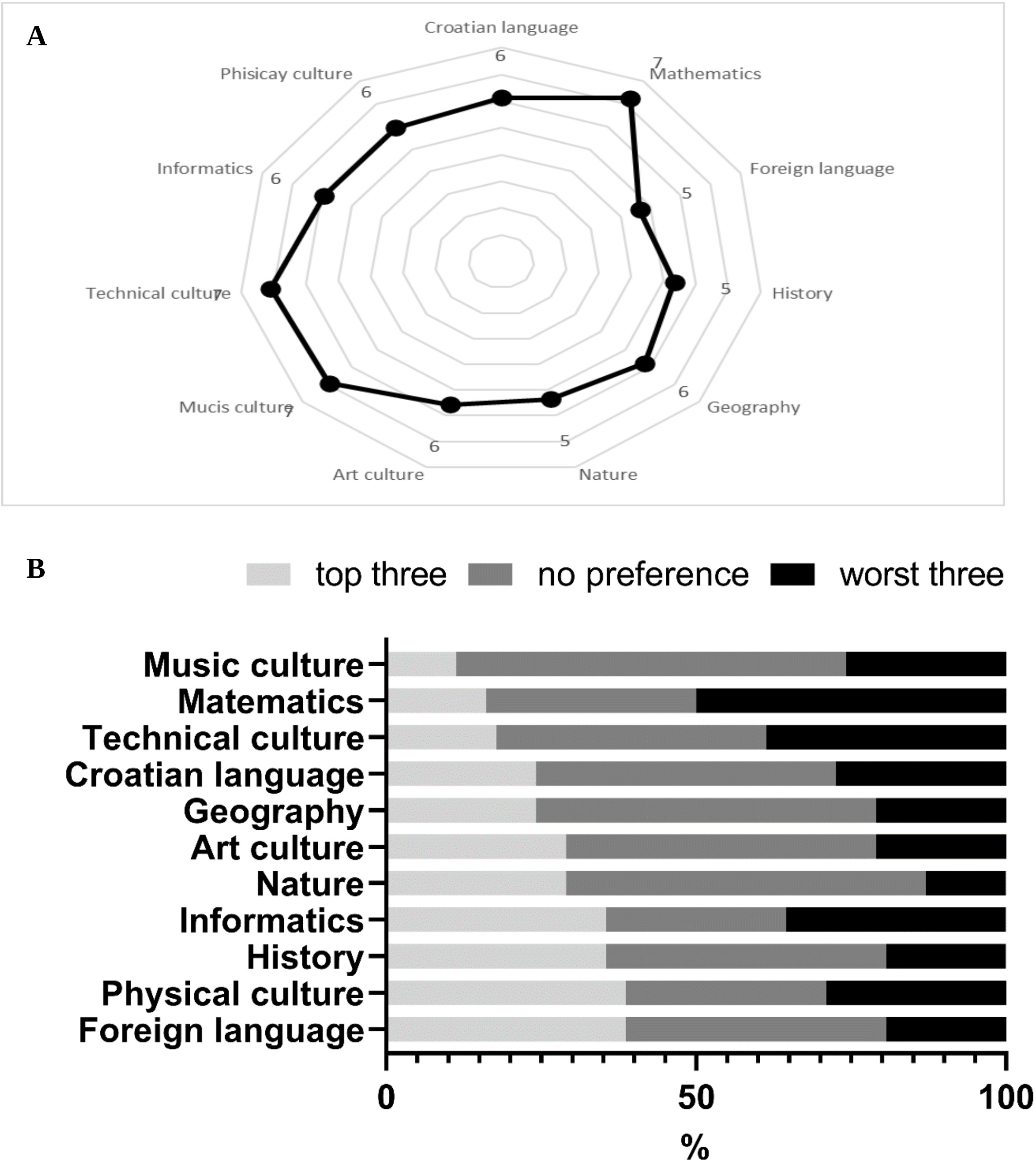

Figure 6. Distribution of ranking of the school subjects overall average (A) and top three and wors tree (B).

and 5 of them watch documentaries on TV. Most of the students (more than half of them) spend their free time in front of TV (series and movies) or on social networks. Between 40 and 50 % of the students said that they play sports, video games, or paint/sculpt.

LIMITATIONS AND FUTHER RESEARCH

The main goal of our pilot study was to develop a motivational monitoring tool that can be adapted for broader use in STEM interventions. Our goal is to create a functional instrument that can be integrated into standard project evaluation forms and provide valuable feedback to STEM educators and science communicators. The hybrid model provides the ability to quantify post-intervention activities. The next step is to link the "hidden motivators" to supplemental materials that can be used for do-it-yourself activities and/or deeper exploration of the topic after the intervention.

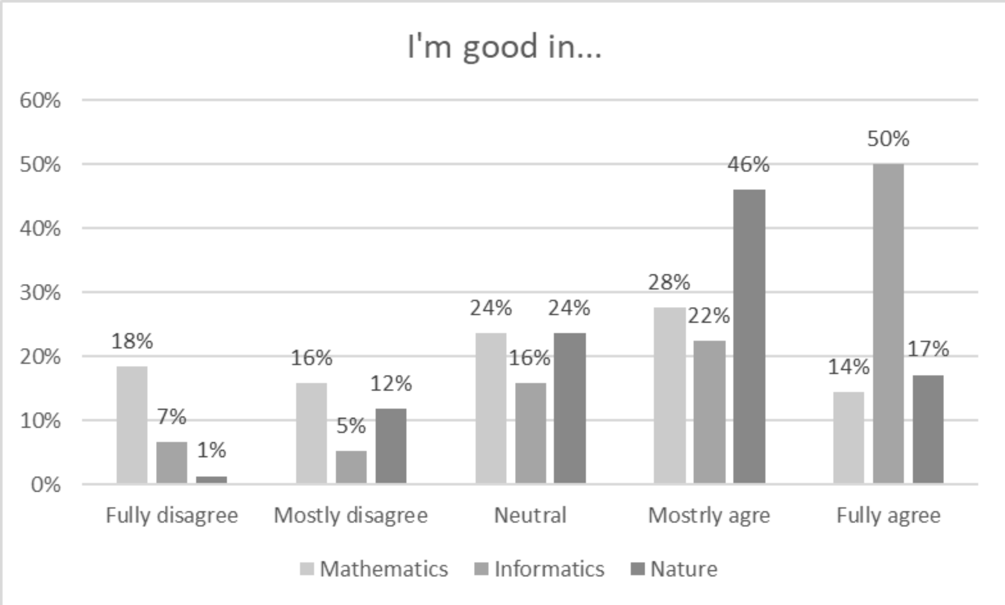

Figure 7. Distribution of self-estimated subject competence.

To provide recommendations for broader application of the tool, we tested our design on a controlled sample. The designed 45-minute workshop was delivered virtually and face-to-face by the same presenter in the same schools in collaboration with the same subject teachers in two consecutive generations of sixth graders. Because our sample is relatively small and not representative, our findings need to be validated in planned broader research.

CONCLUSIONS

Our study suggests that 45-minute interactive workshop-like interventions can motivate students to independently explore STEM topics, regardless of their grades or attitudes toward science. Nature is a widely accepted subject, and interactive activities can provide much more than just the wow effect. Unfortunately, access to optional STEM activities (offered by the academic community and/or NGOs) is not evenly distributed in Croatia. Incorporating these types of activities into "whole-day school" may partially overcome this problem. Our findings suggest that online versions of activities may be a good alternative while the system is being developed. Future collaboration among key stakeholders-schools, government, academic community, and NGOs-is a prerequisite for scaling up ongoing activities and experience.

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