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***Abstract* - Elementary and high school students learn about numerous physical phenomena that make up our everyday life. However, physics is most often perceived as boring and only a handful of students remember what they learned in the classroom. Schools nowadays have the necessary equipment, such as micro:bit single board computers (SBCs), to digitalize physical experiments and make them more attractive to students. Due to limited teacher training and learning material availability, these modern tools are unfortunately often left out of the physics class. In this paper, we describe Galileo XR (Extended Reality) – a learning activity, ranked among the best three proposals at the Science is Wonderful! 2023 competition, wherein students' study everyday physical phenomena in a fun and inclusive way. The gamified scenario guides them through 6 workstations, corresponding to 6 physical phenomena, where they are embraced to make certain observations and record measurement data using different sensors on the micro:bit SBC, for which they are rewarded with encrypted clues regarding the final solution. Students are motivated to apply the scientific method throughout their quest to find the forgotten scientist, Galileo Galilei. Additionally, we evaluate the observations and student questionnaire results, obtained during Galileo XR's prototype launch.**

Keywords - microcomputer, physics, extended reality, gamified learning, deciphering

I. INTRODUCTION

When we talk about teaching science, technology, engineering, and mathematics (STEM) in schools, the emphasis is on the upper secondary level of science teaching. The results of the SECURE project [1], which deals with encouraging and preparing children for future careers in MST (Math, Science, Technology) from an early age, demonstrate that positive attitude towards all MST subjects decreases with age, and the biggest drops take place between age 8 and 11. Also, in all three MST subjects, activities in all age groups had the greatest impact on the students' positive attitude towards the subject, except for science at the age of 13 when 'themes' predominate. Although the number of people with higher education degrees is increasing, this increase has not occurred in the field of MST, and among students who graduate in these fields, women are extremely underrepresented. This is supported by the PISA 2018 Science results, in which only 6 EU countries achieved an average score of more than 500 [2]. In 2018, the underachievement rate stood at 21.7% in reading, 22.4% in mathematics and 21.6% in science. Over the 2009-2018 period, performance in science and reading deteriorated at the EU level [3]. Hence, children around the age of 10 require additional attention to nurture their interest in STEM during these pivotal years. In addition, the digital literacy of students should also be mentioned. Contrary to common belief, findings from the first two cycles of the International Computer and Information Literacy Study (ICILS) in 2018 [4] show that today's youth is not a generation of digital natives. Instead, according to the results, young people do not develop sophisticated digital skills just by growing up with digital devices. In 9 of the 14 EU Member States participating in ICILS, more than one third of students scored below level 2 on the ICILS CIL (Computer and Information Literacy) scale, which can be considered the threshold for failure in digital competence. This emphasizes the importance of focusing on the development of digital skills through formal education and enabling the use of digital tools as productive resources for learning and participation in the digital society.

There is general agreement among practitioners [5] that the way science is taught at the primary school level affects students' perception and attitude towards science and the subsequent inclination towards STEM subjects and careers. Elementary school teachers may have a central role; however, they often feel underprepared to approach STEM subjects in their classrooms. Their lack of self-confidence and ability to teach science is a major issue of concern in primary science education [6]. Accordingly, key strategies concerning teacher training have been devised to provide more effective STEM training in schools and foster the STEM culture [7]. A large-scale approach to STEM promotion has been rolled out by the European Commission (EC) in 2015 under the name Science is Wonderful (SiW), which bring together students, teachers, and researchers to discuss STEM topics on a more abstract level [9]. For the 2023 edition, the respective subject area researchers and teachers were given a rare opportunity to team up and to co-create learning material (experiment, quiz, game, or any other activity) that must have a real-life application [10]. Among all SiW proposals, three are chosen by the EC for translation into multiple languages, spoken within the EU, and for further professional development. The work at hand describes our submission to SiW 2023 – ranked by the EC among the best three proposals – *Galileo XR escape room: application of the scientific method in the discovery of physical phenomena with micro:bit programming, experiments and deciphering*

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or shortly *Galileo XR: finding the forgotten scientist*. Our contributions are threefold:

- Describing the STEM learning scenario (LS), where students aged 7 – 15 improve their programming, physics, and auxiliary knowledge through the application of the scientific method.
- Evaluating the proposed activity's impact on students, participating in a prototype implementation, highlighting the positive aspects and the shortcomings that need to be addressed.
- Providing public access to the developed material through an online repository [11], hence, empowering educators to teach science at the primary education level by the International Standard Classification of Education (ISCED 1) and the lower secondary education level (ISCED 2) [12] from a more modern perspective.

The paper is structured as follows: Section II. describes the proposed Galileo XR LS, student questionnaire results from a prototype classroom implementation are presented in Section III., and Section IV. summarizes the work at hand.

II. Galileo XR: Finding the Forgotten Scientist Learning Scenario and Its Application in Elementary School

A. *About the learning scenario*

Affordable single-board computers (SBCs), like the micro:bit, are equipped with several sensors, and are easy to operate [13], allowing students to increase their digital literacy through a multidisciplinary and interdisciplinary approach. It only takes a few visual blocks or lines of code to add an extra dimension to (often outdated) physics experiments. However, measurements alone do not add value in the absence of critical thinking. The glue between the two is the scientific method, which includes thorough observation, review of existing sources, formation of hypotheses, evaluation through measurement, and dissemination of results. By applying the so-called Inquiry-Based Science Education (IBSE) 5-step procedure, students gain an understanding of the studied physical phenomena from a hands-on perspective and are offered insight into the fundamentals of each research activity [14].

The *Galileo XR: finding the forgotten scientist* LS proposes a game-based educational process for students aged from 7 to 15 years that motivates them to critically evaluate basic physical phenomena (e. g. light), formulate a hypothesis, evaluate their opinion by programing an SBC to capture relevant measurement data, and disseminate the lessons learned among their peers.

B. *Work process*

The LS is named after Galileo Galilei, the father of the scientific method, who is the "forgotten" scientist that students are looking for. Teachers can choose one of the two proposed workflows – a *group activity* or a *competition activity* for students divided into a total of 6 teams, depending on how much time they have available for the implementation. Both proposals include the same activities: students participate in a game like a treasure hunt, face physics-based challenges, decipher clues and answer questions through the XR application, with the aim of finding the forgotten scientist (based on collected clues (ciphered facts) from his life), and prepare a presentation on the studied physical phenomena, the corresponding micro:bit sensor together with cases of its use in everyday life and clues from the life of Galileo Galilei. In the end, the teams disseminate their learning results and conclusions by presenting them in front of their peers.

Fig. 1 shows the group activity workflow in which one team of students works on one workstation, and together they uncover the forgotten scientist. Alternatively, the 6 teams can partake in a competition where each team must locate all the micro:bit beacons and attend all workstations with the goal of finding the forgotten scientist first, hence, repeating steps 2 – 6 for each workstation.

C. *Treasure hunt*

The treasure hunt activity takes advantage of the localization capabilities of the Bluetooth RF (Radio Frequency) transceivers found on the micro:bits. Each of the six beacons consists of a micro:bit and a QR code. The latter acts as a gateway to the XR quiz application, while the former continuously transmits a signal on a predefined radio group index (unique channel). The micro:bits first given to students are pre-programmed to measure the RSS (Received Signal Strength) of a particular beacon, allowing students to find its location as if they were participating in a treasure hunt. The beacons scattered throughout the school (or even the school yard, if plausible) will make the activity more fun and give the students much needed mobility.

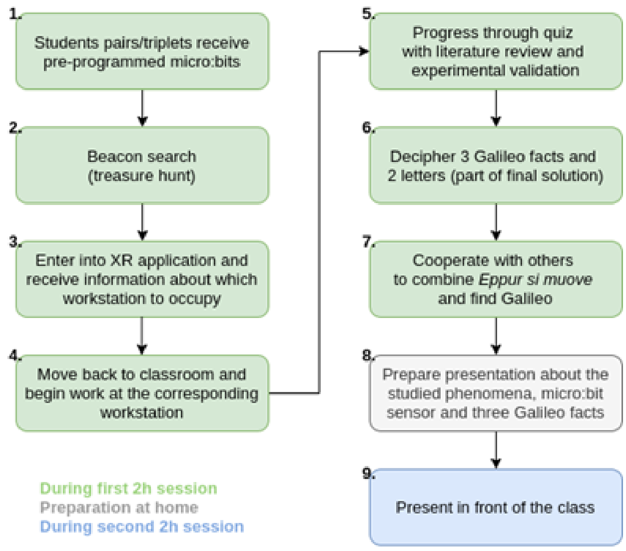

Figure 1. *Group activity* workflow

D. XR quiz application and measurement tables

An XR quiz application, pictured in Fig. 2, is designed for each workstation. It features 3 quiz questions about the corresponding physical phenomena and the micro:bit sensor's applications. Upon completion, the students are granted 3 encrypted clues about Galileo Galilei's life and 2 letters (part of the famous Galileo quote *Eppur si muove*) that make up the final key. The quiz is designed as an XR application, since this has proven as a particularly effective way of motivating students in the 7 – 15 age group [15].

In addition, each workstation comes with pre-designed measurement tables, shown in Fig. 3, to provide the students with more guidance on which measurements to conduct, and to give them a tangible resource that they can use for orientation when designing the final presentation.

E. Deciphering task

The students receive three encrypted clues from Galileo Galilei's life upon completion of the XR quiz at one workstation. These are encrypted using Caesar's cipher, a form of encryption where the letters in a word are substituted by their counterparts in a shifted alphabet. A straightforward, yet very mysterious encryption the first-time students encounter it. The encryption offset is fixed for all deciphering tasks, and students are provided with conversion tables, in addition to a deciphering procedure example. With this task, students are offered insight into the basics of information theory, useful for password and data encryption, as well as encoding in communication systems.

F. Workstation overview

Fig. 4 shows the 6 workstations that comprise Galileo XR, further detailed in the following paragraphs. Examples of students experimenting at workstations 1 and 6 are provided in Fig. 5 and Fig. 6, respectively.

1) Nikola who? (Magnetometer) The students learn about the Earth's magnetic field, how strong it is, and that not only cars are named after Nikola Tesla. They confirm that magnets have a magnetic field and discover that an electrical current will produce its own magnetic field (optional); hence, they understand what is meant with the word electromagnet. Hopefully, they will remember the lessons learned and not follow the compass (analog or on a smartphone) in the wrong direction the next time they go on an outdoor adventure.

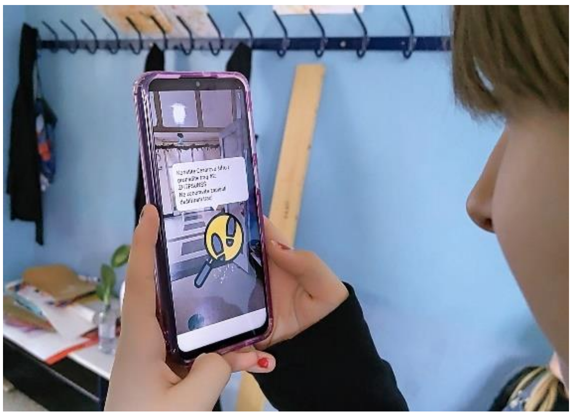

Figure 2. XR app for engaging students in solving quiz questions and deciphering clues from life of Galileo Galilei

Workstation: *You can run, but you can't hide - I still see you (radio communication)*

Remember to take notes from the material (micro:bit sensor and physical phenomena) at each station. You will need it later to create a team presentation. Notes write below.

Think, discuss with your peers and mark the answer - which material will block the radio signal best?

a) Normal paper
b) Baking paper
c) Aluminum foil

Now, use the measuring tables to note the measuring results and to check your assumption.

1. Wireless signal attenuation by different materials

	Normal paper	Baking paper	Aluminium foil
Received strength when obstructed			

Figure 3. Pre-designed measurement tables at each workstation

2) The laws of attraction (Accelerometer) The students grasp the concept of physical force through acceleration. Starting from gravitational acceleration, they evaluate the forces exerted on different parts of their bodies during physical activity and discover the shock absorbing role that joints play in our bodies. E.g., that's why we don't see blurry while running.

3) You are as cool as deodorant. Wait, what? (Temperature sensor) The students learn about the connection between gas temperature and density. They get to experience how warm air rises upwards, making way for colder air to sink towards the ground. Hence, they become acquainted with convection. They also get acquainted with an everyday phenomenon – compressed gas expansion (deodorant) – to get an idea of how gas expansion / compression can be used for heat conversion. For example, in refrigerators and air conditioning. Finally, they are introduced to the concept of efficiency by comparing the light intensity of a projector (through heat conversion) to the temperature of the projector's outlet air.

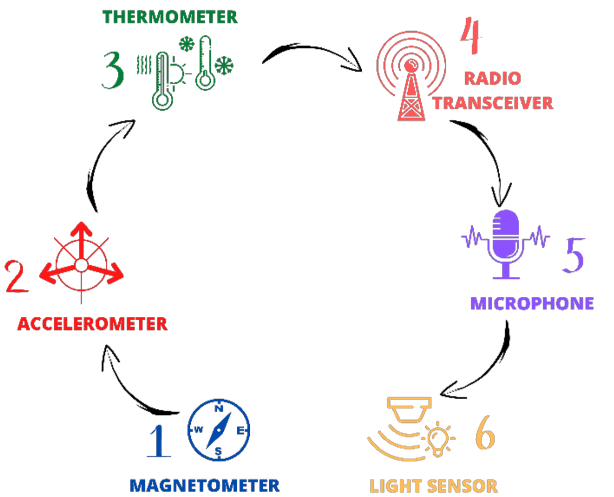

Figure 4. Workstation overview

Figure 5. Example of a classroom workstation setup

4) You can run, but you can't hide - I still see you (Radio transceiver) The students become acquainted with the propagation characteristics of electromagnetic waves – mainly their obstruction and amplification using different materials. They also grasp the concept of radar, letting them to understand how their ears enable them to locate sound sources, in addition to realizing how everyday technology, such as cruise control in cars or aircraft / vessel tracking works.

5) You are too loud! (Sound sensor – microphone) The students are introduced to machine learning (ML) through process characterization and knowledge-based inference. They use the micro:bit's microphone to determine the dependency of the measured noise in relation to the number of people clapping, which they can then use for occupancy estimation. Moreover, the students are introduced to sound level measurements and embraced to look further into more complex measurement techniques (frequency, tempo).

6) Roses are red, violets are blue, don't be so sad cause I'll enlighten you (Light sensor) The students understand that the perceived color of objects is the result of light reflection. For example, a leaf is green since chlorophyll reflects green light and not the other way around. Furthermore, they get a glimpse into the color spectrum by dissecting white light into red, green, and blue (RGB) color components, elaborating on sunlight's spectrum, and evaluating the micro:bit's frequency response at all three color components.

G. Finding the final key

Successful quiz completion also grants students with 2 letters of the final, most well-known, hint connected to the life of Galileo Galilei. The 6 letter pairs are: *EP PU RS IM UO VE*. This is Galileo Galilei's most widespread statement ("and yet it moves"), showing his determination in supporting scientific fact despite the lack of public support. A statement that the students should keep in mind during their educational journey and in their later careers. The students are provided with an online shuffler application where they can rearrange the letter pairs until they obtain the correct phrase *Eppur si muove*. Once the students start to assume that the forgotten scientist is Galileo Galilei, they can verify their assumption by entering his name as the passphrase in an online form.

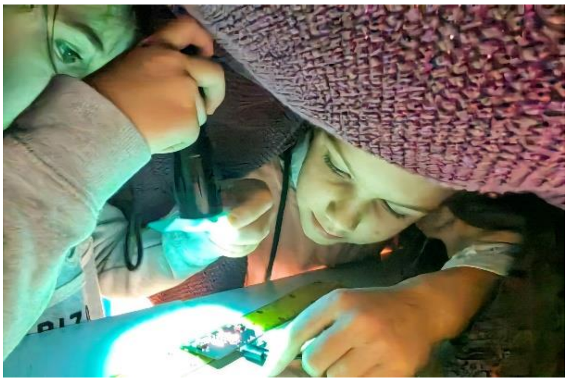

Figure 6. Evaluating the micro:bit's frequency response at all three components (RGB)

H. Work process instructions

Student instructions are arranged in four tiers in accordance with the level of guidance they provide, giving teachers full liberty in how much support they wish to give, e.g., age groups or even particular teams based on the ambitions of the students. The teacher can, appropriate with the age and programming skills of their students, choose the materials according to which the students will program the micro:bits (in the visual MakeCode editor or in the Python editor) for performing experiments. The four tiers offer incrementally less guidance: tier 1 provides the students with full instructions on how to design the program using MakeCode or Python, including screenshots of the final solution, while tier 4 only describes the studied physical phenomenon and employed sensor.

Student instructions are designed using MS Word (printed version) and MS Sway (web version), shown in Fig. 7, both of which feature built-in *text translation*, allowing students of all nationalities to access the material in their native language. Moreover, Sway's adaptability – adjustable contrast levels and the screen reader functionality – makes it applicable to student groups with special personality traits and visual impairments.

III. CLASSROOM IMPLEMENTATION RESULTS

The Galileo XR escape room prototype was tested at the Eugen Kvaternik Elementary School in Velika Gorica during the *22nd Winter School of Informatics* from January 2 to 5, 2023, organized by the Association of Technical Culture and Informatics Pedagogues, Velika Gorica, for a

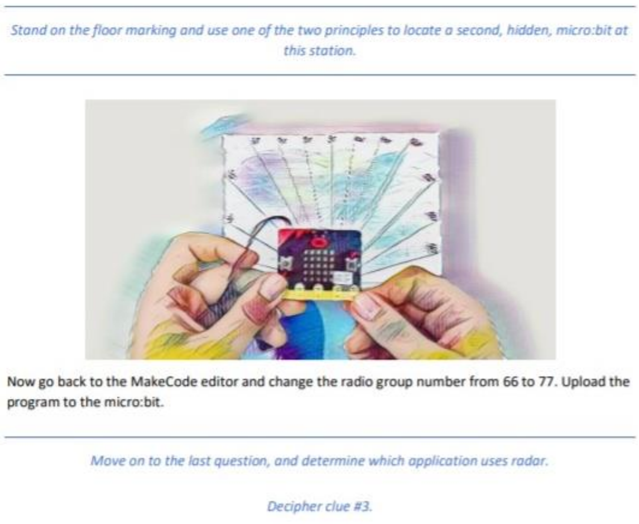

Figure 7. Student instructions are available online and on paper

total duration of 6 full hours (6 x 60 minutes). Workshops for the Winter School of Informatics are usually designed and conducted by ICT or technical culture teachers to enable students to spend quality free time during the winter holidays. The total number of students who participated in testing the learning scenario prototype (contest version) over 4 days was 18 (6 girls and 12 boys) aged 7 to 14 (ISCED 1 and ISCED 2 level). 15 students (4 girls and 11 boys) participated in the evaluation [16] of the activities carried out during the learning scenario testing. Fig. 8 shows the students' evaluation responses regarding the activities carried out and the content of the learning scenario itself. The overall conclusion obtained through the evaluation form, including other questions and statistical information (e.g., age), is as follows:

- 60% of students found the tasks at the workstation's were always fun and interesting, 26.7% found the tasks often fun and interesting, while 13.3% of them found that the tasks were difficult (ISCED level 1 students),
- 20% of students occasionally needed the teacher's help during work, and 6.7% of them needed help all the time (ISCED level 1 students),
- 46.7% of students said that it was never difficult for them to work in a team, and for 40% of students it was rarely difficult, which is supported by the fact that 53% of respondents selected the sound workstation as their first choice as the most entertaining and most instructive, because they cooperated with each other through joint clapping, as they explained in the free form comments,
- 40% of students believe that all team members contributed equally to solving tasks.
- 60% of students felt comfortable and relaxed during work,
- in reference to the clarity and transparency of the written instructions for micro:bit programming, 73.3% of students indicated that the instructions were always clear, 13.3% thinks that they were often clear, and 13.3% decided that micro:bit programming instructions were occasionally clear,
- 60% of students declared that the instructions for conducting the experiments were always clear to them, 13.3% consider that the instructions were often clear, and 26.7% students declared that the instructions were occasionally clear to them,
- 80% of students think that deciphering with Caesar's code was fun and easy.

Students emphasized their own activity and engagement in work, experimenting and research, multidisciplinary application of micro:bit coding through physical computing in solving real-life problems, as well as team collaboration. Their impression of the whole workshop is that they felt comfortable and learned a lot while having fun.

After implementing the learning scenario prototype, analysing the evaluation results and other data collected by

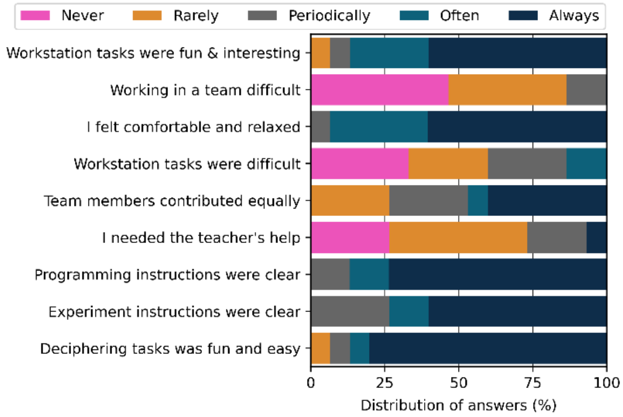

Figure 8. Students responses in evaluation of the Galileo XR activities, Likert scale

observing the work process, we concluded that the activities and instructions should be organized and adapted for the three student age groups, since they have different knowledge and concentration levels that will require different amounts of support. An exception are students with special needs (students with learning and / or developmental difficulties, i.e., gifted students). For such students, the teacher can choose materials adapted for a higher or lower age group, to meet their needs and ensure inclusion in the organized activities.

Age group 7 – 9:

- work in pairs or groups of 3 members and only the group activity is carried out (one team – one workstation),
- program the micro:bit using the visual programming language MakeCode,
- receive tier 1 or tier 2 instructions (full guidance or assembling pre-defined code blocks).

Age group 10 – 12:

- carry out activities in one of the two proposed versions (group or competition), according to the teacher's decision,
- create programs for micro:bit in the visual MakeCode editor according to the instructions for either of the 4 programming skills levels.

Age group 13 – 15:

- carry out activities in one of the two proposed versions (group or competition), according to the teacher's decision,
- create programs for micro:bit in the Python MakeCode editor according to the instructions for one of the 4 programming skills levels; optionally, the teacher can also choose a visual programming language for this age group, but only for programming skills levels 3 and 4.

IV. Conclusion and Future Work

The work at hand proposes a multidisciplinary STEM learning scenario for improving the programming knowledge of students, aged 7 – 15, during the performance of fundamental physical experiments, while also acquainting them with the scientific method. Gamification [17] is employed to motivate the students to actively participate, as well as to freshen up their minds through moderate physical activity. Using micro:bit SBCs as the principal learning platform, we enable a cost-efficient way for schools to incorporate the proposed STEM learning scenario into their curriculum. A prototype implementation in the classroom shows that the benefits of this STEM learning scenario are multiple: the engagement of students and their motivation are increased by applying the Inquiry Based Learning (IBL) method that increases student autonomy; students are active during work, which achieves a more significant pedagogical effect; the activities in which they participate relate to real situations and problems, so students build not just knowledge and understanding, but higher-order skills needed in everyday life - ability to synthesize and evaluate, creative thinking and critical thinking, i.e. competencies needed in the 21st century. Physical computing, which involves using specialized hardware to interact with the real world, i.e. writing programs to control input and output devices, such as in this case the buttons, sensors and LEDs on the micro:bit, promotes a broader perspective and deepens students' programming skills with theoretical knowledge of how hardware works. In this way, digital skills are linked to other subjects, such as science in this case, showing students how these skills can be applied to solve real-world problems. Furthermore, the use of microcomputers in the classroom helps bring learning to life through a holistic computing experience by combining hardware and software, linking it to subjects outside of computing, and evening out gender inequality by allowing students to be expressive and creative. Based on the results of the student evaluation and the data collected by observing the implementation process of the learning scenario prototype, we concluded that future work should address the limited inclusion of ISCED level 1 students by arranging the otherwise written instructions into short video excerpts or animations, that would better capture their full attention. Furthermore, ISCED level 2 students would benefit from a preliminary study of the addressed phenomena in physics class, preceding the learning scenario activities, thereby acquiring the necessary prior knowledge needed to formulate a well-thought-out hypothesis.

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