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Secondary Education Students' Knowledge Gain and Scaffolding Needs in Mobile Outdoor Learning Settings

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Abstract: Science education enhances students' scientific literacy in order to interact with the world responsibly and contribute to democratic and informed decision-making. The emergence of place-responsive pedagogy and mobile technology with a variety of affordances has refocused attention on students' direct embodied experience. P-responsive pedagogy combined with mobile technologies provides numerous opportunities for investigating, across contexts, everyday socio-economical environmental problems inherent to a particular location. Forming an evidence-based decision on socio-economical environmental real-life problems requires a more in depth understanding of natural processes than just making use of everyday knowledge that is based on perceptions and direct observations. Therefore, this paper aims to explore the secondary education students' (a) awareness and understanding about a timely socio-environmental challenge, (b) development of the scientific vocabulary, (c) scaffolding needs during the mobile outdoor collaborative inquiry-based learning event. To fulfill the aims, action research with an experimental technology-enhanced collaborative inquiry learning design was created to investigate students' knowledge gain and scaffolding needs. Three interventions with a total of 68 secondary education students (age 14–15) were conducted. Both quantitative and qualitative data were collected and analyzed. The results demonstrate the change in students' opinions about the complex socio-economical environmental challenge and transformation from everyday concepts to more scientific knowledge, and their need for conceptual and procedural scaffolding. This paper adds new insights on how to utilize non-gamified use of mobile technology to empower secondary students' scientific literacy and understanding in authentic settings.

Keywords: mobile outdoor learning; inquiry-based learning; sustainability; scaffolding; scientific knowledge

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1. Introduction

The United Nations Educational, Scientific and Cultural Organization (UNESCO) describes sustainability as an evolving concept related to improving everyone's quality of life by considering social, economic development, and environmental protection [1]. The idea of sustainability, as defined by UNESCO, encompasses three critical dimensions: economy, society, and environment. These dimensions are not distinct from one another; they are all intertwined. As part of the 2030 Agenda for Sustainable Development, the Sustainable Development Goals have been defined [2,3]. These goals draw attention to common needs across nations, societies, and cultures for practices that preserve the survival of environmental and social institutions while also considering people's economic needs. Therefore, it is crucial to pay more attention to the environment and enhance awareness about different problems around us and raise a new generation of people who already are prepared for the rapidly changing future.

Educational systems have a big role in raising future generations' awareness about different problems around us. Especially, science education can support societal change and reinforce responsible interactions with the world [4]. The ultimate goal of science

education is to contribute to building up citizens' science capital: what one knows about science, how one thinks about it, what science related activities one does, and who one knows. All the previously mentioned aspects have a role in shaping students' attitudes, actions, and feelings about science [5]. One important component of an individual's science capital is scientific literacy—vital and strategic to meet the global challenges ahead [6]. In particular, being scientifically literate means being aware of and able to form an opinion about the socio-economical environmental problems in society. This presumes understanding and conducting scientific investigations in collaborative teams with the help of modern technologies that allow engaging in critical and socio-scientific reasoning and making evidence-informed conclusions considering the implications for themselves and the society [7]. Being scientifically literate, one can contribute to democratic decision-making [8]. Furthermore, the focus of scientific literacy has also moved towards gaining scientific vocabulary and developing scientific concepts of the studied phenomena on top of existing everyday ideas and using the gained knowledge in real-life situations.

To support individuals' development of scientific literacy, especially scientific inquiry, a lot of authentic outdoor location-based learning experiences have started to gain momentum. The emergence of location-based approaches has refocused attention on the pedagogical value of place and the power of direct embodied experience in education. Thus, place-responsive pedagogy creates a potential to incorporate real socio-economical environmental problems inherent to a particular location [9] as a focus of scientific inquiry to the learning design. On the other hand, with the support of mobile technologies, it mediates technology-enhanced collaborative inquiry processes and facilitates students' conceptual understanding and transformation from everyday concepts to more scientific knowledge.

There are many studies exploring outdoor technology-enhanced inquiry learning [10,11]; however, measuring students' scientific concept formation and acquiring necessary vocabulary to explain the complex socio-economical environmental phenomenon and gaining scientific understanding to provide critical and evidence-informed arguments has not been in the focus. Furthermore, often research focuses on one aspect of the inquiry cycle [12]; we emphasize going through the whole cycle of inquiry and explore students' problems in the process. There is a knowledge gap of mobile technology-supported collaborative inquiry-based learning in secondary science education [13], in particular an understanding of utilizing mobile technologies for empowering students' scientific literacy and understanding in authentic settings. Furthermore, it has been emphasized that more evaluation could be done in non-gamified use of mobile technology in outdoor learning [14].

The aim of this study is to design and conduct an experimental learning event, investigating the development of students' opinions and conceptual understanding of a real-life socio-economical environmental challenge. Moreover, this study aims to explore the students' scaffolding needs during mobile collaborative inquiry-based outdoor learning events. Based on the action research [15], three consecutive learning events were organized to get an understanding of the learning design—students' scientific inquiry into real-life socio-economical environmental challenges outdoors supported by mobile technologies—and scaffolding needs and opportunities.

Every learning event was analyzed and reflected by two teachers/researchers and necessary changes were made to the design of the next event and its research approach. The research was guided by the following research questions:

- What is the level of students' awareness and understanding of the local socio-economical environmental problem-road construction along the seaside?
- How does mobile outdoor inquiry learning facilitate students' scientific vocabulary development and understanding from everyday language to more scientific concepts?
- What are students' scaffolding needs during mobile outdoor inquiry learning events and how are they related to the development of students' scientific understanding?

These insights will help to better understand how students learn and what affects their learning outdoors. Furthermore, the study provides an understanding of how to better

design the learning activities and scaffolding to support students' development of their scientific literacy more efficiently during mobile outdoor collaborative learning activities.

2. Theoretical Background and Related Works

2.1. Collaborative Inquiry across Authentic Mobile Outdoor Learning Contexts

Learning science and acquiring scientific literacy should happen seamlessly across authentic contexts to capture the wholeness and complexity of socio-economical environmental problems and phenomena. In outdoor education portions of daily school time are relocated out of the classroom and into the local environment [16], where 'in situ' learning episodes outdoors can be used as a resource for learning [17]. Students learn by experiencing the real world in a natural, authentic setting, located at the source of data and natural phenomena by engaging in and through the local environment [12,18].

Going outdoors can embrace different activities and levels of connectedness with a particular location creating a need for a place-responsive pedagogy that recognizes and uses the local environment, culture, and place [19]. Mannion and colleagues [20] have provided a taxonomy of outdoor activities: place-ambivalent (anywhere); place-sensitive (taking some account of place); and place-essential (only possible within a particular authentic place). The core concept of place-responsive education is that it "implies openly educating by-means-of-an-environment with the goal of understanding and enhancing human–environment relationships" [21]. Place-responsive pedagogy means being present in, and with the particular place [22].

Emphasizing the importance of a particular location, place-responsive pedagogy forms a valid theoretical basis for enhancing students' scientific literacy and developing their inquiry skills. Conducting investigations about natural phenomena is seen as a critical component in developing a scientifically literate community [23]. In science education, the value of student inquiry and student-generated questions has long been emphasized [24]. Inquiry-based learning refers to the student-centered approach, in which students actively participate and take responsibility for exploring phenomena and developing knowledge [25] following the types of investigative processes carried out by real scientists [17]. In particular, orientation (problem statement), conceptualization (question and hypothesis generation), investigation (planning and implementing investigations, collecting, analyzing and interpreting data), conclusion (constructing evidence-based explanations and arguments), discussion while presenting and reflecting on findings [26,27] form a complex scientific process, which should take place in authentic, real-life settings.

The relevance of outdoor learning in natural science education cannot be overstated [28,29]; however, instructions and the level of guidance for inquiry learning can vary, having different influences on student learning [30]. The least favorable according to Blanchard et al. [30] is the verification laboratory type of instruction (level 0) in which the teacher defines the question and methods of investigation and guides them toward an expected conclusion. In structured inquiry (level 1), a question and a method are presented to students, but students are responsible for interpreting the result. Guided inquiry (level two) leaves quite a bit of room for students to design their own method of investigation and generate interpretation of the results, while in the case of open inquiry (level three), students generate their own question or hypothesis and take responsibility for conducting the investigation [30]. There is consistent evidence that, for instance, guided inquiry with simulations can benefit student learning [31].

Engaging in scientific inquiry is best fostered through social interactions with others [32] because science is a demanding domain involving complex and challenging learning tasks that can be beyond individual attainment and require group work [33]. According to a socio-constructivist approach [34], knowledge is created through collaborative search in communities with distributed information among its members [35]. Therefore, in collaborative inquiry learning, students learn how to practice science as a team endeavor [35].

Research has demonstrated many benefits of practicing inquiries in collaboration. For instance, carrying out inquiries in groups impacts students' motivation. In collabora-

tive settings, students jointly form a shared motivation for task performance, prioritize shared responsibility and ownership rather than personal progress, interest, and working manners [36]. Conducting complex inquiries about a socio-environmental phenomenon, peer students also offer zones of proximal development [37] to each other [35]. Evidence also shows that collaborative work in small groups is positively associated with student achievement in high school science [38].

In the era of digitalization, mobile technologies have become an integral and natural part of students' inquiry tasks [39], allowing students to participate in the learning process outside the classroom anytime and anywhere [40]. According to several studies, mobile technology outdoors has certain advantages, particularly in terms of giving potential for increased safety and information [41,42], for a deepened learning experience and an increase in participants' knowledge (of a place) [43–46], and for increased motivation [47,48]. Mobile devices can mediate "flow of learning" across different contexts [17], connecting school life with life experience [16].

Mobile technology has also a great potential to actively immerse students in realistic scientist roles [17], enhance students' science learning experience in inquiry-based learning [13], and support and guide the inquiry phases of this complex scientific process [49]. Systematic literature reviews on inquiry-based mobile learning report that mobile technology has helped students to engage with the inquiry questions and mediate their involvement in data collection and analysis [13], and in a few studies, mobile devices have been used for the purpose of scaffolding [12].

Incorporating affordances of mobile technologies, they can be used to present instructions [50] and provide learning paths to follow [51], to record results [52], to shoot photographs and films [53], to view different representations [54], etc. Consequently, taking inquiry-focused learning outside in authentic, real-world settings, different mobile technologies provide seamless learning experiences across various contexts [55,56]; and possibilities to apply concepts and integrate scientific knowledge with everyday experiences [57].

2.2. From Everyday Knowledge to Scientific Understanding

The inquiry-based learning (IBL) process incorporates two main areas where students may gain knowledge and skills: scientific inquiry process skills and scientific knowledge about the phenomenon [58]. There are different ways to conceptualize and measure students' thinking and understandings of a natural phenomenon. Often scientific knowledge is measured as a learning performance or knowledge gain in a particular content area. There are studies that demonstrate through questionnaires and pre- and post-tests that the process of scientific inquiry supported by mobile technologies has a positive impact on learning performance [59,60]. Liu and colleagues [13] explain the positive results with the enhanced student motivation, engagement, and participation in these hands-on investigations.

However, research has also shown that understanding scientific explanations of natural phenomena is difficult [61]. Kikas [62] differentiates knowledge as everyday, synthetic, and scientific. Everyday knowledge refers to information that is visible or perceivable and is used for describing phenomena [62] Synthetic knowledge emerges when common perceptual knowledge is integrated with abstract scientific information [62]. Scientific knowledge means describing the phenomenon with accurate, abstract scientific vocabulary. According to Malleus and Kikas [63], synthetic knowledge can emerge as a consequence of (1) simplifying and/or integrating scientific information to match with daily experiences or (2) using scientific information bits without correct integration. Referring to Tytler [64], Malleus and Kikas [63] claim that for scientific understanding to form, there is a need for engaging students in learning designs, which emphasizes conceptual change.

Forming an evidence-based decision on socio-economical environmental real-life problems requires a more in depth understanding of natural processes than just making use of everyday knowledge that is based on perceptions and direct observations. Exploring a socio-economical environmental problem through the inquiry phases exposes students to a situation where they have to make use of their everyday knowledge to form hypotheses

and then through collecting, analyzing, and interpreting their collected data has a potential to direct students to use a more specific and scientific vocabulary and form synthetic or scientific understanding of the phenomenon. On the other hand, it must be noted here that there is a chance that students may acquire scientific-like descriptions by using scientific vocabulary about the phenomenon without real comprehension [63].

2.3. Scaffolding Needs in Mobile Outdoor Collaborative Inquiry Learning

Offering students the opportunity to work in groups does not mean that high-level science learning will definitely take place [65]. Furthermore, technology-enhanced collaborative inquiry learning into a multifaceted socio-economical environmental phenomenon in authentic outdoor settings, where students are distributed and have to be more independent, requiring them to use self-directed learning strategies and navigate between several contexts, calls for different types of support and scaffolding [66]. Scaffolding refers to a variety of instructional techniques that help students to move towards understanding and at the same time also fosters self-regulation in a learning process [67]. Therefore, allowing learners to accomplish tasks with assistance that they could not accomplish independently [68].

To enhance the outdoor learning experience across contexts in distributed settings, mobile devices are the necessary tools to be integrated with outdoor science learning activities for supporting and scaffolding learning [68,69]. They have the potential to scaffold different levels of inquiry [70] and facilitate seamless learning across a range of learning spaces [71]. On the other hand, mobile learning is more complex in comparison to traditional learning, because students are exposed to the real world and situations in which they have to handle material in mobile devices [72] and operate between real and virtual contexts.

In such complex conditions, scaffolding will obtain even higher importance to set learning context and guide students through different activities while instructing them on how to think metacognitively or solve a certain problem. Hannafin, Land, and Oliver [73] describe four scaffolding functions that are relevant also in the context of mobile outdoor inquiry-based learning settings for conducting investigations and gaining scientific understanding of the phenomenon:

- Conceptual: providing guidance on the concepts and knowledge to consider, defining the problem.
- Metacognitive: helping students firstly to plan, then monitor (following this plan), control all steps, revise (if needed), and accordingly manage their learning.
- Procedural: providing assistance of how to use features or perform certain tasks, guiding how to utilize the available environment functionalities; ongoing "help" and advice on feature functions and uses; for instance, how to operate different devices, sensors.
- Strategic: providing guidance on how to approach a task or problem, for example data collection and analysis [73].

Going through various inquiry phases (orientation, conceptualization, investigation, conclusion, discussion), students may encounter different challenges that require conceptual, metacognitive, procedural, or strategic scaffolding that can be mediated by mobile technologies.

So far, the majority of studies have focused on more technocentric topics [74] rather than exploring in-depth how mobile technology might promote inquiries in science learning [13]. Kacoroski [75] points out that mobile technologies have a potential to be useful for outdoor lessons, but their role is more of a learning aid instead of a central activity. Based on the systematic review on inquiry-based mobile learning in secondary school science education, Liu and colleagues [13] report that in secondary scientific education, where student engagement issues are well-known, little attention has been paid to get a better understanding of inquiry-based learning in mobile settings [76] and what the implications of mobile devices for outdoor learning are [77].

3. Method

3.1. Learning Design, Underpinning Concepts and Procedure

A four-hour learning event was organized around an authentic and timely societal problem in Tallinn—construction of a four-lane street, Reidi tee, along the seaside and through the green area. The learning design was informed by a set of pedagogical models and concepts:

- Student-centered open inquiry-based learning approach [30] following all the phases of inquiry from orientation to discussion [26];
- Outdoor, authentic learning setting across different contexts [16];
- Focus on timely, real-life socio-economical environmental challenge in the society [6];
- Place-responsive pedagogy [78] with the focus on place-essential teaching strategies [21] with specific pre-defined locations;
- Use of mobile technologies as a scaffolding and guiding tool during the inquiry process [13].

The main focus of the four-hour learning task was to provide students a full inquiry learning cycle: defining hypothesis, collecting, analyzing, and interpreting data for mapping the current environmental situation in the location of a planned Reidi's road and based on that drawing conclusions to form an evidence-based opinion about Reidi's road construction. The activities and instructions were discussed thoroughly with the subject teachers based on the Estonian National curriculum [79]. The study had four learning goals:

- To learn how to make and justify informed decisions about socio-economical environmental questions, taking into account social and natural science concepts, as well as ethical values.
- To set research questions and hypothesis, analyze and interpret collected data and make conclusions from results.
- To gain know-how of how to make use of technology (web-based application, robot, sensors) for supporting inquiry activities (air quality, soil quality, water quality).
- To value the environment and a sustainable and healthy lifestyle.

The focus on a complex socio-economical environmental challenge allowed it to integrate many subjects. Therefore, it also had specific learning objectives according to the subjects, which were related to the national curriculum:

- Biology—values biodiversity and responds with responsibility and sustainably to different ecosystems and habitats. Provides reasons about the dilemmas of biodiversity protection.
- Geography—makes use of printed and digital maps, tables, charts, drawings, pictures, and texts to find information, describe processes and phenomena, find links between them, and draw conclusions. Finds weather data from the Internet without a description at a predetermined location.
- Physics—determines the concentration of ions in water by conduction of electricity. Understands the effect of sound on the environment. Measures temperature in different environments and locations (Thermal Education).
- Chemistry—determination of the alkalinity/acidity of the environment and the conclusions to be drawn from it. Inorganic substances in the air-oxides, acids, and atmospheric and environmental effects.
- Estonian language—preparing and making presentations.
- Mathematics—data analysis (calculation of average, comparing data, reading graphs) and conclusion drawing.
- Social sciences—interaction between society and the environment, informed and responsible decision-making.
- Art—putting together a presentation, presentation of research results, assessment of the beauty of nature in the course of research activities.
- Technology—the impact of human and engineering on the environment, the use of ICT tools (Avastusrada app, participants' own smartphones, Lego robots, Vernier Sensors: salinity, conductivity, temperature (2), pH(2), TRIS pH, turbidity, anemometer,

barometer, dissolved oxygen, sound level sensor, relative humidity, light sensor, soil moisture sensor, infrared thermometer).

- Physical education—walking and healthy lifestyle.

The table below (Table 1) summarizes the inquiry-based learning and teaching scenario based on inquiry phases [26] and provides scaffolding types for every phase.

Table 1. Learning scenario based on inquiry phases and provided scaffolding types.

IBL-Phase	Activity	Provided Scaffolding
Orientation	Whole class activity Introduction to the day and to the topic. Dividing students into groups, dividing topics between groups. Topics for groups: 1. Soil quality based on ion concentration 2. Seawater quality based on turbidity and visual estimation of algae (turbidity) 3. Air quality based on lichen diversity (mapping lichen, with picture analysis) 4. Sound levels and its effect on human health (Pulse, Blood pressure) 5. Soil quality based on invertebrate diversity, moisture, and temperature 6. Clean/Wastewater collection and analysis based on ion concentration Short overview of learning tools—Avastusrada, robots, sensors	Conceptual Procedural
Conceptualization Questioning	Group work activity Students are divided into groups. Every group gets information about one environmental indicator that they will be working with. The information is mediated to students with the Avastusrada App. Students read the information and pose a research question regarding the problem and their environmental factor in the Avastusrada app.	Conceptual Metacognitive
Hypothesis Generation	Based on the information, the group forms the preliminary hypothesis that they will be testing. The research question and hypothesis are discussed with teachers before continuing with planning the experiment. The research question and hypothesis are inserted into the Avastusrada app and later presented to students after the experiment with the data.	Strategic Metacognitive Metacognitive
Investigation Experimentation	Group work activity Groups familiarize themselves with the equipment (sensors and the Avastusrada app) and plan their investigation. They are guided outdoors from location to location by the Avastusrada app. They collect the data and insert the results to the app. The app also provides instructions on how to use the equipment and how to conduct measuring. The app also provides reflection about the experiment and hypothesis in every location.	Metacognitive Procedural Procedural Metacognitive
Data Interpretation	Group work activity After outdoor experiments, students are gathered to the class. The Avastusrada app summarizes their results of collected data. Students make meaning of the data with the help of teachers.	Procedural Strategic
Conclusion	Group work activity Students compare their results with their hypothesis and draw conclusions about their results.	Metacognitive
Discussion Communication	Whole class activity Every group presents their results to peers and teachers. Whole group discussion about the problem and current environmental situation in the area.	Metacognitive
Reflection	Reflection is supported in every phase. In addition, every group is asked to reflect on their whole inquiry process during the presentation.	Metacognitive

The activities started with a whole class introduction to the topic, which happened in the Tallinn University classroom (Table 1). The students were given an overview of the study topic, learning goals, and learning tools, which included the mobile application Avastusrada (Discovery track—https://avastusrada.ee/en, accessed on 6 June 2022), Lego EV3 robots, and Vernier sensors. Then, collaborative inquiry-based learning activities followed. The groups were formed beforehand by their own teacher to make sure that every group had a member with a personal smartphone equipped with mobile data. Every group had a different ecological theme (air, soil, water) that they were going to investigate in this certain area near the Reidi roadworks. In groups, the students searched for background information about the theme and formulated hypotheses and research questions about their specific topic. After setting their research topic, the students headed outside to start collecting data from the environment. The entire learning event was structured and framed with a location- and web-based tool, Avastusrada (see a more detailed description below). Every group had a specific track with five marked locations in it. The Avastusrada system also provided them with instructions on how to conduct measurements and was used as a tool for collecting and saving data about different locations. Lego EV3 robots, iPads and different sensors (salinity, conductivity, temperature (2), pH(2), TRIS pH, turbidity, anemometer, barometer, dissolved oxygen, sound level sensor, relative humidity, light sensor, soil moisture sensor, infrared thermometer), presentation papers, and pencils were provided for every group. Practical work outside was followed by analysis and presentation of the collected data in the classroom. Every group summarized their results and presented these to other groups. As a closure activity, whole class discussion and reflection was used, and general conclusions were drawn.

Technological Support: Avastusrada; Vernier Sensors and Lego EV3

The Avastusada app (Discovery Track—https://avastusrada.ee/en, accessed on 6 June 2022) was used to facilitate the outdoor group work activity. It is a browser-based platform for creating and playing location-based learning tracks outside the classroom. Avastusrada was used to help students navigate in an unfamiliar location and provide them with necessary support and guidance. Avastusrada was utilized with four goals in mind: to guide instructions, give content access, facilitate data collection, and allow context and learner involvement [80]. Using Avastusrada requires a smartphone or a tablet, which has an Internet connection (WiFi, 3G or 4G) that allows making use of GPS location services. Questions related to chosen locations can be created and incorporated into meaningful tracks. Questions can be textual, including photos, videos, audio, or animations for additional information.

The application offers a list of templates for creating different types of questions: multiple choice answers, free form answers, one correct answer, providing info and photos. Different types of questions could be created allowing players for instance to explore the surrounding, answer the questions, or carry out some measuring in the surroundings and submit the value. To support teachers' awareness about students' progress while following the track, it is possible to see submitted answers to every location point by every student (or student groups). The students' movements and their location are monitored by GPS. The location points with questions and tasks get activated when students reach the particular location (see Figure 1) and turn to blue as soon as the answer to the question or the task has been submitted. Depending on how the track has been designed, the students can visit location points randomly or in a predefined order. The application also displays simple statistics, such as the number of players, location points, time for completing the track, etc. In this study, the mobile application Avastusrada in our study was used with four aims: to direct instructions, to provide access to content, to support data collection, and to enable interaction between context and learner [80].

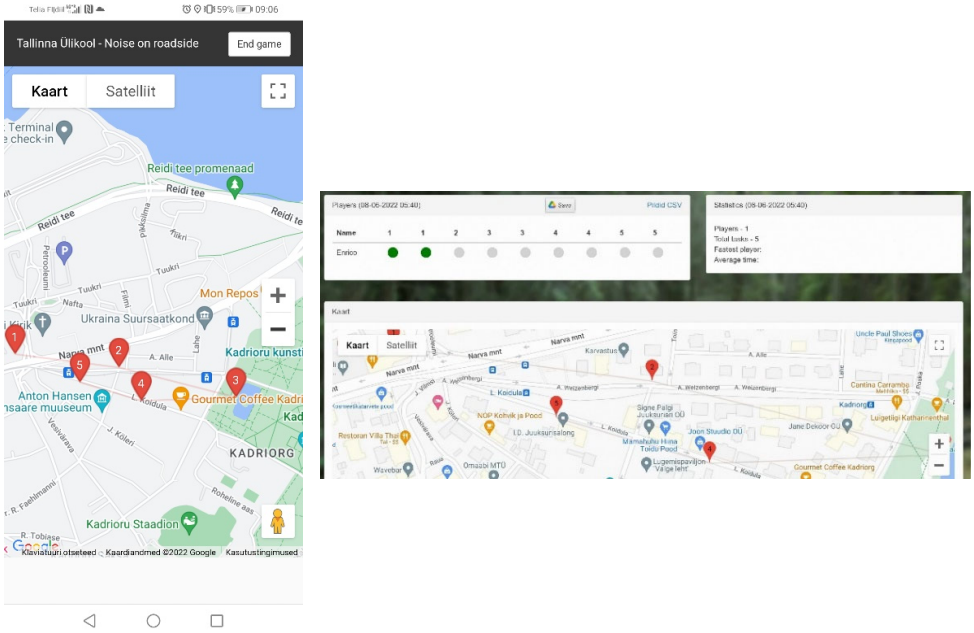


Figure 1. Screenshots of Avastusrada. Translation of words on images: Avastusrada-Discoverytrack, Tallinna Ülikool-Tallinn University, Kaart-Map, Satelliit- satellite, Pildid-pictures, kasutaja otseteed-user shortcuts, kaardiandmed-map data, kasutustingimused-user terms.

The Avastusrada app directed the pupils to various destinations. Every specific site had a task where they had to read the instructions and then observe, measure, compare, analyze, take a picture, gather, and so on, based on the information. They were directed to follow the trail and continue to fill in the tasks in other sites once the activities in one location were completed (Figure 1). The tracks were made up of five various location points.

As a measuring tool, Vernier sensors and Lego EV3 brains were used additionally to students' smartphones and other tools. Vernier sensors are designed specifically for active, hands-on experiments allowing carrying out various measurements in outdoor settings. Due to some economic reasons within the context of our project, the sensors were used in combination with an EV3 robot's brain to read measured data. The data can be inserted manually by students to the Avastusrada application as an answer to a question in the particular location point.

3.2. Participants

This study involved 68 students from 8th to 9th grade (fourteen to fifteen years old) from three different schools in Tallinn. Eighteen students were from the 8th grade (school A) and 50 students were from the 9th grade (twenty-five from school B and twenty-five from school C). The schools who participated volunteered for this study and were informed about the goals and design of the study. Therefore, a convenience sampling was used. Although being a non-probability sampling method, the participating schools represented a typical school in the region. Running this experimental learning design three times with three different groups of students gave us a sufficient dataset and confidence to draw some conclusions from this experimental learning design that can inform more extensive research about the issue.

All participating students had informed consent from their legal representatives. Due to different reasons (some students arrived later or had to leave earlier, etc.), for the analysis we only included the data of students who filled in both pre- and post-questionnaires. In total, 50 students were included in the sample (fourteen students from school A, twelve students from school B, and twenty-four students from school C).

3.3. Data Collection and Analysis

For data collection, two instruments were used. The first instrument was used before the learning activity, the second instrument was used after the learning activity (Table 2). The instruments were presented via Google forms. The items in the questionnaires were focused on the expected learning outcome, in particular students' opinion and certainty of their opinion. The list of challenges was created based on Hannafin et al.'s [73] scaffolding needs, and the list of information sources according to the possible sources exposed to youth.

Table 2. Data collection instruments and question types.

Questionnaire	Tasks	Answer Types
Pre-and post-questionnaire	Indicating their opinion regarding the Reidi road (What do you think, is the Reidi road construction reasonable?)	Yes, No, I don't know.
Pre-and post-questionnaire	Explaining their opinion about the socio-environmental problem based on their current knowledge	Free form answer
Pre-and post-questionnaire	Indicating the level of certainty regarding their opinion	Five-point Likert scale from Not certain at all to Very certain
Pre-questionnaire	Indicating what information they have been exposed to regarding the socio-economical environmental challenge.	List of predefined sources of information, selecting as many as relevant
Post-questionnaire	Marking problems and challenges regarding the whole learning activity	List of pre-defined challenges, selecting as many as relevant

The collected data were categorized, coded, and analyzed as follows:

1. Students' opinions regarding the socio-environmental problem before and after the learning event were analyzed and compared. The answers were coded as follows: No—2, I don't know—1, and Yes—0.
2. Students' awareness and their sources of information about the socio-economic-environmental situation were analyzed through descriptive statistics and translated as a demonstration of students' emotional engagement, indicating their affective entrenchment.
3. The certainty of the opinion before and after the learning event was compared. The answers were coded as follows: 1—I am not certain at all to 5 —I am very certain.
4. Students' explanations about their opinion of the socio-environmental problem before and after the learning event were used to determine the type of knowledge [66] they have about the problem. Knowledge types were coded as follows:
    (a) No knowledge—0.
    (b) An answer was coded 'everyday' if it reflected the use of perceptual experiences to describe the phenomena (e.g., It damages nature a lot, and then there will be less green; It is reasonable but it reduces the park and beach). Everyday answers also included more general descriptive definitions (e.g., Nature suffers; It damages the nature in the area; I believe it is harmful for nature but it is useful for car drivers)—1.
    (c) An answer was coded 'synthetic' if it reflected a combination of everyday and scientific knowledge (e.g., Because it stops the way to the beach and reduces the city biodiversity which lacks anyway; Soil gets more salty). Synthetic answers reflected (1) assimilation of scientific knowledge to fit better with prior everyday understanding; and (2) more superficial use of scientific information together with everyday experience—2.

(d) An answer was coded 'scientific' if it reflected the use of a general concept to define the word and/or the answer was also scientifically correct (e.g., It decreases the amount of nature, sound levels increase, plants cannot grow so well, the number of animals decreases, and the air gets polluted more; Nature suffers due to the increasing noise levels and decreasing quality of soil and water)—3.

5. Regarding the students' problems and challenges, the analysis was carried out according to Hannafin et al.'s [73] four categories of scaffolding needs (conceptual, metacognitive, procedural, strategic).

The coding of free form answers was done by two researchers and differences were discussed and agreed. Inter-rater reliability was calculated using Cohen's Kappa, the result ($K = 0.78$, 95% CI, 0.69 to 0.87, $p < 0.01$) showed substantial agreement. After coding the students' explanations, analysis was conducted with the SPSS statistics program using descriptive statistics and Spearman's correlation, Chi-Square test and Wilcoxon signed-ranks tests were applied to identify significant findings.

4. Results

4.1. Students' Awareness of the Socio-Environmental Problem

First, we analyzed the information sources the students used to get information about the study topic—a socio-environmental challenge in the society regarding the road construction (Figure 2). Simple descriptive statistics was applied to describe the overall division of the answers. As the questionnaire allowed multiple selections, all together 78 responses were given. A lot of students acquired information about the topic via different types of media (42% of the students) or by hearing their parents talking about this subject (42% of the students). It was surprising that school was only chosen as a source of information by 8% of the students. The students even talked more about it with friends (12% of students). It is also important to bring out that 34% of the students had no information about the socio-economic issue at all. It is interesting to note that none of the three schools is located in the neighborhood of the Reidi road but still the majority of the students were informed in some way or the other about the issue in the society.

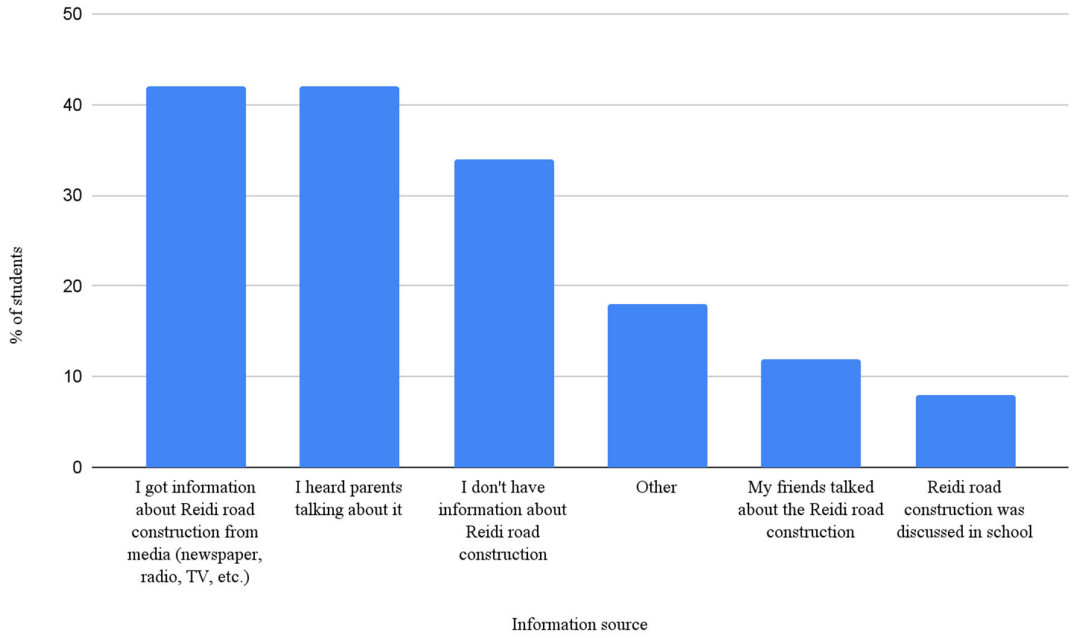


Figure 2. Students' source of information about the socio-environmental problem.

4.2. Change in Opinions Regarding the Socio-Environmental Problem

To study whether the students' opinions changed during the learning activity, they were asked in the pre- and post-questionnaires if it is reasonable to build the Reidi road. In the pre-questionnaire, students did not have a certain opinion about the road construction and the most frequently chosen option was I don't know (M = 1.30, SD = 0.58; *Median* = 1). In the post-questionnaire, the opinions were on average more against the road construction (M = 1.66, SD = 0.59; *Median* = 2). The Wilcoxon signed-ranks test was conducted to compare the opinions about the Reidi road construction before and after the learning event. There was a significant difference in the opinions before (*Median* = 1) and after (*Median* = 2) the learning event; $Z = -3.67$, $p < 0.001$. These results suggest that the event had an impact on students' opinion about the socio-environmental issue. The change in students' opinions is shown in Figure 3.

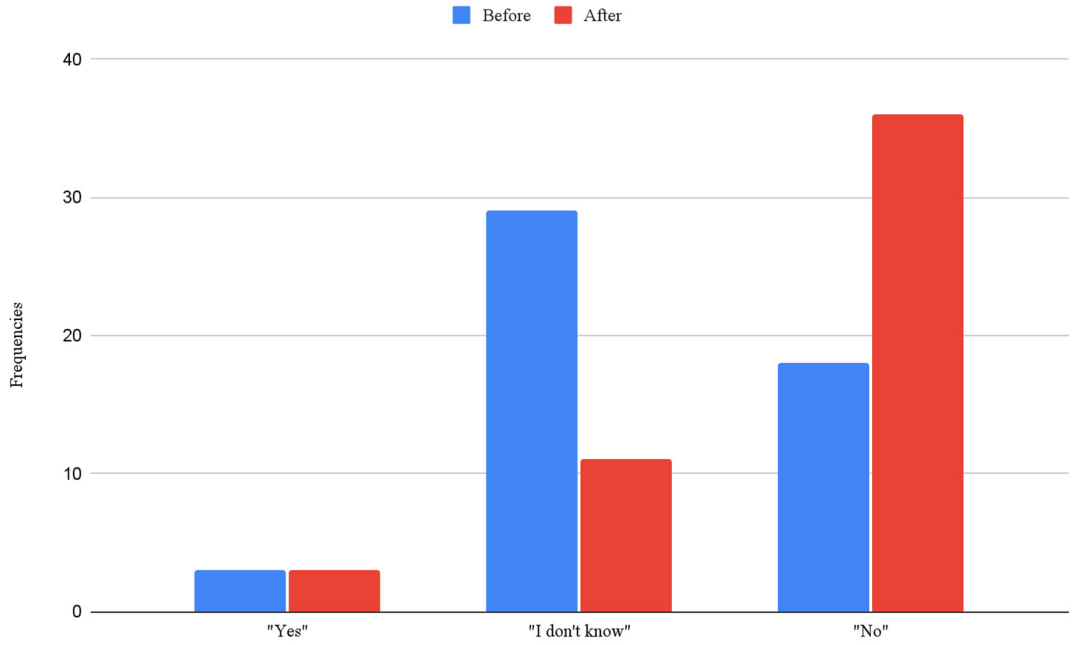


Figure 3. Students' opinions about the road construction (Is it reasonable to build the road?) before and after the learning activity.

To get a better overview on how many students actually changed their opinion and in what direction, we also analyzed students' opinions individually. Approximately 52% of the students remained with their opinion, whether it was for, against, or unclear. Thirty-eight percent of the students changed their opinion about the Reidi road from I don't know to No; 2% from No to I don't know; 4% from I don't know to Yes, and from Yes to I don't know (Figure 4). The students who had indicated in the pre-questionnaire that they were against the road construction mainly kept their opinion. The nineteen students who did not have an opinion about the issue changed their opinion to No, eight students remained with the same opinion, and two students changed their opinion to Yes. There were three students who were in favor of road construction, two of the students changed their opinion to I don't know and one remained with the opinion.

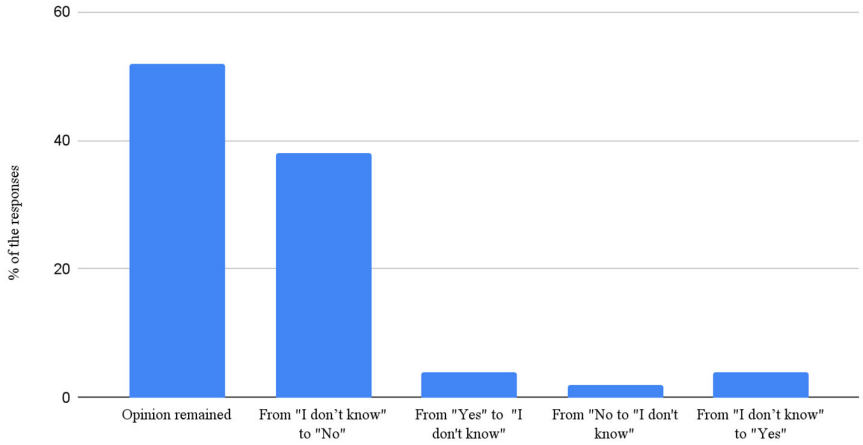


Figure 4. Change in students' opinions of the Reidi road construction after the learning activity.

4.3. Certainty of Students' Opinion and Their Changes

The students were asked to evaluate how certain they were about their opinion before and after the learning event. The graph below (Figure 5) shows that the students were much more confident in their opinion after the learning activity. The Wilcoxon signed-ranks test was conducted to compare the certainty of the opinions about the Reidi road construction before and after the learning event. There was a significant difference in the certainty of the opinions before ($Mdn = 4$) and after ($Mdn = 5$) the event ($Z = -2.74$, $p < 0.01$). These results suggest that the learning event gave the students more information and in case they were doubting their opinion before, after the learning event they were much more certain in their opinion.

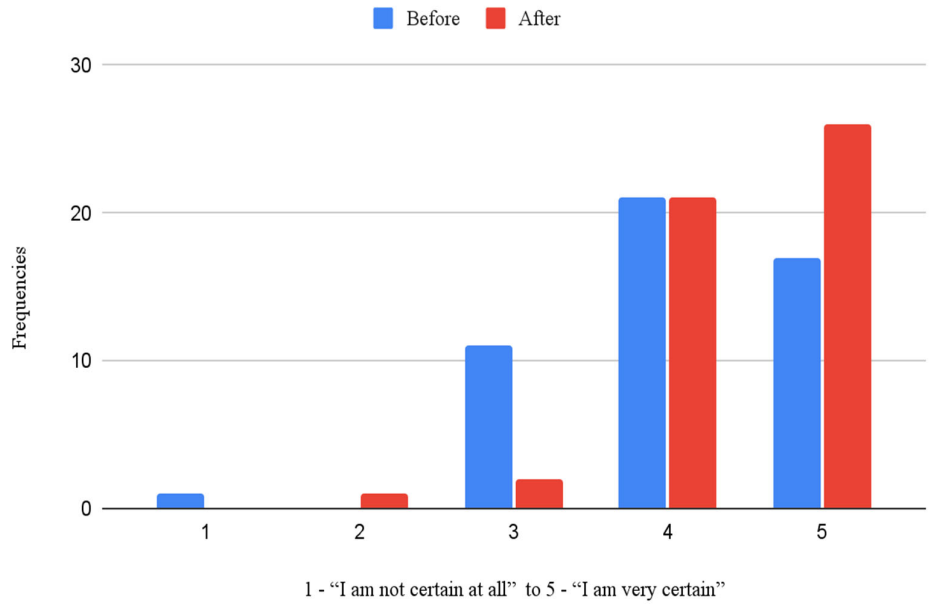


Figure 5. Students' level of certainty before and after the learning activity regarding their opinion about the Reidi road construction (horizontal axis 1 refers to I am not certain at all to 5—I am very certain; vertical axis presents every individual student's answer).

4.4. Explanations of Students' Opinions

To investigate any significant changes in the students' knowledge types about the Reidi road construction, students' explanations before and after the event were categorized according to the knowledge types and compared (Figure 6). The Wilcoxon signed-ranks test was conducted to compare the types of explanations before and after the activity. There was a significant difference in the explanation before ($Mdn = 1$) and after ($Mdn = 1$) the

event ($Z = -4.26$, $p < 0.01$). The number of students who stated they had no knowledge of the problem was reduced from thirteen to three. The number of students who had everyday explanations was reduced from 31 to 25 and remained the most numerous category. The number of students with the synthetic knowledge type increased from four to eleven and the number with scientific knowledge increased from two to eleven. These results suggest that, during the learning event, the students acquired a more detailed and in-depth knowledge about the study content. The possibility to practice a scientific approach to the problem raised their awareness about the socio-economic situation, resulting in more thorough explanations in their answers.

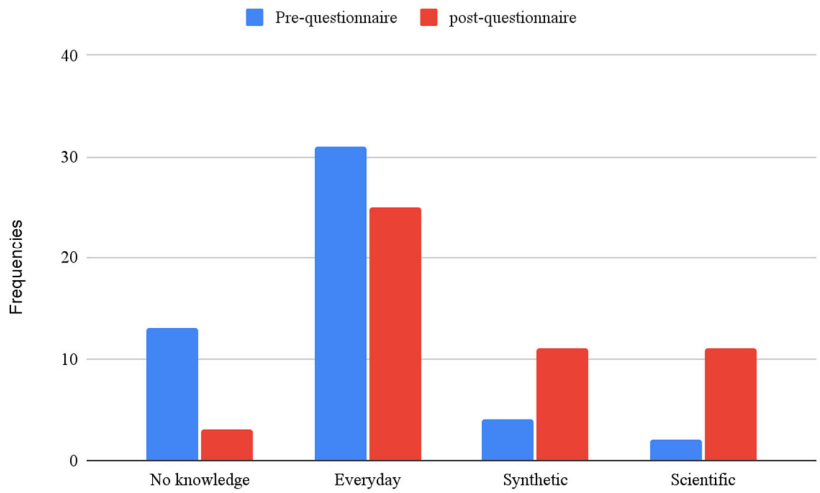


Figure 6. Students' knowledge types before and after the learning activity.

In order to find out how many students developed a more sophisticated knowledge type, a new variable, "Change in knowledge types", was calculated by subtracting the post-questionnaire knowledge type from the pre-questionnaire knowledge type. It was revealed that half of the students provided scientifically more developed explanations in the post questionnaires (Figure 7).

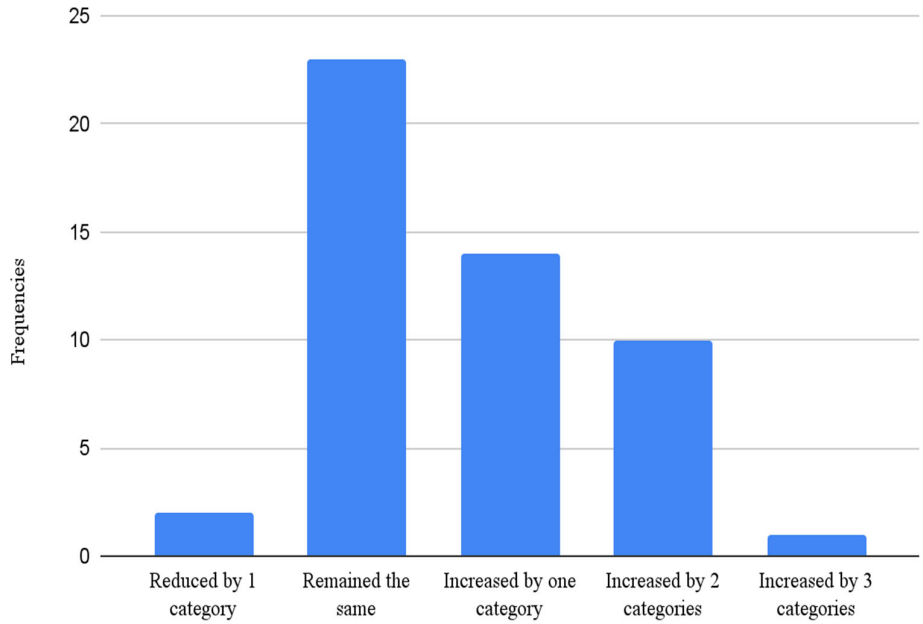


Figure 7. Level of change in students' knowledge types (from No knowledge as the lowest to Everyday, Synthetic, and Scientific as the highest level).

4.5. Students' Task-Related and Technological Problems

As expected during this complex, mainly technologically scaffolded open inquiry-based learning activity, students experienced some problems and challenges. A total of 123 answers from the predefined list of potential challenges were submitted. The results show that the most challenging task for the students was related to the conceptualization phase of the scientific inquiry process, namely setting up hypotheses for their investigation (22 students), as seen in Figure 8.

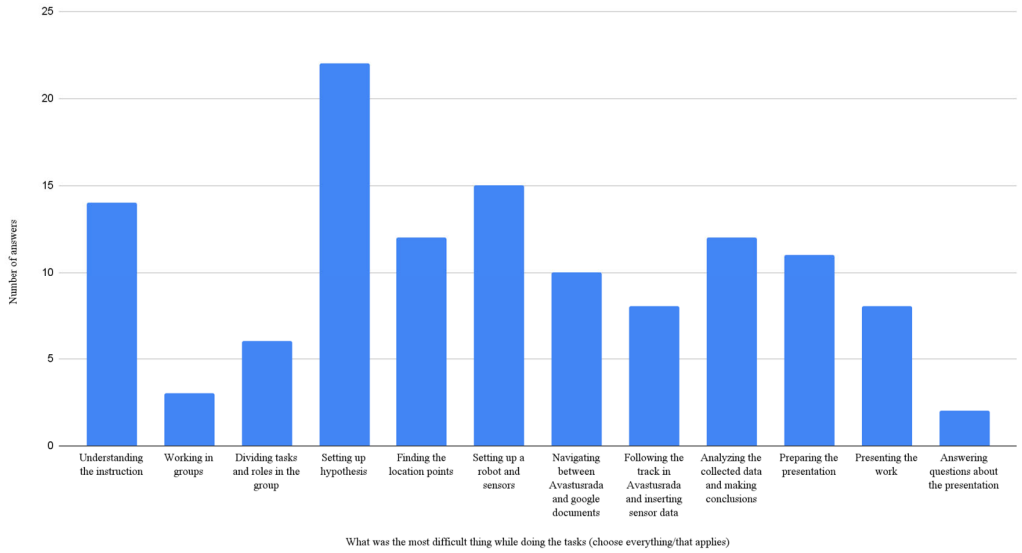


Figure 8. Students' challenges and problems during the mobile outdoor open inquiry learning event.

Setting up robots and sensors (fifteen students) as well as understanding instructions presented in the mobile application Avastusrada (fourteen students) posed challenges for some of the students. Finding the location points and analyzing the collected data and making conclusions were marked as challenges by twelve students. Other challenges were marked less. More than half of the challenges and problems were related to the aspect of the learning process rather than technology-related issues. A few technology-related problems that occurred were connected with the Avastusrada application displaying the wrong location or with robots and sensors not showing any readings, being too slow, or students not knowing how to connect them.

In order to find out if students' knowledge gain was related to the number of problems they encountered, we counted the number of problems listed by every student. The median for the number of problems that students had was 1. Based on the median, the variable "number of problems" was recoded into two categories: few problems (no problems or one problem) and many problems (two to eight problems). Then cross tabulation was created with the recoded knowledge types (change in knowledge type to more scientific, knowledge type remained the same). The cross table and Fisher's Exact test indicated that there was no significant difference between the groups ($\chi^2 = 0.00$, $p > 0.05$). Therefore, we can conclude that the technological and instructional challenges the students encountered did not have any significant effect on their knowledge gain toward becoming more scientific.

5. Discussion

5.1. What Is the Level of Students' Awareness and Understanding of the Local Socio-Economical Environmental Problem—Road Construction along the Seaside?

Being aware of and having an evidence-informed opinion of the socio-economical environmental problems in a technologically intertwined society is one of the key aspects of scientific literacy [7]. This enables people to engage in critical and socio-scientific reasoning considering the implications for themselves and the society. As it turned out, the students were not very well informed about the timely socio-economical environmental challenge—

construction of the road through the green area and along the seaside—in their hometown, although it got a lot of media attention and public discussions. Students had heard about the issue from different information sources, but they mostly did not have an opinion about it or if they did have an opinion, they were not sure about it.

Collaborative inquiry learning with collecting evidence for making an informed decision definitely had an influence on the students' awareness and opinions about the socio-economical-environmental problem in the society as well as the certainty of their opinion. Before the learning event, the students were rather neutral about the socio-environmental challenge, mainly because they lacked information or were not fully aware of the issue and its potential consequences. However, engaging students in studying a real-life challenge, through analysis and conclusion drawing based on the collected evidence about the environmental situation, allowed the students to form their own opinions and strengthen their confidence with respect to their view.

It is somewhat surprising that such an important and all-encompassing topic had hardly been discussed in any of the school lessons, although it would have been an excellent real-life problem to tackle within the context of many subjects allowing a trans- and interdisciplinary approach to enhance scientific literacy. This calls for attention to embracing not only learning of scientific contents and processes (Vision I), but also focusing on socio-cultural and situated vision of the educational process connecting it to technology, environment, and society (Vision II) as well as promoting greater social activism and active participation in the public debate [6]. This, in turn, leads to, what Barad [81] calls an agential literacy as a posthuman scientific literacy, i.e., to intra-act responsibly within the world [82]. It should not be "about reproducing decontextualized scientific knowledge, or about relevancy and context as culture-influencing science . . . it is about responsibility in and through the understanding of our entanglement with the world" [4]. For that, being able to develop a more scientific understanding of a socio-economical environmental phenomenon is essential.

5.2. How Does Mobile Outdoor Inquiry Learning Facilitate Students' Scientific Vocabulary Development and Understanding from Everyday Language to More Scientific Concepts?

Specific insights into some of the environmental aspects gained through the collaborative inquiry-based learning activities in authentic settings invited the students to reconsider and restructure their understanding of the socio-economical environmental challenge. This can be shown with the fact that 30% of the students had no opinion before the learning event about the problem and after the learning event the respective number was only 6%. This missing 6% indicates that either the students considered not gaining enough information to form a certain opinion, their interest towards the topic was low, they were not concerned with the issue, or the collaborative inquiry-based learning activity was not emotionally engaging enough for those students. Those students who were already against the road construction mainly reconfirmed their opinion after the learning event. Immersed in authentic, outdoor open investigation and actually being in the particular location with all the contextual information has the potential to shape students' opinion and its certainty about the studied issue. Being convinced and certain of one's understanding and opinion about a particular socio-environmental issue is an important quality in engaging and actively participating in public debates.

Regarding the development of scientific vocabulary and understanding of the socio-environmental problem, our study demonstrated that while before the learning event most of the students' explanations (those who had an opinion) were considered accurate, but their explanations reflected mainly their everyday understanding. After the learning event, the students' ability to provide richer and more accurate, either synthetic or scientific, explanations, leaned on their collected evidence, increased. Similarly to Merlino et al., [83] and Locritani, Merlino, and Abbate [84], our study indicates that the students changed their perception of the studied problem and they gained knowledge about the issue. Thus, this type of learning design can improve education in the environmental field. On the other

hand, we must be cautious with the fact that making use of more abstract and scientific vocabulary for explaining one's opinion about the socio-environmental problem might not definitely demonstrate students' true comprehension of the problem [63]. A more in-depth exploration of students' acquired knowledge must be carried out. Nevertheless, it can be concluded that open inquiry learning in an authentic situation with a set of mobile devices has the potential to support students' scientific concept development and the formation of richer, scientifically more accurate, and well nuanced explanations. Acquiring a more synthetic and scientific understanding of the phenomenon provides a better basis to contribute to societal change and interact with the world responsibly [4].

5.3. What Are Students' Scaffolding Needs during Mobile Outdoor Inquiry Learning Events and How Are They Related to the Development of Students' Scientific Understanding?

Mobile learning across authentic outdoor and virtual settings, in which students are operating in groups without teachers' direct guidance, is a complex endeavor in comparison to a traditional classroom setting [72]. In the beginning and at the end of the learning scenario, a teacher was present to instruct and direct the discussion; however, for the whole open inquiry process, the mobile application Avastusrada "replaced" the teacher and instructed the students through the inquiry phases. Our learning design leaned towards an open inquiry process, in which students, based on the information provided to them during the orientation phase, had to generate hypotheses for their investigation and take responsibility for most of the phases of the investigation (conceptualization, investigation, conclusion, and partially discussion) [31]. Considering the fact that the students were placed into an open inquiry process, they reported relatively few problems and challenges and gained at the same time a more coherent scientific understanding of the problem.

Taking into account the scaffolding aspects already provided through the mobile application Avastusrada during the learning event and according to the results presented above, our study demonstrated that the students mainly required conceptual scaffolding. In particular, the scaffolding was needed during the conceptualization phase of the inquiry, where the students generated research questions and hypotheses regarding the presented problem. Table 3 provides a comprehensive overview of the scaffolding types provided, reported students' needs, and potential scaffold improvements. Various mobile technologies as additional components in the learning design added an extra layer of complexity. The students mentioned some technological issues during the learning event, mainly related to the procedural scaffolding, i.e., there is a need to provide assistance on how to set up and use measuring devices. Although such an instruction was given in the beginning of the learning event and detailed instructions were also provided via the Avastusrada application, it seems that ways of presenting additional information and instructions need to be reconsidered for the mobile learning settings.

There have been reports on negative pitfalls of mobile learning like the risk of failing equipment during mobile outdoor learning [85,86]. In this case, students had some minor technical problems and the mobile apps and batteries of the smartphones and sensors lasted until the end of the activity. It seems that this problem was more relevant a decade ago but as technology gets more reliable with every year, this is not a suitable justification any longer for choosing not to use technology in outdoor learning. Furthermore, Lai et al. [87] have argued that participants do not develop the same level of active thinking and problem-solving skills if they rely too heavily on mobile technology. In the case of this study, students had numerous problems but these problems did not seem to have an impact on their knowledge gain. One of the reasons could be using reflection. Kraalingen [14] suggests, based on the mobile outdoor learning literature review, that educators should hold space for reflection on the learning experience and maintain a focus on the learning experience, rather than on the technological means. In the learning activity design, the reflection on students' activity was planned into all phases. Therefore, it helped students to keep themselves focused on learning.

Table 3. Scaffolding during the learning event and improvement ideas.

Scaffolding Type	Students Problems	Current Scaffold	Potential Scaffold Improvement
Conceptual	Setting up hypothesis for their investigations	Students were provided with information about the problem and aspects they were about to investigate.	Provide steps that would help to set up hypotheses.
	Understanding instruction	Instructions were provided at every location.	Make instruction more clear and present every step separately.
	Preparing presentation	Students were instructed to prepare paper presentations.	Provide more information resources, divide the preparation process into steps. Prepare an example.
Metacognition	Dividing tasks and roles in group	No scaffold	Prepare specific roles in each group and every student has to take up one.
	Working in group	No scaffold	Create a feature in the app that would help guide students with group management.
	Answering questions about presentation	Guiding questions and discussions by the teacher.	Introduce these questions earlier, so that students would have time to analyze the situation and context.
	Analyzing collected data	Students were given instruction to compare results and make conclusions based on the results. Instructions and help were given by the teacher if it was necessary.	Give more specific instructions on how to exactly analyze the data and what can be concluded.
Procedural	Finding the right location	No scaffold	Provide also some description of the location or regular map, in case of technical problems.
	Following track in Avasturada	Avastusrada provided the location and direction for what to follow to get to the correct location.	Provide also some description of the location or regular map, in case of technical problems.
	Navigating between Avastusrada and Google docs	No scaffold	Avoid using two environments, create shorter instructions or a row of instructions under one task in Avastusrada or provide instructions on paper or on a tablet.
	Setting up robots and sensors	Instructions were provided at the beginning of the learning activity and also in Google documents in every location point through Avastusrada.	Set up the first control assignment in the start point to assure that students have correctly set up everything.
	Presenting their work	Students were given instructions how to create presentations.	Present an example

Despite the occurring instruction related and technological problems, we can report that the encountered challenges did not have any significant effect on students' knowledge gain and the development of more synthetic or scientific understandings of the studied phenomenon. Thus, it can be concluded that the emerging problems, be it instructional or technological, which cannot be entirely eliminated in these complex learning settings, are not the reason to give up mobile outdoor learning. Rather, we should try to find ways to support students learning better on this demanding task.

6. Conclusions

The presented study introduced a complex learning design that incorporates ideas from student-centered open inquiry-based learning, outdoor authentic learning across different contexts, and a timely, real-life socio-economical environmental challenge in the

society. Moreover, the learning design followed place-responsive pedagogy with the focus on place-essential teaching strategies and use of mobile technologies as a scaffolding and guiding tool during the collaborative inquiry process. The study provided a glimpse of evidence of how practicing a complete open inquiry into a real-life socio-environmental challenge affects students' opinion of the challenge and the development of scientific understanding as well presented potential scaffolding opportunities through mobile technology.

The results of the study, in particular the fact that students are not very well informed about their hometown socio-economical environmental challenges, call for incorporating these challenges as the object of inquiry to learning designs. Such learning designs create conditions for students to form their own opinions and strengthen their confidence with respect to their view on the studied authentic challenge in the society. The study has demonstrated that the learning event encouraged the students to form an opinion, and to reconsider and restructure their understanding of the socio-economical environmental challenge. Furthermore, the study showed that the students' everyday understanding was transformed into richer, scientifically more accurate, and well nuanced explanations classified either synthetic or scientific knowledge.

The results in terms of suggested scaffolding would be relevant for science teachers who plan to design similar, technology-enhanced collaborative inquiry learning into an authentic real-life economical-environmental challenge in the society. Furthermore, in addition to students' knowledge gain and as hardly any technological scaffolding was needed, it would be encouraging for teachers to incorporate into their pedagogical repertoire collaborative inquiry learning scenarios in outdoor settings mediated and scaffolded by a set of mobile devices.

The outcome of the study allows us to further take up at least two directions among many others. On the one hand, we will fine-tune the design of the learning event and dig deeper into individual students' learning gains and paths in collaborative settings as well as the limiting factors for further personal growth, be it technological solutions, collaboration settings, or personal particularities with prior knowledge and motivation. In particular, an effect on the students' immediate, out of school life—transformative experience [88] would be also of interest. On the other hand, the study has provided a solid basis to scale up the implementation of this design and widen the research scope and focus. Namely, exploring teachers designing, implementing, scaffolding, and monitoring these types of outdoor learning events in which every student group operates on their own. As the current formal science education often fails to address a holistic view on life-related phenomena, not connecting learning tasks with actual everyday socio-economical-environmental problems or finding ways to demonstrate how science relates and influences every person and the whole society, one of the further steps is also to explore the actual potential of this type of design to contribute to a person's science literacy and capital [5].

Despite the positive research results in terms of students' knowledge gain, we are well aware of the limitations of the study. Due to the small sample size of the study, the results are not generalizable; however, the study provides some insights to better understand how this particular mobile outdoor collaborative inquiry-based learning design supports the development of knowledge types and the role of mobile applications as scaffolding aids.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institute of Education (1 September 2020).

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