

## Empowering future generations by enhancing critical competencies through sustainable transport learning

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### ABSTRACT

In the rapidly evolving landscape of the 21st century, modern education faces the imperative to adapt, embracing the cultivation of interdisciplinary and intercultural competencies to prepare students for future challenges. This study investigates the integration of sustainable transport education through thoughtfully designed teaching interventions that adhere to a project-based learning model. The primary objective of these interventions is to enhance students' development of the four critical competencies known as the 4Cs: communication, collaboration, creativity, and critical thinking. Within this framework, a series of engaging activities were implemented, during which students collaborated to design and construct sustainable means of transport, thereby enabling hands-on learning and practical application of theoretical knowledge. Additionally, the students exhibited understanding of the principles of sustainable mobility, illustrating the successful transfer of knowledge from theoretical concepts to practical scenarios. Feedback from participating teachers was positive, highlighting the efficacy of the intervention and the successful implementation of the proposed instructional methods. This study not only underscores the importance of sustainable transport education but also serves as a model for future educational interventions aimed at fostering essential 21st-century skills in students across diverse disciplinary contexts.

**Keywords:** Sustainable transportation; Educational programs; Elementary; 21st-century skills; Education for sustainability; STEAM; Education in transportation

### INTRODUCTION

In recent years, science teaching has displayed a fundamental role in elementary school, given its multidimensional contribution to young students. First, it lays the foundations of scientific literacy (NRC, 2007), which contributes to the understanding and interpretation of the environment, avoiding fictional elements. It tames curiosity, framing it in structured investigation. Young students are naturally curious. By introducing them to scientific concepts, they are supported to tame curiosity and channel it into structured investigation. The way in which scientific instruction helps young students is linked to modern educational perspectives that emphasize the

importance of building, applying, and evaluating scientific interpretations (NRC, 2007). It also encourages the cultivation of scientific skills because it is based on the formation of hypotheses, data collection, and the analysis of findings—all skills that are more widely applicable to various life situations (Driver et al., 2000).

In 2015, the concept of sustainability was identified as part of the 17 Sustainable Development Goals of the United Nations. In particular, the importance of the concept of sustainable mobility is underlined in the short, medium, and long terms. In the short term, sustainable mobility promotes energy savings and reduces exhaust gas emissions, which, in conjunction with protecting water and air quality, helps to combat climate change (OECD, 1996; Stag & Gifford, 2005). In the medium term, it contributes to the reduction of infrastructure maintenance and healthcare costs related to pollution. For example, a well-designed road network needs fewer repairs and has lower maintenance costs due to fewer vehicles. When roads are better designed, they can more effectively manage the flow of traffic, which reduces congestion. This means that vehicles spend less time idling and moving slowly, which directly contributes to energy savings and fewer emissions. Moreover, well-planned road networks may incorporate public transportation options, bike lanes, and pedestrian pathways, which encourage people to choose these alternatives over driving personal vehicles. In essence, by providing more efficient, accessible, and safer transportation options, a well-designed road network can reduce the overall number of vehicles on the road, thus lowering wear and tear on the infrastructure. As a result, reduced maintenance costs will be noted, as there will be fewer repairs needed over time. Therefore, the interconnectedness of sustainable mobility and infrastructure design is critical for achieving long-term sustainability goals.

In the long term, these reductions in pollution will result in fewer health problems caused by air pollution, such as respiratory and cardiovascular diseases. However, despite the importance of sustainable mobility, K-12 education faces multiple challenges, including resistance to changes in routines, especially regarding the reduction of car use, which is often associated with comfort and status (Steg & Gifford, 2005). There is a notable absence of a comprehensive curriculum that thoroughly addresses sustainable transport issues, as highlighted by Litman (2003) and Shahidullah & Hossain (2022). Additionally, there exists a lack of accurate information, along with the prevalence of misinformation and misconceptions about the efficiency of public transport in comparison to private car use, as pointed out by Ercin and Hoekstra (2012). Taking the above into account, this study aims to highlight educational interventions and teaching materials related to sustainable mobility in support of a relevant, integrated curriculum. It also seeks to cultivate 21st-century skills among primary school students and to evaluate the STEAM (Science, Technology, Engineering, Arts, and Mathematics) teaching intervention on sustainable mobility in order to inform young students and avoid misinformation.

## **Theoretical framework**

### ***Sustainable mobility***

The concept of “sustainable mobility” describes a mobility system that meets the basic needs of individuals, businesses, and communities while also ensuring health and intergenerational equity and minimizing environmental impacts (Zietsman & Rilett, 2002). It includes a variety of modes of transportation, including public transportation, cycling, walking, and electric or alternative fuel vehicles, all of which reduce emissions and resource consumption. The course of sustainable mobility as a concept can be traced through the international conferences, reports, and initiatives that have shaped its current framework (Gudmundsson et al., 2016).

Although the issue of transport was not specifically addressed in the Stockholm Declaration, this document formulated the fundamental principles of sustainable transport. In particular, Principle 15 recommends urban planning that avoids adverse environmental impacts and highlights the need for integrated planning that takes into account not only socio-economic but also environmental benefits. The Brundtland Commission’s report “Our Common Future” (Stockholm Declaration, 1972) introduced the concept of “sustainable development” by linking it to the role of transport in socio-economic development.

The United Nations Conference on Environment and Development, also known as the Rio de Janeiro Conference or the Earth Summit (Rio Declaration, 1992), produced Agenda 21, which includes important sections on sustainable transport, recommending the integration of land use and transport planning. The Rio Declaration calls for efforts to strengthen public transport, promote non-motorized transport, and integrate environmental considerations into transport planning.

The Johannesburg Summit (Report of the World Summit on Sustainable Development, 2002) cemented the importance of sustainable transport, focusing on transport connectivity and sustainable development and stressing the need for efficient transport systems that are environmentally sound and equitable. Ten years later, the Rio 20+ conference (UNCSD, 2012) explicitly recognized sustainable transport as crucial for achieving sustainable development in the report “The future we want,” underlining the sustainable transports role in improving economic growth, social equity, and environmental protection.

Following the United Nations' notions on sustainable development, sustainable mobility has gained even greater importance. The "2030 Agenda for Sustainable Development" (Huck, 2022) recognizes the priority of sustainable mobility as a means of improving quality of life and reducing social inequalities. The strategic framework developed by a nation's government to enhance transportation systems, policies must be interconnected with strategies to address climate change and promote sustainable development (Arce-Ruiz, 2022).

Education for sustainable mobility is now necessary as society faces increasingly acute environmental problems and the consequences of climate change. Education contributes to raising awareness about the environmental and social impacts of transport systems, equipping people with an understanding of how their choices affect climate change, air quality, and public health (Haider et al., 2019).

These series of international conferences, reports, and efforts constitute global initiatives that focus on the need for integrated development approaches that account for environmental impacts. The evolution of sustainable transport has been significantly influenced by global discussions at historic conferences, resulting in the design of policies and frameworks aimed at integrating sustainability into transport planning and practices. Key reports such as those of the Brundtland Commission and the United Nations continue to promote policies that strive for environmental management, social equity, and the economic sustainability of transport systems at a global level. These historical landmarks form the backbone of sustainable mobility, collectively steering transportation towards more sustainable practices.

### ***The importance of education for sustainable mobility***

Education plays a vital role in cultivating awareness of the environmental and social impacts of transportation systems, equipping individuals with knowledge about how their travel choices influence climate change, air quality, and public health (Gallo & Marinelli, 2020).

Educational initiatives can empower the public to shift their behaviours toward more sustainable transport options, such as public transit, cycling, and walking. A study by Pan and Ryan (2025) found that informed citizens are significantly more likely to adopt sustainable transportation practices, thereby reducing greenhouse gas emissions and promoting a healthier environment. Knowledge dissemination in sustainable transport is not only about changing individual behaviour but also influences policy decisions that support investments in sustainable mobility infrastructure (Putz et al., 2018).

Knowledge therefore, empowers the public to make more responsible decisions, with policies that promote sustainable practices at the local, regional, and national levels. Furthermore, an informed public can influence decision-making to support investments in sustainable mobility infrastructure and technologies (Gudmundsson et al., 2016). Education promotes a shift towards assessing environmental and social impacts alongside economic benefits to achieve a balance of economic, environmental, and social needs.

Moreover, integrating sustainable transport education into school curricula is essential to fostering a culture that values sustainability among future generations. Recent research has demonstrated that interdisciplinary and experiential learning approaches effectively enhance students' understanding of and engagement with sustainability concepts (Putz et al., 2018; Grewe, 2025). For instance, project-based learning initiatives enable students to actively participate in solving real-world sustainability issues, thereby developing skills in critical thinking, collaboration, and creativity that are necessary to address the complexities of sustainable mobility (Bramwell-Lalor et al., 2020).

In short, integrating education into sustainable transport initiatives is an essential strategy for building an informed, proactive society. Education plays a crucial role in facilitating behavioural changes, raising awareness, and supporting development policies. The synergy of educational efforts with sustainable transportation efforts and policies not only advances UN SDGs but also promotes a healthier, more equitable future for all societies.

### ***STEAM education and 21st-century skills***

The need for 21st-century skills, including learning and innovation skills, information, media, and technology skills, and life and career skills, is emerging as a response to rapid developments in technology, the labor market, and the globalized economy, and has a major impact on how to prepare students for the future. Critical thinking, innovation, and collaboration are key to successfully adapting to a rapidly changing world (Darling-Hammond, 2010; Tashtoush et al., 2024; Yıldız & Ecevit, 2024).

Adapting to a globalized society increases competition and requires the ability to work in a cross-cultural and multi-dimensional environment (Friedman, 2005). Consequently, the need for knowledge and skills that enable people to thrive in a complex and interconnected world is greater than ever. Thus, education is no longer limited to traditional models or the transfer of knowledge but must also include the development of skills to solve complex problems.

The goals of modern education include preparing students to overcome challenges that require interdisciplinary and/or intercultural competencies (Wagner, 2008). Such competencies include the ability to collaborate effectively

with people from different backgrounds and to apply knowledge from various fields of knowledge to solve problems.

STEAM education is an interdisciplinary educational approach that integrates the numerous skills necessary for students' success in the 21st century. STEAM education encourages a broader understanding of knowledge and its application in realistic situations, connecting theory with practice while also emphasizing the importance of critical thinking and collaboration for problem-solving (Bybee, 2010; Suryani et al., 2025).

STEAM education is not limited to strictly academic skills but also comprises the development of creativity and innovative abilities (Jukes & Macdonald, 2007; Olalowo, 2020; Bicer et al., 2020; Isnawan et al., 2025). The distinctive difference between STEM (Science Technology Engineering Mathematics) and STEAM is the latter's inclusion of art, which contributes to the development of innovative ideas and the solving of complex problems. The synthesis of these fields produces interdisciplinary learning, which renders students more capable and flexible in a labor market that increasingly requires interdisciplinary approaches. Production and innovation occur through collaborative research, which enriches the educational process, leading to a more comprehensive learning environment. STEAM approach is strategic as it lays the foundations for students' future success by both strengthening their academic knowledge as well as promoting their overall development.

Recent literature has underscored the crucial role of education in addressing sustainability issues. UNESCO's emphasis on education for sustainable development (ESD) aligns with the goals of STEAM education by advocating for a curriculum that integrates knowledge about environmental sustainability, thereby preparing learners not only to understand but also to act on pressing global issues (Rieckmann, 2017). Furthermore, the incorporation of sustainability concepts into the curriculum fosters a sense of responsibility in students, encouraging them to engage in actions that promote sustainable practices (Elmassah et al., 2022).

The significance of project-based learning within STEAM education cannot be overstated. Project-based learning creates a context for students to apply academic knowledge in real-world scenarios, thus enhancing both engagement and knowledge retention (Kokotsaki et al., 2016). The recent work of Plotnikova et al. (2025) illustrates that when students collaborate on projects that have sustainable implications, they not only develop technical skills but also socio-emotional competencies that are vital for holistic development.

In conclusion, modern education must adapt to the realities of a constantly evolving world. A holistic educational approach that combines science, technology, engineering, the arts, and mathematics becomes imperative. Through STEAM education, students not only acquire important knowledge but also cultivate critical modern skills in creativity, collaboration, and communication. Application of the STEAM approach can contribute to the development of a generation of capable, innovative individuals who are ready to contribute to solving global challenges.

### ***Sciences in education***

Contemporary educational practice is part of a constantly evolving dialogue that seeks to understand and improve teaching methods. By critically describing current teaching methods, challenges are identified and ways for better teaching and learning are explored. Modern methods of teaching science in primary school include a variety of strategies that contribute to the creation of a dynamic learning environment.

Recent studies underline the significance of inquiry-based learning as a vital pedagogical strategy in science education. Nguyen et al. (2024) noted that inquiry-based methods empower students to formulate their own questions, conduct experiments, and draw conclusions based on evidence. Inquiry-based instruction is based on constructivist learning theories, where knowledge is built through experience. It invites student engagement and cultivates problem-solving skills (Jack-son & Ash, 2011). However, substantial guidance is required from teachers to ensure that students, especially those in primary school, remain focused and do not deviate from the topic.

Problem-based learning encourages students to learn by engaging with real-world problems, connecting education to life to add practical value (Tao & Wong, 2000). This method not only promotes critical thinking but also enables the application of scientific concepts to real-world situations (Krajcik & Czerniak, 2018). The method's success is contingent upon the availability of relevant problems and the participants' ability to address complex issues.

Integrated STEM education combines science, technology, engineering, and mathematics, connecting various subjects to promote holistic understanding (Hightower, 2011; Plotnikova et al. 2025). In this way, students gain awareness of the interconnections between cognitive fields, enhancing their understanding of real-world applications. However, this method raises challenges in designing and implementing relevant curricula and may require training for teachers.

Hands-on experiments allow students to interact directly with scientific phenomena, fostering curiosity and excitement (Orlich et al., 2012). Experiential learning of this type nurtures both the development of practical skills and curiosity, but it requires resources and materials that are not always available and relies on the provision of appropriate guidance by the teacher.

Cooperative learning improves social skills through teamwork as well as deepens understanding because students can learn from their peers (Vintner et al., 2015). However, individual contributions at the group level can be limited if some students rely on their peers or are not fully engaged. In addition, group dynamics can affect participation levels, which may distort learning outcomes.

In summary, modern educational practice is being renewed and is evolving towards providing higher-quality teaching and learning, documenting the challenges that arise from the implementation of innovative teaching strategies. Through experiential learning, holistic learning, and solving real problems, students are actively involved in learning, thereby enhancing their understanding and thinking. Teacher guidance is a critical factor in students' concentration and focus on learning objectives. Although collaborative learning enhances collaborative skills, it poses challenges for individual participation in the group. In general, methods that combine experimentation and collaboration are effective, although they require careful planning and resources. This study recognizes the importance of cultivating 21st-century skills and the interaction of STEAM fields to create a comprehensive teaching intervention focused on sustainable mobility that prepares students for future challenges and opportunities.

### **Research purpose and questions**

The intention is to examine how the teaching scenario based on the project-based learning model influences the development of the 4Cs—Communication, Collaboration, Creativity, and Critical Thinking—in fourth-grade students. Essentially, the study aims to assess the impact of this particular teaching approach on enhancing these essential skills among the students. By evaluating the intervention, the researchers seek to understand the effectiveness of the teaching method in fostering these 21st-century skills, thereby providing insights into its potential contribution to student learning and development in the context of sustainable mobility.

The following three research questions are investigated:

- (1) What is the effect of the teaching intervention for sustainable mobility on encouraging the 4Cs (communication, collaboration, creativity, critical thinking) among students working in small groups?
- (2) What is the effect of the teaching intervention on students' understanding of the principles of sustainable mobility?
- (3) How do teachers evaluate the teaching intervention?

### **Methodology**

#### ***Research process and sample***

A qualitative approach was preferred because it provides the opportunity to explore internal states and behaviours in real-world settings such as the classroom (Patton, 2015). It is also considered suitable for understanding complex phenomena like skill development that cannot be adequately captured through numerical data (Miles & Jozefowicz-Simbeni, 2010). The qualitative methodology was combined with quantitative data through a process known as convergent analysis or the mixed-methods approach (Creswell, 2014). This approach allowed the researchers to achieve a more comprehensive understanding of the examined topic. Qualitative research provides in-depth information regarding the views, experiences, and behaviours of participants, thereby enriching and informing understanding of conventional quantitative statistics (Denzin & Lincoln, 2011).

The study was designed around an action plan in accordance with the research objectives. The plan included the following actions:

1. Creation of a common standard file for the teaching intervention design (teaching scenario)
2. Creation of the educational material that accompanies each scenario (student worksheets and presentation files)
3. Creation of a common scale of graded criteria (rubric) as a standard file for the evaluation of the 4Cs, to be completed by the classroom teachers
4. Creation of a common evaluation form for teaching interventions, to be completed by the classroom teachers
5. Creation of an information and consent form for the principal and teachers
6. Creation of an information and consent form for parents/guardians

The teaching scenario emerged from these steps and was aligned to the new Curriculum of Environmental Studies, the thematic field of "Citizenship," and the module "Highway Traffic Code." due to the relevance of its content about principles of responsible citizenship and understanding traffic laws. It was also integrated thematically into the Skills Workshops Zone and specifically in the 1st thematic module "Living Better-Well-Being" in the subsection "Health-Road Safety."

In line with the qualitative methodology, purposive sampling was used. Purposive sampling is a widely used sampling strategy in qualitative research because it allows researchers to select participants who are more likely to

provide valuable, relevant information (Borden-Hudson, 2010). Furthermore, through purposive sampling, researchers can leverage the capabilities and experiences of participants and focus on those who have the greatest knowledge or interest in the subject of the research (Trost, 1986).

The research process was carried out in three phases. During the first phase, the headmaster of the largest primary school in the city of Kavala, Greece, was contacted by the researchers to determine whether the site was suitable for this study and to gain the headmaster's permission. Two teachers responsible for two classes of 38 students total agreed to participate after being informed of the objectives and content of the intervention. The selection was based on multiple standards; in addition to teaching and administrative experience, it also considered the fact that the researchers worked in school units in the same area, which allowed them to better understand the local educational context and dynamics.

It is important to highlight that all teachers involved in this process were certified professionals with extensive experience in their respective areas. They possessed either master's degrees in education or a 400-hour certification in STEAM education, alongside specialized training certification in Skills Labs Zone and a minimum of five years of teaching experience applying active learning methods. Their extensive experience in incorporating technology and hands-on learning into their curricula provided them with valuable insights into the suitability and effectiveness of the tools used, including worksheets, presentation files, teacher reflection sheets, and the grading scale. The concept of "Skills Labs Zone" refers to dedicated learning environments or frameworks designed to enhance the acquisition and development of various skills through hands-on, interactive learning experiences. Within a Skills Labs Zone, educators implement active learning methodologies that allow students to engage with material in dynamic and meaningful ways. This might include project-based learning, simulations, workshops, group activities, and the use of technology to facilitate experiential learning.

Adjustments were made based on their observations, resulting in the final preparation of the materials. To ensure uniform evaluation approaches, two training sessions were organized for the teachers, focusing on the grading scale. The first session provided an overview of the grading scale's structure, detailed explanations of each performance level, and discussions on how to observe and evaluate students based on established criteria. The second session involved calibration exercises in which teachers collaboratively practiced assessing student performance using the grading scale. No sensitive data was collected regarding teachers or students, and their anonymity was preserved. All parents or guardians of participating students provided informed consent via a consent form. This form outlined the objectives, content, teaching procedures, and duration of the research. It was distributed to the students to take home, and a signed copy was required before they could participate in the study.

In the second stage of implementation, each teacher adhered to the phases outlined in their scenario while students engaged in educational activities and interacted with the instructional material. Furthermore, every teacher completed the 4Cs rubric.

In the final phase, the teachers filled out an evaluation form that assessed the relevance of the scenario's topic, the educational resources and the teaching methodology and that offered space for their reflections. The teaching intervention lasted 15 hours and took place during April, May, and June 2024.

### ***Description of the teaching intervention***

The teaching scenario involved the construction of a sustainable vehicle. This project aimed to help 4th-grade students develop key 21st-century skills, including critical thinking, collaboration, communication, and creativity. The primary goals were to raise students' awareness of sustainable transportation options like cycling, walking, or public transit, and to have them construct a model of a sustainable vehicle.

The choice of 4th-grade students for this study was deliberate and based on their developmental stage. According to Piaget (1973), children at this age are ready to understand concepts like group dynamics, collaboration, and the importance of social relationships. They are capable of working together in groups and participating in group activities. Vygotsky (1978) also noted that rapid cognitive development in this age group enables greater critical thinking and the grasping of complex concepts. Thus, this age group presented an ideal audience for learning about sustainable mobility and students' roles in it. Furthermore, as Berk (2013) pointed out, fourth graders have already developed social skills that allow them to interact and cooperate with their peers.

The pedagogical approach was grounded in social and constructivist principles, emphasizing that students build knowledge through interaction. The teaching model was student-centred, with a strong focus on collaboration and project-based learning. Students worked in groups, and the teachers acted as facilitators and guides, providing support rather than direct instruction.

The 15 teaching hours were spread over three months (April, May, and June) to ensure adequate coverage of the topics and to allow students enough time to absorb the concepts and engage in practical exercises. Each month included five teaching hours, focusing on different stages of the project: the introduction to sustainable mobility, the vehicle construction phase, and the final presentation of their work. Activities included an educational field

trip, where students participated in a scavenger hunt for road signs, as well as the assembly of a solar-powered vehicle kit. Students were encouraged to enhance their kits with additional components. The subsequent sections describe the steps of the first, second, and third teaching interventions in more detail.

#### Steps of first teaching intervention

1. Orientation stage: Based on images of accidents, the students formulated hypotheses regarding the behaviours that may have led to them. Each group took an image and recorded their guesses through brainstorming. The teacher encouraged the students to ask themselves if they knew the road signs and to check by participating in a sign treasure hunt.

2. Action planning stage: The students were divided into groups, where each group was tasked with identifying road signs in their area. Students' safety was a primary concern, and a visit to a traffic education park was suggested.

3. Activity execution stage: The group members drew the signs they identified, noted where they were located, and provided possible interpretations during a game of hunting for road signs.

4. Presentation stage: The groups presented the signs they identified to the class as a whole. They received feedback from their classmates on correctness and expressed concerns.

5. Evaluation stage: The students recorded, at group level, to what extent they achieved the desired results.

#### Steps of the second teaching intervention

1. Orientation stage: The teacher presented the pedestrian brochure and the brochure for safe cycling found on the e-drive academy website. Student concerns were discussed, and pre-existing perceptions were detected.

2. Action planning stage: Students were divided into pairs or trios and discussed the order in which they would play the games and who would record their observations on the worksheet.

3. Activity stage: Each student played in the game application and received helpful comments from the classmate with whom they shared the computer. At the same time, the classmate recorded their observations on the worksheet.

4. Presentation stage: The answers to the worksheet were discussed and commented on group discussion in the class plenary. If possible, changes or improvements were made in the class-rooms.

5. In the evaluation stage, the students recorded the extent to which they achieved the desired results.

#### Steps of the third teaching intervention

1. Orientation stage: The students were formed into groups and discussed the concept of sustainable mobility. Appropriate methods of transportation were examined, such as cycling, walking and public transportation.

2. Action planning stage: The students were organized into teams to facilitate the design and construction of sustainable transportation solutions. Each group assumed distinct roles in order to successfully carry out the construction process.

3. Activity execution stage: The students worked actively to build their means. Practical skills and creative thinking were applied to complete the project. Several factors influenced the selection of the kit, especially its low cost, which enhances affordability and appeal for schools and educators. Additionally, the ease of procurement was significant as the kit should be easy for the average consumer to purchase. Above all, it is crucial that the kit includes essential components such as a motor, solar battery, four wheels, and the vehicle chassis, as these elements are necessary for constructing a functional and sustainable vehicle. This attention to affordability, accessibility, and the main components of the kit enables the replicability of the educational intervention in more schools.

4. Presentation stage: The groups presented their vehicles they built to the rest of the class explaining the process they followed and the characteristics of each media.

5. Evaluation stage: The students evaluated their work, reflected on the fulfilment of their initial goals, and recorded their successes as well as points for improvement.

The language of instruction was the students' native language, Greek. This ensured that students could actively participate and fully understand the instructions and activities related to the intervention without language barriers.

### ***Data collection process***

The data collection process was carried out after the teaching intervention and consisted of three distinct forms: the individual student form, which served to measure the students' knowledge related to the educational intervention, particularly in the context of sustainability education; the 21st-century skills rubric covering the 4Cs, completed by the two teachers; and the teachers' reflection form.

The individual student form focused on the expected cognitive learning outcomes and thus addressed sustainable mobility, sustainable means of transport, and safe transport. It contained three single-answer questions and six true–false questions. An example of a single-answer question is “It is NOT a means of sustainable mobility (bicycle/scooter/hybrid car/car). An example of a true–false question is “Sustainable mobility means: More walking, cycling, and public transport.”

The 21st-century skills rubric 4Cs was constructed by the researchers based on the rubric of Herro et al. (2017), which has been used for at least 10 teaching interventions, with resulting data presented at national and international conferences. Additionally, this assessment tool was used to determine students' performance across the four skills.

The structural components of the rubric were outlined as follows (Andrade, 1997). The criteria for each dimension pertain to the specific requirements that a behaviour must fulfil to be deemed appropriate and comprehensive. Essentially, the assessment criteria detailed all the features that the demonstrated behaviour should encompass. Each of the four skills was tied to five dimensions.

(1) The communication criteria featured five dimensions: respecting others' ideas, exhibiting socially acceptable language and conduct, listening and acknowledging turn-taking, expressing a personal viewpoint, and considering the perspectives of others.

(2) The collaboration criteria were also composed of five dimensions: reviewing assignments/projects with peers; negotiating roles within the team; sharing responsibilities and striving towards task completion; ensuring comprehension of the process and/or content; and providing feedback, assistance, or guidance on the work/project.

(3) Creativity comprised five dimensions: showcasing fluency in expression and adaptability in thought; modifying or refining an existing design; creating something new, such as a design or composition; proposing or developing ideas and defending them; and reflecting on the outcome produced.

(4) Lastly, critical thinking encompassed five dimensions: formulating relevant probing questions, summarizing a topic or argument, analysing data, supplying research or evidence, and clarifying the influence of new information.

The criteria were structured as follows. The scoring levels provided descriptive assessments of the rubric, illustrating the extent of achievement regarding the assessment criteria. The levels ranged from the minimum (numeric value of 1), indicating the need for more effort (2), to the maximum, representing excellent effort (3). Each level featured precise and detailed descriptions of the criteria for students' behaviour to be categorized at each level. For instance, respecting others' ideas is crucial in collaborative settings. When more effort is needed to improve their collaboration skills, the student tends to reject others' ideas without justification, reflecting a closed mind-set towards new suggestions or opinions. In satisfactory cases, the student occasionally permits others to share their ideas and may diplomatically disagree only at certain times, indicating a lack of consistent manners or understanding of differing opinions. Conversely, excellent effort is demonstrated by the student consistently allowing others to contribute their thoughts and diplomatically disagreeing, showcasing both respect and acceptance of diverse views. The use of socially appropriate language and actions is similarly critical in interactions. When more effort is needed, the student resorts to socially unacceptable language and behaviours, which can manifest as disrespect or insults. With satisfactory effort, the student sometimes employs socially acceptable language and behaviour, showing respect intermittently but not consistently. In contrast, excellent effort is characterized by the student consistently using socially acceptable language and behaviours in peer communications, reflecting continuous politeness and respect.

Each level of performance corresponded to a particular score on a numeric scale, with the highest score linked to superior performance and the lowest score to the least effective performance. Each skill was evaluated on a scale from 5 to 15. Hence, the minimum score a student could receive was 5, while the maximum was 15. Consequently, the overall score spanned from 20 to 60, calculated by summing the lowest possible scores (5 for each skill, totalling 20) with the highest possible scores (15 for each skill, totalling 60).

To assess developmental appropriateness for 4th-grade students, several factors were taken into consideration. Cognitive development in 4th-grade students (aged approximately 9 to 10 years) involves students beginning to engage in more complex thinking and understanding abstract concepts. Cognitive development theories, such as those proposed by Jean Piaget, suggest that children at this age transition from the concrete operational stage to a more advanced form of cognitive processing. That transition allows for enhanced logical thinking, improved problem-solving, and a better understanding of the dynamics of collaboration (Pritchard, 2017).

Regarding the development of social skills, 4th graders become increasingly capable of collaborating with their peers. This is crucial for strengthening social skills such as negotiation, conflict resolution, and self-expression. Emphasis on collaboration and communication within the rubric aligns well with the social developmental milestones expected at this age (Vygotsky, 1978).

Creativity also begins to manifest more distinctly during middle childhood as children are encouraged to explore various solutions and apply innovative approaches to problems. The rubric captures this development by emphasizing creativity and fostering an environment where imaginative thinking can flourish (Craft, 2005).

The introduction of critical thinking activities is suitable for this age as it cultivates their ability to analyse information, ask reflective questions, and reflect on their learning experiences. The rubric supports this cognitive development by providing criteria that promote deeper thinking and assessment of their work processes (Facione, 2011).

To validate the rubric, it was essential to assess the quality methods through a two-phase process. In the first phase, the rubric underwent seven evaluations by a panel of experts, along with an assessment regarding the significance of its characteristics. The expert group consisted of highly skilled educators with advanced degrees and extensive experience in pedagogical practices pertinent to elementary education, ensuring that the rubric accurately measures the intended framework. To determine if the experts considered each characteristic to be a robust indicator, they were presented with a follow-up question to indicate the degree to which they agreed that each characteristic aligned with their expectations for each dimension. Their agreement was quantified using a 5-point Likert scale.

The educational scenario was regarded as a pedagogical tool. It was suggested that both its creator and other educators participate in its evaluation. After its implementation, the evaluation sections of the scenario were filled out with the intention of assessing teaching practices and the relevance of the scenario's components. The evaluation form was structured around three main axes: 1) evaluation of the scenario's topic, 2) evaluation of the pedagogical approach, 3) evaluation of the educational materials used. Each of these axes was rated on a 3-point scale, whereby Poor (1) signified that the aspect failed to meet expectations, Satisfactory (2) indicated that some expectations were met but improvements were needed, and Very Good (3) meant that the criteria were fully met or surpassed.

To evaluate the topic, four criteria were established. These included compatibility with the curriculum, or whether the scenario aligns with the educational program and fits within the timetable; relevance to the students' cognitive level, or if the scenario matched the developmental stage and comprehension of the learners; feasibility concerning the proposed timeline, or if the allocated teaching time was adequate; and the contemporary nature of the content, or whether it reflects current practices and knowledge. Additionally, a comment section was provided for educators to offer qualitative feedback or clarifications concerning each criterion.

The second axis concentrated on the educational approach, focusing on its effectiveness in implementing STEM principles and collaborative teaching. This axis aimed to ensure alignment with the curriculum, appropriateness for the students' cognitive levels, adequacy of the proposed implementation time, and the relevance of the content. A comments section was also included for any additional information or observations.

The final axis assessed the educational materials utilized in the scenario, which included presentations and worksheets given to the students. Evaluation criteria addressed whether the material was aligned with the curriculum, appropriate for the students' cognitive levels, consistent with the proposed implementation time, and user-friendly and accessible to students. The usability and accessibility of the educational materials were specifically evaluated. Similar to the other sections, there was a space for comments to allow for detailed feedback on the materials.

The educators' reflections included two statements, "I followed the steps as outlined in the 'Educational Activities' section," and "I sought and received assistance regarding challenges I faced that hindered my work," as well as the open-ended response "Please provide observations, suggestions for improvement, challenges, or thoughts that may enhance the scenario." There was also an option to succinctly describe the methods used for the first two questions, with a 3-point scale applied to gauge the level of exhibited behaviour (Poor, Satisfactory, and Very Good).

## Results

For analysis of the research data, the convergent parallel design method was employed, allowing for the simultaneous analysis of qualitative and quantitative data. The results from both sets were subsequently integrated (Creswell & Clark, 2017). Data analysis for quantitative data was carried out using the IBM SPSS Statistics 29.0.2.0 statistical package, while qualitative data, including photographic material from the teaching interventions related to sustainable mobility, provided complementary insights. Each component reinforced the overall effectiveness of the intervention, enhancing student engagement and learning through the application of concepts related to sustainable transportation.

The procedures included collecting data from 38 students participating in the intervention by processing three different forms: the individual knowledge form, which aimed to assess students' knowledge about sustainable mobility; the rubric (4Cs) used by teachers to assess students' communication, collaboration, creativity, and critical thinking skills; and the teacher feedback form used to evaluate the effectiveness of the teaching intervention. Each successful student response was coded as "1" and each incorrect response as "0," and the means, standard deviation, and percentages of correct answers were calculated. Teachers assessed their overall performance on the 4Cs skills using a rating scale from 1 to 3.

The qualitative findings highlighted themes such as students' engagement and participation and educational environment characteristics. Furthermore, documentation from the teaching interventions illustrated student participation and the collaborative process, affirming levels of engagement and the achievement of learning outcomes. Qualitative data were analysed using a thematic approach, which led to the extraction of key themes

and categories regarding student participation and engagement, as well as the conditions of the educational environment (Naeem et al., 2023). After the quantitative and qualitative data analyses were completed, the results were integrated to provide a more comprehensive picture of the effectiveness of the teaching intervention. The qualitative results enhanced understanding of the quantitative results, providing context and depth to the interpretation of the data.

**Results of the individual student form**

Of the 38 students, only one did not complete the acquired knowledge form due to absence. Therefore, the results reflect the scores of 37 students. All students answered the three questions correctly (Figure 1).

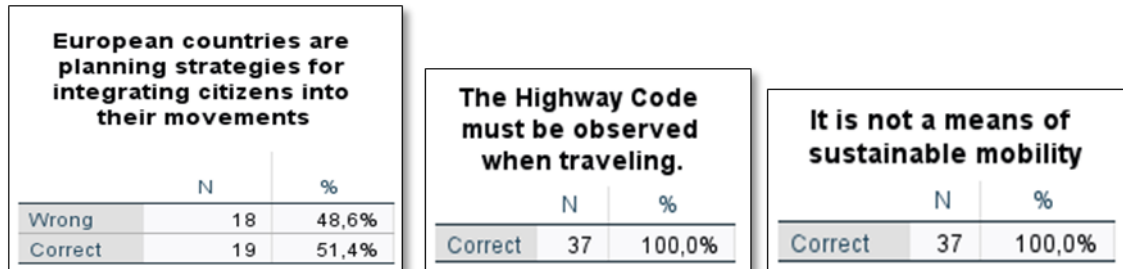


Figure 1. Correct answers of individual form

Table 1 of the document provides information on students’ incorrect answers to the individual knowledge form, which is related to the principles of sustainable mobility. It includes different questions that the participants had to answer, with their overall error rate analysed. The questions cover the following categories: Means of sustainable mobility, which explore what is meant by sustainable mobility (e.g. what are the means of sustainable mobility), strategies of Europe, which are related to understanding whether European countries are developing strategies for the integration of citizens in mobility, and summary and meaning, which refer to the general principles of sustainable mobility and their meaning.

Through the data presented, it can be observed that students completely avoided errors in some questions, such as questions 1, 6, and 8, indicating that they had a good understanding of the relevant concepts. In contrast, in other questions, there was a significant number of incorrect answers, such as in questions 3 and 5, where students present a weakness in understanding complex concepts related to sustainable mobility (Table 1). The interpretation of information supports the study’s findings that teaching about sustainable mobility has a positive effect on students’ understanding, but also highlights the need for more reinforcement in specific areas where sunstroke is observed. The analysis of the difficult questions can serve as a guide for future educational interventions and the development of targeted teaching materials that will enhance students’ understanding in these thematic areas.

Table 1. Incorrect answers of individual form

		It is not a means of sustainable mobility	Not related to mobility	European countries are planning strategies for integrating citizens into their movements	Sustainable mobility means stopping cars from dominating cities	Sustainable mobility also means: More walking, cycling and public transport	European countries do NOT promote the use of bicycles for public transportation	Safety, efficiency and comfort are important when traveling	The Highway Code must be observed when traveling.	Road traffic signs only apply to those driving a car
N	Valid	37	37	37	37	37	37	37	37	37
	Missing	0	0	0	0	0	0	0	0	0
Mean		1	0.8	0.5	0.7	0.7	1	0.9	1	0.8
Std. Error of Mean		0	0	0	0	0	0	0	0	0

Median	1	1	1	1	1	1	1	1	1
Mode	1	1	1	1	1	1	1	1	1
Std. Deviation	0	0.3	0.5	0.4	0.4	0	0.2	0	0.3
Variance	0	0.1	0.2	0.2	0.1	0	0	0	0.1
Range	0	1	1	1	1	0	1	0	1
Minimum	1	0	0	0	0	1	0	1	0
Maximum	1	1	1	1	1	1	1	1	1
Sum	37	11	19	26	29	37	34	37	32

### Rubric Results

The rubric identified the dimensions of each of the 4 skills, as assessed by the two participating teachers, following a 15-hour teaching intervention, which they implemented in the Skills Labs zone of the timetabled program. The numerical score was the result of the teachers' findings based on their observations on a weekly basis, for 5 teaching hours per month.

The teachers assessed the students' overall performance in the 4 skills as excellent (Figure 2).

Collaboration-Creativity-Communication-Critical Thinking		
	N	%
satisfactory effort 34-46	6	16,2%
excellent effort 47-60	31	83,8%

Figure 2. Overall performance in 4Cs

Table 2 in the study provides a comprehensive overview of students' statistical performance in the 4Cs following the completion of the educational intervention, playing a pivotal role in evaluating the effectiveness of this intervention in fostering 21st-century skills. The table delineates the scores for each skill, featuring distinct columns that present the overall scores for each of the 4Cs, facilitating the identification of which skills were most and least developed among the students. Furthermore, the data yields quantitative insights, offering numerical evidence of student progress; for instance, high communication skills are reflected in a total score of 109 points, underscoring the effectiveness of the teaching methods employed in promoting communication competencies.

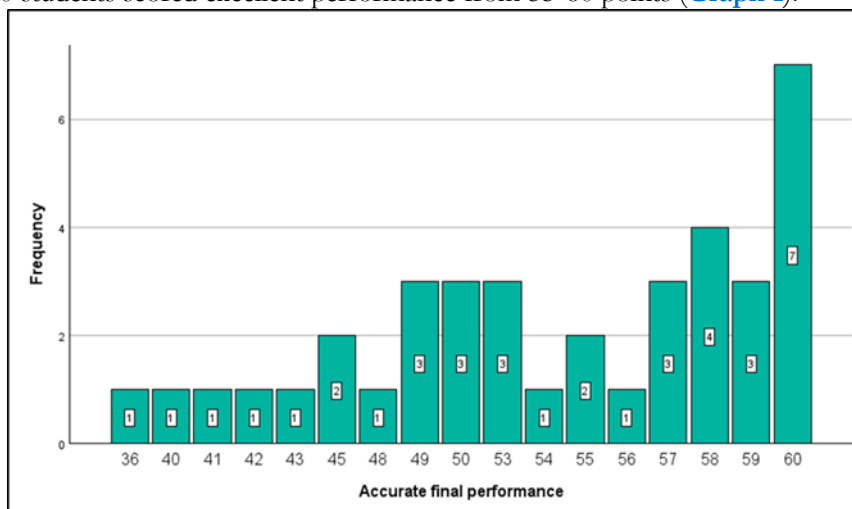
By enabling a comparative analysis of performance across different skills, it serves as a valuable tool for assessing the success of various teaching strategies. The relatively lower score in collaboration highlights a need for greater emphasis on teamwork and collaborative activities within the curriculum. Additionally, the information presented can assist educators in identifying areas where students may require further support, as well as which instructional approaches prove to be the most effective.

Ultimately, the observed enhancement in students' communication and creativity skills serves as strong evidence of the success of project-based learning and the integrated teaching approach, further enhancing the value of curriculum content related to sustainable mobility.

Table 2. Statistics of 4Cs

	Gender	Cooperation total	Creativity total	Communication total	Critical thinking total
N Valid	37	37	37	37	37
Missing	0	0	0	0	0
Mean	0.5	2.7	2.8	2.8	2.8
Std. Error of Mean	0	0	0	0	0
Median	1	3	3	3	3
Mode	1	3	3	3	3
Std. Deviation	0.5	0.5	0.4	0.3	0.3
Variance	0.2	0.3	0.2	0.1	0.1
Range	1	2	2	2	1
Minimum	0	1	1	1	2
Maximum	1	3	3	3	3
Sum	21	101	104	107	104

When the students' exact scores were displayed, it was revealed that 7 cases of students achieved the maximum of 60 points while 20 students scored excellent performance from 55-60 points (Graph 1).



Graph 1. Final performance

**Results of the teacher reflection form Paragraph.**

Each teacher recorded on the reflection form that they implemented the steps of the educational scenario to the maximum extent as they mobilized the proposed/integrated technology tools in the scenario, such as websites and PowerPoint presentations, while at the same time not neglecting the educational visit to a traffic education park. They also noted that they requested and received support in the obstacles they encountered, which made their work difficult. This was the case where the ready-made kit for assembly was preferred, and the subsequent addition of additional components, depending on the creativity, imagination of the students, and the availability of resources. Be-cause the construction from scratch with materials such as straws, AA battery base, DC motor, switch, pulleys (as was the initial design of the scenario) turned out to not only be problematic for the teachers, resulting in them being hesitant to experiment, but also not in line with the students' experiences in relation to the group-centred organization of teaching and the existence of only one teacher in each of the two large classes.

**Results of core themes and categories**

The visualization of key themes and categories in a tabular format provides a clearer and more organized presentation, facilitating the understanding of information. Table 3 summarizes the main themes and categories of the study.

Table 3. Main themes and categories

Theme	Category	Description
Student Participation and Engagement	Participation in Collaborative Tasks	Emphasizes the importance of collaboration for the development of social skills.
	Participation Strategies	Techniques that promote engagement and involvement of all students.
Educational Environment	Characteristics of the Educational Environment	Elements that define the course, such as resources and the atmosphere of experimentation.
	Student Empowerment Through Student-Centered Learning	Creating an environment that places students at the center of the learning process.

The analysis of the research data revealed several core themes and categories that emerged from the students' experiences during the project (Panel A–F).

Core theme 1: Students' participation and engagement

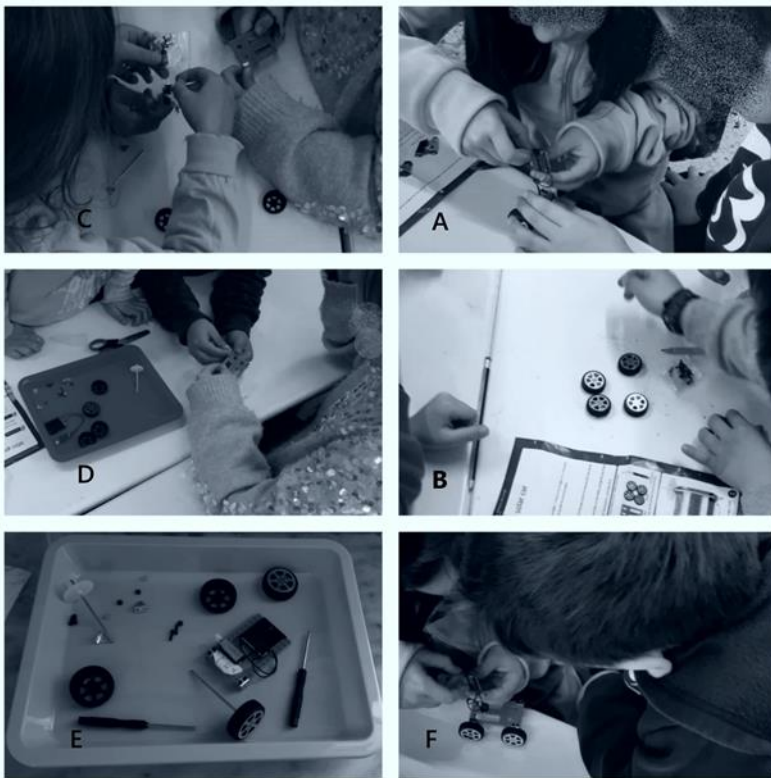
Category 1.1: Participation in collaborative tasks: This category emphasized the importance of students working together on tasks that required collaboration. Collaborative tasks enhanced students' social skills, fostered a sense of community, and enriched the learning experience by allowing students to share diverse ideas and perspectives. In the context of the teaching intervention analysed in the document, students engaged in group activities aimed at designing and building sustainable means of transportation (Panel A–B).

Category 1.2: Participation strategies: Participation strategies refer to the methods and techniques employed to promote engagement among students. Effective participation strategies included structured group work, peer feedback sessions, and interactive discussions, as highlighted in the teaching intervention. These strategies were designed to encourage all students to contribute to the learning process, ensuring that everyone had a role and that their voices were heard (Panel C–D).

Core theme 2: Educational environment

Category 1.1: Characteristics of the educational environment: This category focused on the elements that defined the educational environment in which learning took place. A supportive educational environment was characterized by resources that facilitated interaction, access to materials necessary for projects, and an atmosphere that promoted experimentation and creative problem-solving. The integration of technology in the classroom and access to hands-on materials, such as the vehicle kits mentioned, contributed to a rich educational environment that encouraged students to immerse themselves fully in the learning experience (Panel E).

Category 1.2: Students' empowerment through student-centred learning: This category addressed the concept of student-centred learning, wherein students were placed at the centre of their own learning journey. Empowerment in this context relates to students having autonomy and agency in their learning processes, making decisions about how to approach tasks, and expressing their thoughts freely. The teaching intervention fostered this empowerment by allowing students to take charge of their projects, collaborate with peers, and engage with content in a meaningful way (Panel F).



Panel 1. Panel A-F

## Discussion

This study explored in depth the connection between sustainable mobility and 21st-century skills education, implementing a teaching scenario addressed to fourth-grade students. The diverse theoretical background of the study was based on the principles of sustainability and the rational management of natural resources, highlighting the value of scientific knowledge in shaping informed and responsible citizens (Zietsman & Rilett, 2002). In particular, the concept of sustainability is linked to modern educational strategies that promote critical thinking, communication, and collaboration skills that are considered essential for the formation of 21<sup>st</sup>-century students (Darling-Hammond, 2010; Jukes & Macdonald, 2007).

The findings of the research confirmed the subjective experience of the students, who, by participating in experiential activities and collaborative projects, not only developed knowledge about the principles of sustainable mobility but also cultivated important skills. The observations regarding the higher scores in communication and creativity skills highlighted the value of the dialectical nature of learning (NRC, 2007).

Additionally, it is important to mention that the implementation of the teaching scenario revealed the various challenges that teachers face during their teaching practice. This underscores the urgent need to support and train

teachers in strategies that combine theory with practical applications of scientific concepts to create a more favourable learning environment (Driver et al., 2000). The organization of students into groups, enhanced by interactive activities, highlighted the role of their involvement in the learning process, which is at the heart of STEAM education models (Herro et al., 2017).

In conclusion, this research project highlights the potential of experiential education for combining scientific knowledge with social skills, thus offering a comprehensive learning framework for preparing students for a series of contemporary challenges. Moreover, continuous development and the adaptation of educational programs strengthen students' awareness of sustainable mobility and their development of critical thinking, and are consistent with the ongoing need to educate responsible citizens (Holden et al., 2013).

## **Conclusions**

The present study examined a teaching intervention related to sustainable mobility that sought to develop skills in the 4Cs among fourth-grade students. The research included a qualitative approach with purposive sampling and the application of project-based learning, which was a necessary condition for achieving the educational objectives. The conclusions are formulated based on four axes: the broader impact of the teaching intervention, the understanding of the principles of sustainable mobility, teacher evaluation of the scenario, and evaluation of the set of 21st-century skills.

Regarding the first axis, the results show promising effects on the 4Cs when the students worked in small groups. Teachers noted that students developed communication and collaboration skills, while their creativity was exercised by building sustainable means of transportation.

In terms of the second axis, analysis of students' individual forms revealed that most of the answers to the questions on the principles of sustainable mobility were correct. Students demonstrated a good understanding of sustainable modes of transportation, with only a few giving incorrect answers to specific questions.

Per the third axis, teachers assessed the teaching intervention as particularly effective, underlining students' universal participation. In addition, they admitted that they followed the steps of the scenario precisely, making maximal use of the integrated educational material.

Regarding the fourth axis, students' performance in 21st-century skills ranged from 20 to 60 points, with the highest scores observed in creativity and communication. These results can be attributed to the fact that students not only enriched their knowledge but also developed skills that are necessary for future challenges.

With regard to the fifth axis, teachers' support of the implementation of the scenario proved to be crucial for the success of the intervention. The modifications proposed by teachers to the initial design contributed to its completion. In addition, their observations regarding the obstacles they encountered contributed positively to the overall learning process.

To summarize, the findings support the value of teaching projects that combine sustainable mobility with the cultivation of 21st-century skills. This teaching proposal can function as a model for future educational interventions, strengthening the connection between theoretical knowledge and practical application.

## **Limitations and recommendations for the future**

The study is subject to certain limitations regarding its sample and methodology. Initially, the sampling was purposive as the two teachers were selected based on specific criteria, such as the class they taught and their teaching experience. Teachers with less than five years of service in schools were not considered since they would be relatively inexperienced and may not be able to manage the challenges arising from the implementation of advanced teaching methods associated with STEAM education. However, this approach could lead to different results as less experienced teachers may perceive classroom conditions differently and present varying results. A second limitation relates to the sample size. The small size of 38 students may not be representative of the broader school community or the student population in general. Limited participation may limit the generalizability of the findings and limits the ability to make broader recommendations.

Furthermore, the success of the intervention depends to a large extent on the participation of the students. In other words, if teachers are not offered guidance, the effectiveness of the intervention and the results of the research are likely to be affected. Additionally, lack of commitment or participation can negatively affect outcomes, and if students do not demonstrate active participation, the intervention may not produce the desired results.

Finally, the suggestion for a longitudinal approach to assess knowledge retention over time is indeed valuable. In the initial study design, the researchers aimed to capture immediate impacts. However, longitudinal studies offer the potential for understanding how students' perceptions and knowledge evolve as they continue to engage with concepts of sustainable mobility. This possibility was discussed in the limitations section and is recommended as a suggestion for future research due to the insights it could offer regarding knowledge retention and long-term behavioural changes.

Future research could also include comparative analyses of the learning outcomes of students participating in traditional and STEAM programs related to sustainable mobility or examine the cultural factors that influence students' mobility habits and how these influences are integrated into education. These proposals aim to deepen the understanding and implementation of sustainable practices in the educational process, to develop 21st-century skills in students.

To conclude, the connection between STEAM programs and students' mobility habits is essential for fostering holistic development in students, as STEAM programs promote interdisciplinary learning by integrating science, technology, engineering, art, and mathematics with the educational process. The STEAM approach supports the cultivation of knowledge and skills related to sustainable mobility, such as the use of sustainable forms of transport (e.g., cycling, public transport). Through activities that explore the benefits and challenges of sustainable mobility, students develop a better understanding of the impacts of their personal mobility on the environment, promoting responsible decision-making in their daily lives. Students' access to sustainable mobility is influenced by their knowledge and understanding of sustainable practices, which they acquire through STEAM programs. This knowledge impacts their willingness and ability to use sustainable transportation options such as walking, cycling, or using public transit.

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**Data Availability Statement:** Data supporting Tables 1–3, the panel, Figures 1–2, and the graph are publicly available as part of this current document. The Herro et al. rubric is available from the International Journal of STEM Education at <https://doi.org/10.1186/s40594-017-0094-z>. This paper is intended to serve as a springboard both for application in the classroom and for future research related to applications of STEAM educational implementations.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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