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Examining the impact of open schooling in science education: the case of educational seismology

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ABSTRACT

This study explores the impact of science education projects focusing on educational seismology to enhance school openness and enrich students' civic responsibility and views on their science learning. The sample comprised 515 students from 33 different schools. The study involved specialised training for educators and administrators on integrating seismology into an open schooling framework. Schools then developed and implemented projects that incorporated stakeholder engagement and addressed societal issues. The evaluation employed four tools, namely the seismology-related projects developed by each school, a Self-Reflection Tool to measure organisational changes of participating schools, the 'My Science Classes' questionnaire assessing student views of their science learning, and the 'Civic Responsibility Survey' to assess students civic responsibility awareness. Data, analysed through qualitative and quantitative methods, revealed varied project types, differing in terms of student involvement and stakeholder engagement. Results showed a significant rise in perceived school openness post-project and a positive shift in student views towards science learning and civic engagement awareness. These findings highlight the effectiveness of integrating real-world issues through science education, such as educational seismology, suggesting significant implications for curriculum design and educational policy by emphasizing the importance of project-based learning and community engagement in fostering academic and civic excellence.

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Introduction

In recent years, there has been a focused push within Europe to explore and implement strategies aimed at breaking down the invisible barriers that separate educational institutions from the wider societal context. While not physical, these barriers hinder the dissemination, application, and interchange of knowledge and expertise developed within academic environments and the local community. The traditional separation between

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schools and society is being challenged and needs to be phased out from the educational philosophy and culture, prompting institutions to reevaluate and redefine their role, impact, and engagement within the local community. Research has shown that when educational institutions actively collaborate with local communities, the learning process becomes more dynamic and impactful, benefiting both students and society (Sachs, 2001; Smith & Sobel, 2010).

Initiatives oriented towards this paradigm shift, such as the Horizon Coordination and Support Actions of the European Commission, underscore the imperative of transforming schools into innovation hubs that actively engage as collaborative partners with their local communities. Prior calls, as evidenced by reports from the Organization for Economic Co-operation and Development (OECD, 2004; 2006), have advocated for a recalibration of the role and mission of schools, identifying an emergent need to endow them with renewed dynamism, recognition, and purpose. To achieve this goal, a set of guiding principles has been proposed, designed to facilitate the adoption of an 'Open Schooling' approach. Open Schooling refers to an educational model that gives priority to inclusivity, flexibility, and community engagement, breaking down the traditional barriers of formal education by integrating learning environments with the broader community and real-world contexts (Facer, 2011; Smith & Sobel, 2010). This approach fosters collaborative and project-based learning that extends beyond the classroom, involving learners, educators, families, and community members in meaningful, participatory educational experiences (European Commission, 2015; Sotiriou et al., 2021). Embracing such an approach entails the collective engagement of school stakeholders (administrators, educators, and students) in project-based learning activities, yielding tangible projects with the potential to transcend traditional educational boundaries. Notably, European policies and funding opportunities have increasingly emphasized the promotion of open schooling in science education across educational levels, demonstrated by initiatives such as Horizon Coordination and Support Actions of the European Commission (Sotiriou & Bogner, 2023).

Transitioning to an open school requires a comprehensive re-evaluation of pedagogy, organisational structure, culture, and resources (Hamilton, 2015). Successful implementation involves managing change and fostering innovation, collaboration, and personalised learning (Winthrop et al., 2017). The Erasmus+ funded project reported in this study highlights open schooling in science education through educational seismology. This approach offers interdisciplinary engagement, fostering interactions among students, researchers, and citizens (Berenguer et al., 2020; Lebedev et al., 2019). Schools have adopted innovative and discovery learning methods to address local issues, shifting towards community-centred schooling.

Theoretical background

The concept of open schooling

The evolving global educational landscape, emphasized by UNESCO's 'Rethinking Education' (2015), underscores the urgent need for educational systems to adapt to today's complex society. This adaptation is critical for preparing individuals to handle emerging societal tensions. At the same time, a major concern relates to the declining student engagement in science education, marked by rising dropout rates and a sense of irrelevance among students (Finn & Zimmer, 2012; Rumberger & Rotermun, 2012; Sinatra et al., 2015; Wang & Degol, 2014). This situation highlights the challenge of 'disengaged achievers,' students who succeed academically but lack intrinsic motivation and struggle to apply their knowledge in real-world contexts. Research examines student disengagement through various lenses, including educational pathways (Blondal & Adalbjarnardottir, 2012), teachers' perceptions of low achievers (Agrusti & Corradi, 2015), shifts in engagement among achievers in subjects like math (Skilling et al., 2021), and strategies to re-engage learners (Davies et al., 2011). Consequently, there is an emergent need for transformative educational frameworks that foster learners' meaningful engagement and enriching learning experiences.

In response to these challenges, the concept of open schooling has emerged as a pivotal driver of innovation in education. The term 'open schooling' originates from the broader concept of 'open education,' which appeared in the late twentieth century as part of a movement towards more accessible, flexible, and inclusive educational practices. The foundational idea behind open schooling is to break down the traditional barriers of formal education by fostering a learning environment that extends beyond the conventional classroom setting, integrating with the community, and utilising a variety of educational resources and modalities. This approach encourages collaborative, project-based learning and emphasizes the importance of real-world applications of knowledge.

The term 'open schooling' dates back to educators like Ivan Illich, who in 'Deschooling Society' (1971) criticised traditional education and proposed self-directed learning networks. The concept has since evolved to emphasize the physical openness of schools, as well as openness in curriculum, teaching methods, and educational resources. Recently, digital technologies have boosted the accessibility and variety of educational content, further advancing open schooling. European Commission initiatives like Horizon 2020 (see SwafS-15-2016) have promoted open schooling across educational levels.

Consequently, open schooling advocates for a significant shift toward educational practices that are more collaborative and inclusive, by integrating formal, non-formal, and informal learning environments (Sotiriou et al., 2017). This model is highlighted by initiatives like the project reported in the present study, which underscores the significance of bottom-up approaches – where change is driven by the active participation of teachers, students, and communities in shaping the curriculum and integrating new subjects, such as seismology, into learning experiences. Unlike top-down approaches, where decisions are made by policymakers or administrators, bottom-up approaches focus on grassroots involvement, allowing educators and learners to co-create and adapt learning activities that meet local needs and contexts. By fostering innovative collaborations across various stakeholders, open schools aspire to extend beyond the conventional schooling framework, advocating for a culture rooted in collaborative learning and inquiry (Goddard et al., 2015; Wenner & Campbell, 2017). In summary, the open schooling framework transforms education by bridging formal, informal, and non-formal learning environments, fostering a holistic educational experience (Aikenhead, 2017). This approach not only promotes innovative, community-engaged science education but also enhances student understanding and engagement by making learning more relevant and connected to real-world challenges (OECD, 2018, 2020). By integrating practical, hands-on activities with theoretical knowledge, students are better equipped to grasp complex scientific concepts, such as seismology, and apply them in meaningful ways (Bevan et al., 2017). This approach also facilitates the development of critical thinking, problem-solving skills, and collaboration – key competencies for the twenty-first century (Barron & Darling-Hammond, 2008). Furthermore, by involving students in community-based projects, open schooling fosters a sense of ownership and responsibility, motivating them to contribute to societal solutions (Bang et al., 2010). Ultimately, this leads to improved academic achievement, deeper conceptual understanding, and increased student engagement, preparing them to become socially responsible, academically proficient individuals who can meaningfully contribute to their communities (Anderson & Shattuck, 2012).

Open schooling in science education: the case of educational seismology

Educational seismology is a transformative approach within earth sciences education, emphasizing practical, hands-on learning of seismic phenomena, their origins, and impacts. The seismic phenomenon of earthquakes represents a multifaceted geophysical event characterised by its unpredictable occurrence and potential for significant devastation within both the physical and human environment. Within the European context, the Southeastern Mediterranean basin stands out as an area of heightened seismic activity, exhibiting the highest frequency of seismic events across Europe (Cantore et al., 2003). Despite the significant impact of earthquakes on the lives of European citizens, many Southeastern Mediterranean countries historically did not incorporate the topic of earthquakes into their national curricula. Consequently, students in these regions possessed limited knowledge regarding earthquake disaster prevention and mitigation strategies.

In recent years, the field of educational seismology has gained traction within primary and secondary education globally, with the establishment of school networks dedicated to the study of earthquakes and the exchange of pertinent information and pedagogical techniques (Subedi et al., 2020; Mavromanolakis et al., 2019). These initiatives aim to enhance awareness of seismic risks among students and local communities. The advent of online platforms hosting seismic databases, in conjunction with the utilisation of technologies such as seismometers, has provided both students and educators with opportunities for active participation and engagement in relevant research practices (Balestra et al., 2020; Berenguer et al., 2020; Zollo et al., 2014). This includes activities centred on identifying seismic parameters, analysing waveform data, and adopting inquiry-based learning approaches (Chiu et al., 2016).

The collaborative nature of activities facilitated by seismic networks mirrors the collaborative endeavours of scientists engaged in the authentic study of earthquakes. Through data exchange and communication of findings, participating schools foster a sense of collective inquiry and scientific discovery. Teachers involved in such initiatives have reported positive outcomes on both their instructional practices and student learning experiences (Berenguer et al., 2020; Lebedev et al., 2019). This underscores the value of incorporating educational seismology into curricular frameworks as a means of promoting scientific literacy and fostering preparedness for seismic events within vulnerable regions. In addition, this approach brings the intricate dynamics of earthquakes closer to students, enhancing their understanding of geological processes and the importance of disaster preparedness.

Integrating seismology into educational frameworks, especially through open schooling, offers significant potential to increase student engagement and widen access to the subject. The interdisciplinary nature of these efforts promotes sustained interaction among diverse participants (Zollo et al., 2014), fostering openness within schools to both the scientific community and the local population. The Erasmus+ project 'SSE' (Schools Study Earthquakes, project number: 2015-1-EL01-KA201-013966) launched in 2015 in Southeastern Europe, involved hundreds of schools. The subsequent ERASMUS+ project 'SNAC' (School Networks Alert Citizens protetion, project number: 2018-1-EL01-KA201-047847, https://snac-project.ea.gr/) expanded this initiative, transforming schools into local centres of innovation and information on earthquakes. This expansion connected local citizens, protection agencies, businesses, research centres, and other stakeholders, engaging students in authentic problem-solving, situational analyses, and meaningful scientific inquiry activities.

Educational seismology and students' civic responsibility awareness and views toward science learning

Civic responsibility awareness in education involves teaching students their rights and duties as community members, fostering informed decision-making, and active participation in societal issues (Lin & Hess, 2021). In this context, the terms 'civic responsibility' (Hart et al., 2007; Schneider, 2010) and 'civic engagement' (Levine, 2007; Zaff et al., 2003) are closely related and can be used interchangeably, as they both emphasize the active role individuals play in contributing to the well-being of their communities. Whether referring to an individual's moral obligation to participate (civic responsibility) or their active involvement in community or political activities (civic engagement), both terms focus on encouraging students to take part in addressing collective issues. In science education, this extends to scientific literacy and proactive involvement in societal matters, essential for addressing real-world challenges (Carretero et al., 2016; DeLaet, 2016). Together, these concepts underscore the importance of preparing students to contribute meaningfully to their communities and society at large.y.

Integrating civic engagement in science education prepares students to apply scientific knowledge to challenges like environmental sustainability, public health, and disaster preparedness. Citizen science projects, for example, enhance public understanding of science and civic responsibility (Bonney et al., 2016). The ICCS 2009 report highlights civic engagement's role in shaping students' knowledge and attitudes (Schulz et al., 2010). Service learning and digital platforms further facilitate civic engagement and learning (Banaji & Buckingham, 2010; Butin, 2010).

In educational seismology, civic engagement awareness includes understanding roles and responsibilities regarding natural disasters. This fosters informed, proactive citizens ready to participate in community preparedness and response. Disaster prevention education significantly enhances students' civic responsibility and self-awareness (Tsai et al., 2020). Also, science education settings addressing socioscientific issues empower students to engage in their communities (Rudolph & Horibe, 2016).

Educational seismology promotes civic responsibility awareness and community involvement, especially when integrated with open schooling. This approach can influence students' views on science learning, fostering positive attitudes toward the subject. Inquiry-based learning in educational seismology enhances critical thinking and scientific literacy, improving students' engagement and interest in science (Duran & Dökme, 2016; Liou, 2020).

Given the scarcity of research on the impact of educational seismology within the open schooling framework on students' civic responsibility awareness and perceptions of science learning, our study aims to shed light on this relatively uncharted field of research. We hypothesize that these initiatives can synergistically enhance students' growth as informed, responsible citizens with strong scientific literacy, linking civic participation with science education.

Purpose and research questions

The research project reported here aimed to integrate the open schooling framework into participating educational institutions, focusing on educational seismology initiatives. It examined the impact of schools' integration of open schooling principles over one year and potential differences in perceived openness based on their seismology project approaches. Additionally, it assessed how these experiences influenced students' civic responsibility and views toward science learning.

Consequently, the research questions guiding this study were as follows:

(1) What are the characteristics of the projects initiated and implemented by schools within the Erasmus+ project?
   (a) What was the level of involvement of external stakeholders in these projects?
   (b) What were the forms of collaboration between school staff?
(2) Did participation in the Erasmus+ project lead to a significant increase in the perceived openness of the participating schools?
   (a) Is there a discernible relationship between the types of projects undertaken and schools' perceived levels of openness?
(3) To what extent did students demonstrate increased civic responsibility and changed views toward science learning as a result of their involvement in the ERASMUS+ project?

Methodology

Participants and procedures

The study involved 33 purposefully selected schools (6 primary and 27 secondary schools) out of a pool of 56 schools from Cyprus and Greece. The schools were selected based on specific criteria, including their commitment to implementing long-term projects with various participants and their adherence to open schooling principles. These criteria ensured that the selected schools were aligned with the study's focus on collaborative, community-engaged educational practices. The sample consisted of 515 students from these schools (352 upper primary and middle school and 163 high school students) who completed both pre- and post-questionnaires.

Before project implementation, teachers and administration staff underwent professional training sessions on educational seismology within an open schooling approach. Training covered seismology software and hardware, earthquake concepts, and inquiry-based learning activities. Participants also learned to embed open schooling in school initiatives and discussed engaging various stakeholders, societal issues related to seismic risk, and integrating open schooling and educational seismology.

Participating schools followed the Open Schooling Roadmap (Sotiriou et al., 2017), a comprehensive framework for cultivating openness in educational contexts. This roadmap provided detailed instructions for establishing an open school ethos, including administrative procedures and required educator competencies.

Following training, schools designed and implemented projects in educational seismology, incorporating key aspects of open schooling such as stakeholder engagement, staff collaboration, and addressing a real societal issue.

Data collection

Four evaluation tools were used to address the research questions of this study.

To investigate the types of educational seismology projects, external stakeholder involvement, and school staff collaboration (first research question), we analysed the portfolios developed by each school. These portfolios followed a format provided by the researchers including (1) a project description (including learning products and participant actions throughout the year), (2) a description of stakeholder engagement in activities, and (3) the methods of collaboration among school personnel.

For the second research question, we used the Self-Reflection Tool (SRT; Cronbach alpha = .916) developed by Sotiriou et al. (2021). This multiple-choice questionnaire, created for OSOS (Open Schools for Open Societies), a European-funded project (https://www.openschools.eu/q; Sotiriou et al., 2021), assesses school-level organisational change before and after implementing open schooling initiatives in (i) school management, (ii) processes, and (iii) teachers' professional development. The questionnaire items correspond to eight specific areas for each of the aforementioned organisational aspects. Each area entails four task-specific statements indicating levels of openness: Enabled, Consistent, Integrated, and Advanced (see Sotiriou et al., 2021 for details).

For the third research question, we administered two questionnaires to students. The first, the 'My Science Classes' questionnaire from the ROSE project (Schreiner & Sjoberg, 2004), evaluated student engagement in science lessons using 16 items on a 4-point Likert scale from 'Disagree' (1) to 'Agree' (4). The second, the 'Civic Responsibility Survey' (Furco et al., 1998), assessed students' civic responsibility before and after implementation with 24 items on a 6-point Likert scale from 1 (strongly disagree) to 6 (strongly agree).

All participants were informed that participation was voluntary and anonymous, and consent was obtained before their participation. An administration staff member from each school completed the online SRT tool before and after the implementation phase. Schools also created portfolios for dissemination and evaluation. Students completed the two questionnaires in the presence of their teacher, taking about 25 min each time, both before and after the project.

Data analysis

To address the first research question, the information retrieved from the school portfolios was qualitatively analysed using open coding procedures (Strauss & Corbin, 2008).

Projects with similar learning activity sequences and outcomes in educational seismology were grouped to generate categories of project types. For each type, we identified the involvement of external stakeholders and the collaboration among teaching staff. Stakeholder involvement was categorised by activity and duration (e.g. short-term, ongoing), while teaching staff collaboration was categorised by type (e.g. no collaboration, interdisciplinary, intradisciplinary) and the resulting activities. An independent coder reviewed the data, and all reliability measures (Cohen's kappa) were found to be above 0.88. Differences in assigned codes were resolved through discussion.

To address the second research question, the SRT scores were calculated for each school pre- and post-intervention. The SRT, a four-point Likert scale instrument, assigns specific scores to each level of openness (Enabled-25, Consistent-50, Integrated-75, Advanced-100). All organisational aspects contributed equally to the total score, which was averaged from the chosen statements. IBM SPSS software was used for data analysis with non-parametric and parametric tests. Initial non-parametric tests showed no significant effects of educational level (upper primary vs. secondary) or country on pre-SRT scores (educational level: $\chi^2(2) = 5.6$, $p > 0.05$; country: $U = 81.5$, $p > 0.05$). A paired-sample t-test compared pre-and post-SRT scores to identify any significant increase in perceived openness during the ERASMUS+ project year. Finally, Kruskal-Wallis H tests examined differences in score enhancement (post-SRT minus pre-SRT) related to the type of project implemented by the school.

To address the third research question, pre- and post-intervention scores were calculated for each student on both questionnaires. Paired-sample t-tests were then employed to investigate whether student views of their engagement in science lessons and their sense of civic responsibility exhibited statistically significant enhancements as a result of participating in the Erasmus+ project.

Findings

The results are presented in three distinct sections, each corresponding to a specific research question investigated in this study.

RQ 1

Qualitative analysis of data gathered through school portfolios revealed three distinct project types implemented by participating schools. These projects diverged in terms of student learning activities, the learning products developed, the degree of collaboration among school staff, and the level and nature of external stakeholder involvement (see Table 1).

The first type of project, Investigating Seismic Parameters ($n = 12$), centred on the exploration of real earthquake data gathered through seismograms. Students engaged in the analysis of seismic waves (including P, S, and surface waves), pinpointing earthquake epicentres, and estimating magnitudes and intensities using specialised software such as SWARM (see Figure 1 for representative examples). Presenting their findings to peers and the local community through various channels (e.g. websites, social media, emails) was integral to disseminating information about regional seismic activity. Through these projects, students gained insights into the geological causes and societal

Table 1. Type of projects, learning activities, deriving learning product, as well as level and type of involvement of external stakeholders and schools' staff per type of project.

Type of project	No. of schools	Learning activities	Deriving learning products	*Duration of participation* and the activities the external stakeholders were involved in	*Type of collaboration* and the activities in which the collaboration occurred
Investigating seismic parameters	12	(i) Calculation of seismic parameters (ii) Presentation of findings	Reports regarding seismic parameters of specific earthquakes	*Short-term* Presentations to students	*Interdisciplinary collaboration* Developing students' knowledge for related concepts
Constructing a seismometer	9	(i) Design of seismometers (prototypes) (ii)Programming and development (iii) Testing of the prototype	Seismometer prototype	*On-going* (i) Co-creation process with the students (ii) Provision of feedback for the prototyping process	*Interdisciplinary collaboration* (i) Developing students' knowledge for related concepts (ii) Co-creation process of the prototype
Designing of materials for raising civic awareness	12	(i) Research for societal impact of seismic risk (ii) Designing of materials (iii)Dissemination of materials in school and/or community	Dissemination materials (e.g. posters, social media posts, articles)	*Long-term (sporadic)* (i) Presentations to students (ii) Provision of materials (iii) Participation in dissemination actions	*Interdisciplinary collaborations* Creating dissemination materials

impacts of earthquakes. Interdisciplinary collaboration was a key feature, with teachers from diverse fields engaging students in activities spanning geology (e.g. Earth's inner layers morphology), mathematics (e.g. time interval estimations, graphical analysis, triangulation for epicentre location), and physics (e.g. wave propagation). The projects also facilitated initial partnerships with researchers and seismologists, providing students with support in analysing seismic data and understanding fundamental seismological principles. This interdisciplinary approach and collaboration with experts not only

Figure 1. Students' training for analysing seismograms.

enriched students' learning experiences but also fostered a deeper understanding of seismic phenomena and their implications for both the natural environment and human society.

The second type of project, namely Construction of Seismometers ($n = 9$), was characterised by an engineering-focused approach. Students undertook the task of building seismometers entirely from scratch (see Figure 2 for a representative example). At the outset, students explored the principles of seismic wave propagation and gained a comprehensive understanding of seismometer functionality. Moreover, students were introduced to sophisticated software and hardware, including Arduino microcontrollers, Lego Mindstorms, and Raspberry Pi mini-PCs, enhancing their technical prowess. Through collaborative co-creation procedures, students engaged in ongoing partnerships with seismologists and engineers, facilitating the iterative process of prototyping (including design and testing). These projects also fostered interdisciplinary collaboration among teachers, bridging fields such as physics (with an emphasis on seismic wave propagation) and engineering (encompassing programming, prototype design, and testing). By merging theoretical knowledge with hands-on experimentation, students not only enhanced their engineering skills but also deepened their understanding of seismic phenomena. Additionally, these collaborations underscored the importance of interdisciplinary approaches in addressing complex scientific and engineering challenges.

The third category of projects that centred on the Design of Materials for Raising Civic Awareness ($n = 12$), aimed to inform and engage the school and local community regarding earthquake preparedness (see Figure 3 for representative examples). The primary objective was the creation and distribution of informative materials such as brochures, videos, posters, articles, presentations, and 3D models. Collaboration with external stakeholders, including civil defence organisations and researchers, played a crucial role in these endeavours. Stakeholders contributed expertise on earthquake impact mitigation and civic engagement, delivering presentations and providing relevant dissemination materials to guide and enrich the students' projects. While this collaboration was long-term, it was characterised by discrete actions rather than continuous involvement. Students conducted comprehensive research, including interviews with stakeholders and analysis of seismic data, to inform the content of their materials. They engaged in various dissemination activities, utilising social media platforms, the school website, and magazines, and participation in student conferences and social events. Interdisciplinary collaboration among teaching staff was evident, particularly between physics/science teachers and language and art instructors. This collaboration facilitated both the creation and dissemination of materials, maximising various perspectives and skill sets to effectively convey critical information and promote civic awareness surrounding earthquake preparedness within the school and broader community.

Despite these differences, all 33 schools engaged students in projects addressing real-world issues, fostered collaborations with external stakeholders relevant to their activities, and facilitated interdisciplinary cooperation among teaching staff. Consistency was observed within each project type regarding implemented activities, outputs generated, and collaborative relationships formed with external stakeholders and among teaching staff. Notably, schools undertaking 'Investigating seismic parameters projects' exhibited the lowest level of collaboration with external stakeholders in terms of duration and intensity, whereas those implementing the 'Constructing a seismometer' project

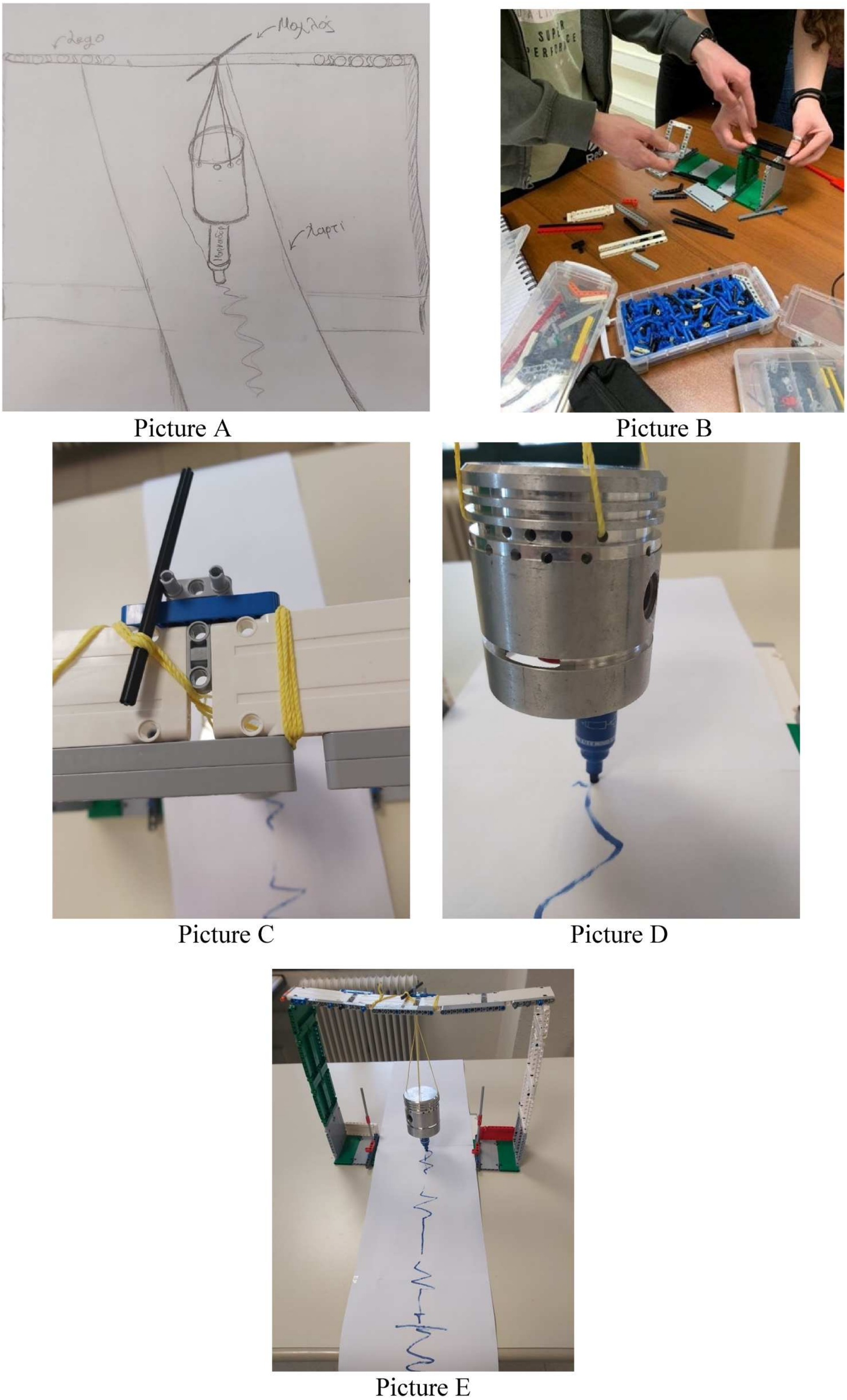
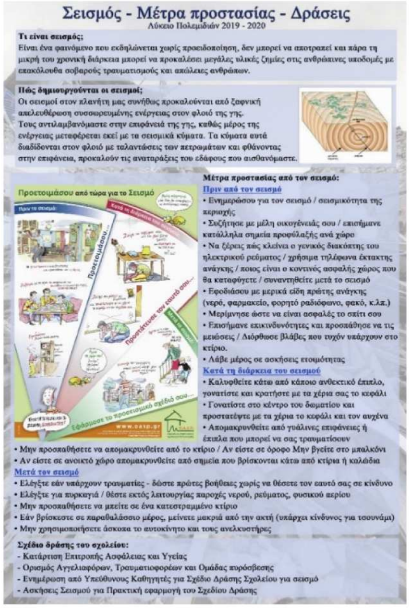
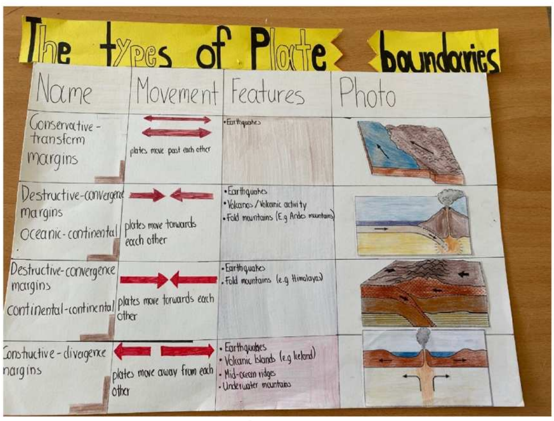


Figure 2. The stages of the 'Making your own Seismometer' project (Picture A: The initial drawing; Picture B: Creating the seismometer base with Lego; Picture C: A lever that was adjusted to change the length of the string, Picture D: Weight with marker; Picture E: Panoramic view of the construction).



Picture A



Picture B

Picture C

Figure 3. Representative examples of students' projects created to raise civic awareness in the surrounding school community (Picture A: A poster created by students to communicate earthquake protection measures and actions; Picture B: A poster created by students to illustrate and explain the types of plate tectonics movements; Picture C: A 3D model created by students to represent an earthquake resulting from the collision of the Indo-Australian and the Eurasian plates).

demonstrated the highest level of continuous stakeholder involvement, as stakeholders were consistently engaged in co-creation processes alongside teachers and students. Schools undertaking 'Designing of materials for raising civic awareness' projects also established long-term collaborations with external stakeholders, albeit in a more sporadic fashion throughout the project duration.

Furthermore, all participating teachers engaged in interdisciplinary collaboration to fulfil project objectives. In the 'Investigating seismic parameters' and 'Constructing a seismometer' projects, teachers collaborated to address students' learning needs, focusing on developing their understanding of subject-specific concepts. In the latter, teachers also participated in co-creation processes to develop seismograph prototypes. In contrast, teachers involved in 'Designing of materials for raising civic awareness projects' collaborated on the development and dissemination of project materials, contributing with their expertise to the overall project goals.

RQ2

A paired-sample t-test was conducted to assess whether there was a significant increase in the level of openness among ERASMUS+ schools, as reported by principals, following the implementation of educational seismology projects within the framework of open schooling. The results are summarised in Table 2.

The paired-samples t-test revealed a statistically significant difference between the pre (M = 51.27, SD = 14.75) and post SRT scores (M = 57.52, SD = 15.89) of the schools ($t(32) = -3.47$, $p < .05$), indicating an increase in the perceived level of openness following participation in the Erasmus+ project.

A Kruskal-Wallis H test was conducted to examine whether there were significant differences among the three types of projects implemented by the schools regarding the enhancement of their SRT scores. Results indicated a significant difference among the projects ($\chi^2(2) = 12.20$, $p = 0.002$). Mean rank scores were 24.06 for 'Constructing a seismometer' projects ($n = 9$), 18.96 for 'Designing of materials for raising civic awareness' projects ($n = 12$), and 9.75 for 'Investigating seismic parameters' projects ($n = 12$).

Post-hoc Mann–Whitney U tests, following the Bonferroni correction, revealed significant differences between the mean ranks of 'Constructing a seismometer' projects and 'Investigating seismic parameters projects' (U = 12.5, $p < .017$), as well as between 'Designing of materials for raising civic awareness' projects and 'Investigating seismic parameters' projects (U = 26.5, $p < .017$). Although 'Constructing a seismometer' projects had a higher mean rank score than 'Designing of materials for raising civic awareness projects', the Mann–Whitney U test did not indicate a significant difference between them (U = 32, $p > .017$).

These findings suggest that while 'Investigating seismic parameters projects' may not have effectively integrated open schooling to the same extent as the other two project

Table 2. Results of the paired-sample t-test for comparing pre and post SRT-scores.

SRT score	Mean	SD	*t*	*p*
Pre ($n = 33$)	51.27	14.75	−3.47	.002
Post ($n = 33$)	57.52	15.89		

types, 'Constructing a seismometer' projects and 'Designing of materials for raising civic awareness' projects demonstrated greater efficacy in enhancing the perceived openness of participating schools.

RQ3

Paired sample t-tests were conducted to assess whether there were significant changes in students' views towards their science classes and their civic responsibility after participating in the project. The results are presented in Table 3.

The paired samples t-tests revealed significant enhancements in students' views towards their science classes and their sense of civic responsibility following their participation in the Erasmus+ project across all educational levels.

For views towards science classes, the results indicated a substantial increase ($t(514) = -41.22$, $p < .001$), suggesting a highly significant positive impact of the project on students' perceptions of their views about their science learning. Furthermore, the effect size was found to be large, underscoring the robustness of this finding.

Similarly, there was a statistically significant increase in students' scores concerning their civic responsibility awareness, both among high school students ($t(162) = -22.07$, $p < .001$) and middle/upper primary school students ($t(351) = -37.19$, $p < .001$). These results suggest that participation in the Erasmus+ project contributed significantly to students' understanding and commitment to civic duties. Moreover, the effect sizes for both groups were large, indicating substantial improvements in students' civic awareness and sense of responsibility as a result of their engagement in the project.

Discussion

The findings of this study shed light on the multifaceted impact of the open-schooling approach in the context of educational seismology, providing valuable insights into science education, seismology education, open schooling, civic awareness, and views on science learning. The discussion of the findings is structured to address each research question, offering comprehensive insights into the implications of the findings in the context of science education.

The qualitative analysis revealed three distinct types of projects implemented by schools within the Erasmus+ project: Investigating Seismic Parameters, Constructing Seismometers, and Designing Materials for Raising Civic Awareness. Each project type exhibited unique characteristics in terms of student activities, collaboration among school staff, and involvement of external stakeholders.

Table 3. Results of the paired-samples t-test for students' views of their science classes and their civic responsibility.

Subject domain	Test	Mean	SD	*t*	*p*	Cohen's *d*
Students views of their science classes ($n = 515$)	Pre	38.16	8.11	−41,22	.000	2.14
	Post	51.85	3.98			
Civic Responsibility (Middle school/upper elementary) ($n = 352$)	Pre	31.41	9.26	−37,19	.000	2.59
	Post	50.07	4.26			
Civic Responsibility (High school) ($n = 163$)	Pre	70.23	20.87	−22,07	.000	2.56
	Post	112.70	10.65			

The Investigating Seismic Parameters projects engaged students in analysing real earthquake data, fostering interdisciplinary collaboration among teachers from different disciplines, and partnering with seismologists. While less intensive than other project types, collaboration with external stakeholders provided valuable support and expertise, enriching students' learning experiences. Evidence from these projects revealed that they promoted deep learning experiences, allowing students to explore seismic phenomena and their societal implications. This approach aligns with contemporary views on science education that emphasize interdisciplinary integration to address real-world challenges (Tytler et al., 2021). By bridging disciplines like geology, mathematics, and physics, students gained a comprehensive understanding of seismic phenomena and their principles, enhancing scientific literacy, critical thinking, and problem-solving skills essential for STEM+ fields (Kloser, 2014; Kottmeier et al., 2016; Pennington et al., 2020; Tataru et al., 2016). Overall, these projects embodied STEM education principles by integrating science, technology, engineering, and mathematics, and preparing students for future STEM+ endeavours.

In contrast, the Construction of Seismometers projects focused on engineering practices, with students designing and building seismometers from scratch. Emphasizing hands-on experimentation and iterative prototyping, these projects fostered collaboration among students, seismologists, and engineers. This hands-on approach aligns with trends in STEM+ education, which advocate for the development of practical skills and problem-solving abilities (Breiner et al., 2012). Engaging students in real-world problem-solving contexts through engineering and design enhances the learning and application of science, mathematics, and technology, therefore enriching their STEM+ experience (Bryan et al., 2015; Kennedy & Odell, 2014; Martín-Páez et al., 2019). Integrated STEM+ education in seismology education seems promising in blending disciplines to solve complex problems, fostering a holistic understanding of scientific concepts and their applications (Akben, 2020; Felder & Brent, 2024).

The Construction of Seismometers projects also underscored the value of engaging external stakeholders in a collaborative creation process, demonstrating the role of sustained partnerships in enhancing students' technical skills and understanding of scientific principles. Such projects highlight the practical application of science, intertwining it with engineering and design principles to make the subject more concrete and relatable for students (Balfour et al., 2014; Berenguer et al., 2013; Courboulex et al., 2012; van Wijk et al., 2013; Zaharia et al., 2016).

The Design of Materials for Raising Civic Awareness projects aimed to inform and engage the community regarding earthquake preparedness. These projects showcase the role of schools in promoting civic awareness and disaster resilience. Collaboration with external stakeholders, including civil defence organisations, facilitated the creation and dissemination of informative materials, contributing to broader societal objectives. This approach exemplifies the concept of open schooling, which emphasizes community engagement and real-world relevance in education (Epstein et al., 2018). Projects like these demonstrate the vital role of educational initiatives in enhancing community awareness and preparedness for natural disasters, drawing on a variety of collaborative efforts to ensure the effective dissemination of crucial information (Adhikari et al., 2016; Becker et al., 2017; Hoffmann & Muttarak, 2017; Paton, 2019).

Concerning the second research question, the findings revealed a significant increase in the perceived openness of schools following participation in the Erasmus+ project. This finding suggests that the implementation of educational seismology projects within the framework of open schooling positively influenced schools' organisational culture and practices. The observed increase in openness may be attributed to several factors, including enhanced collaboration with external stakeholders, interdisciplinary approaches to teaching and learning, and a focus on real-world issues like earthquakes. However, it is important to acknowledge that external factors unrelated to the Erasmus+ project, such as pre-existing institutional initiatives aimed at promoting collaboration, school leadership changes, the introduction of new educational technologies, evolving community dynamics, or broader educational reforms at the national or regional level, may also have played a role in influencing these outcomes. These findings align with previous research, such as Chesbrough's exploration of open innovation as a more collaborative and engaged process (Chesbrough, 2017), and Sharples et al.'s emphasis on innovation in pedagogy through open educational practices (Sharples et al., 2015). Moreover, the construction of collaborative platforms for innovation, as discussed by Wang et al. (2022), further supports the role of open schooling in promoting educational innovation. These insights are complemented by Bogers et al.'s (2018) discussion on the policies and practices surrounding open innovation, which mirror the collaborative essence of open schooling. Collectively, these studies in conjunction with the findings of the present study, point out the transformative potential of open schooling in fostering innovation and collaboration within educational institutions, illustrating the broader trend towards more open, collaborative educational frameworks that extend beyond traditional school boundaries.

Moreover, the association between project types and perceived openness suggests that certain project characteristics may contribute more significantly to school openness. Specifically, projects involving hands-on experimentation and collaboration with external partners, such as the Construction of Seismometers and Design of Materials for Raising Civic Awareness projects, demonstrated greater efficacy in enhancing school openness compared to projects focusing solely on data analysis (Investigating Seismic Parameters). This illustrates the importance of experiential learning and community engagement in fostering organisational change within schools (Forestiere, 2015; Glover et al., 2021). This outcome is in line with insights from earlier research that underscore the advantages of incorporating experiential learning and community engagement into educational frameworks. Such integration is recognised for its potential to foster organisational change and amplify the societal impact of educational institutions, thus affirming the crucial role of experiential and community-oriented approaches in contemporary education (Burke, 2013; Butin, 2010; Celio et al., 2011; Dickinson et al., 2012; Flanagan & Levine, 2010).

In terms of students' views of science classes and civic responsibility, the findings indicate a significant increase in students' civic responsibility and positive perceptions of their science classes following participation in the Erasmus+ project. These outcomes suggest that engaging students in authentic, community-oriented projects can have significant effects on their affective domains. By connecting classroom learning with real-world issues, educational seismology projects not only enhance students' views of their academic achievement but also foster a sense of civic engagement and social responsibility. This finding lends support to the broader goals of open schooling, which seeks to empower students to serve as active participants in their communities and agents of positive change (Hamedani et al., 2015). Additionally, educational seismology seems to help counteract students' disengagement in science by addressing academic and emotional needs, showing the relevance of their studies (Finn & Zimmer, 2012; Rumberger & Rotermun, 2012; Sinatra et al., 2015; Wang & Degol, 2014). This holistic approach encourages more engaged and motivated learners, aiding their development into informed, responsible citizens.

Furthermore, the large effect sizes observed in both civic responsibility and views on science classes indicate the robustness and significance of these findings. These outcomes demonstrate the promise of open schooling approaches to not only improve academic outcomes but also cultivate broader dispositions and competencies essential for active citizenship and lifelong learning (Breiner et al., 2012).

In conclusion, the findings of this study provide compelling evidence of the impact of educational seismology projects within the framework of open schooling. By engaging students in authentic, interdisciplinary projects and fostering collaboration with external stakeholders, schools can enhance their organisational culture, promote civic awareness, and transform students' attitudes towards science learning. These findings highlight the potential of open schooling to promote holistic learning and prepare students for active participation in complex societies.

Implications

Overall, our study contributes to understanding the effectiveness of educational seismology projects in fostering interdisciplinary collaboration, engaging students in real-world issues, and promoting civic responsibility. These findings have implications for curriculum development and educational policy, emphasizing the importance of project-based learning, open schooling, and community engagement in enhancing students' academic and civic outcomes.

More specifically, our findings underscore the broader implications for educational practices and policies, particularly in STEM+ education. Project-based learning approaches, such as those followed in the ERASMUS+ project, align with STEM+ principles, which emphasize interdisciplinary learning and real-world application of knowledge (Sanders, 2009). By integrating science, engineering, and technology with artistic and mathematical concepts, open schooling initiatives like educational seismology projects provide students with holistic learning experiences that promote creativity, innovation, and problem-solving skills essential for success in the twenty-first century (Sumy et al., 2022).

Moreover, the successful integration of interdisciplinary collaboration and community engagement in these projects stresses the importance of promoting holistic approaches to STEM+ education. Interdisciplinary collaboration allows students to explore complex issues from multiple perspectives, encouraging creativity and innovation (Moirano et al., 2020). By forging connections across curriculum disciplines, students develop a more comprehensive understanding of real-world problems and are better equipped to propose effective solutions (Brassler & Dettmers, 2017; Klaassen, 2018; Zhang & Shen, 2015). Similarly, open schooling models that incorporate community engagement foster meaningful partnerships between schools and external stakeholders, empowering students to apply their STEM+ knowledge and competences to address societal challenges while gaining practical skills and knowledge (Christensen et al., 2015; Kelley et al., 2020).

In addition, future research should focus on measuring students' understanding of seismology using contemporary assessment methods. Performance-based assessments can provide valuable insights by having students engage in real-world tasks, such as designing seismic preparedness plans (Darling-Hammond & Adamson, 2014). Formative techniques, including peer assessment and self-assessment, can track student progress and encourage reflective learning (Nicol & Macfarlane-Dick, 2006). Moreover, digital tools such as virtual labs and interactive simulations can assess students' data analysis and critical thinking skills in real-time (DeJong et al., 2013). These approaches will offer deeper insights into how well this educational model prepares students for real-world challenges, while also providing a more comprehensive evaluation of their understanding of seismological concepts.

Furthermore, the positive impact of the ERASMUS+ project on students' science learning perceptions and civic engagement awareness corroborates the need for educational institutions to incorporate experiential learning, open schooling, and community involvement within the STEM+ frameworks. As educational seismology projects demonstrate, engaging students in hands-on, inquiry-based learning experiences not only enhances academic outcomes but also fosters a sense of civic responsibility and social awareness. Thus, educators and policymakers need to focus on creating STEM+ learning environments, particularly through open schooling frameworks, that encourage active participation, collaboration, and community engagement, ensuring that students are equipped with the interdisciplinary skills and mindset necessary to become informed, responsible citizens in an increasingly complex world (Beier et al., 2019; Holmlund et al., 2018; Shahali et al., 2017).

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References

Adhikari, B., Mishra, S. R., & Raut, S. (2016). Rebuilding earthquake struck Nepal through community engagement. *Frontiers in Public Health*, *4*, 121. https://doi.org/10.3389/fpubh.2016.00121

Agrusti, G., & Corradi, F. (2015). Teachers' perceptions and conceptualizations of low educational achievers: A self-fulfilling prophecy of disengagement for future NEETs. *The Qualitative Report*, *20*(11), 1729–1748.

Aikenhead, G. S. (2017). *Science education for everyday life: Evidence-based practice*. Teachers College Press.

Akben, N. (2020). Effects of the problem-posing approach on students' problem solving skills and metacognitive awareness in science education. *Research in Science Education*, *50*(3), 1143–1165. https://doi.org/10.1007/s11165-018-9726-7

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher*, *41*(1), 16–25. https://doi.org/10.3102/0013189X11428813

Balestra, J., Berenguer, J. L., Bigot-Cormier, F., Courboulex, F., Rolland, L., Ambrois, D., Van Driel, M., & Lognonné, P. (2020). The InSight blind test: An opportunity to bring a research dataset into teaching programs. *Seismological Research Letters*, *91*(2A), 1064–1073. https://doi.org/10.1785/0220190137

Balfour, N. J., Salmon, M., & Sambridge, M. (2014). The Australian seismometers in schools network: Education, outreach, research, and monitoring. *Seismological Research Letters*, *85*(5), 1063–1068. https://doi.org/10.1785/0220140025

Banaji, S., & Buckingham, D. (2010). Young people, the internet, and civic participation: An overview of key findings from the Civicweb Project. *International Journal of Learning and Media*, *2*(1), 15–24. https://doi.org/10.1162/ijlm_a_00038

Bang, M., Medin, D., Washinawatok, K., & Chapman, S. (2010). Innovations in culturally based science education through partnerships and community. In M. Khine & I. Saleh (Eds.), *New science of learning: Cognition, computers and collaboration in education* (pp. 569–592). New York: Springer.

Barron, B., & Darling-Hammond, L. (2008). Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning. In L. Darling-Hammond, B. Barron, P. D. Pearson, A. H. Schoenfeld, E. K. Stage, T. D. Zimmerman, G. N. Cervetti, & J. Tilson (Eds.), *Powerful learning: What we know about teaching for understanding*. Jossey-Bass. https://www.edutopia.org/pdfs/edutopia-teaching-for-meaningful-learning.pdf

Becker, J. S., Paton, D., Johnston, D. M., & Ronan, K. R. (2017). The role of prior experience in informing and motivating earthquake preparedness. *International Journal of Disaster Risk Reduction*, *22*, 179–193. https://doi.org/10.1016/j.ijdrr.2017.03.006

Beier, M. E., Kim, M. H., Saterbak, A., Leautaud, V., Bishnoi, S., & Gilberto, J. M. (2019). The effect of authentic project-based learning on attitudes and career aspirations in STEM. *Journal of Research in Science Teaching*, *56*(1), 3–23. https://doi.org/10.1002/tea.21465

Berenguer, J. L., Balestra, J., Jouffray, F., Mourau, F., Courboulex, F., & Virieux, J. (2020). Celebrating 25 years of seismology at schools in France. *Geoscience Communication*, *3*(2), 475–481. https://doi.org/10.5194/gc-3-475-2020

Berenguer, J. L., Courboulex, F., Tocheport, A., & Bouin, M. P. (2013). Tuned in to the Earth … from the school EduSismo: The French educational seismological network. *Bulletin de la Société Géologique de France*, *184*, 183–187.

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2017). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education*, *101*(4), 568–602.

Blondal, K. S., & Adalbjarnardottir, S. (2012). Student disengagement in relation to expected and unexpected educational pathways. *Scandinavian Journal of Educational Research*, *56*(1), 85–100. https://doi.org/10.1080/00313831.2011.568607

Bogers, M., Chesbrough, H., & Moedas, C. (2018). Open innovation: Research, practices, and policies. *California Management Review*, *60*(2), 5–16.

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406
Brassler, M., & Dettmers, J. (2017). How to enhance interdisciplinary competence—interdisciplinary problem-based learning versus interdisciplinary project-based learning. *Interdisciplinary Journal of Problem-Based Learning*, *11*(2), 12. https://doi.org/10.7771/1541-5015.1686
Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x
Bryan, L. A., Moore, T. J., Johnson, C. C., & Roehrig, G. H. (2015). Integrated STEM education. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 23–37). New York, NY: Routledge.
Burke, B. M. (2013). Experiential professional development. A model for meaningful and long-lasting change in classrooms. *Journal of Experiential Education*, *36*(3), 247–263. https://doi.org/10.1177/1053825913489103
Butin, D. W. (2010). *Service-learning in theory and practice: The future of community engagement in higher education*. New York: Palgrave Macmillan.
Cantore, L., Bobbio, A., Di Martino, F., Petrilio, A., Simini, M., & Zollo, A. (2003). The EduSeis Project in Italy: An educational tool for training and increasing awareness of seismic risk. *Seismological Research Letters*, *74*(5), 596–602. https://doi.org/10.1785/gssrl.74.5.596
Carretero, M., Haste, H., & Bermudez, A. (2016). Civic education. In L. Corno & E. M. Anderman (Eds.), *Handbook of educational psychology* (3rd ed., pp. 295–308). Routledge.
Celio, C. I., Durlak, J., & Dymnicki, A. (2011). A meta-analysis of the impact of service-learning on students. *Journal of Experiential Education*, *34*(2), 164–181. https://doi.org/10.1177/105382591103400205
Chesbrough, H. (2017). The future of open innovation: The future of open innovation is more extensive, more collaborative, and more engaged with a wider variety of participants. *Research-Technology Management*, *60*(1), 35–38. https://doi.org/10.1080/08956308.2017.1255054
Chiu, Y. C., Jen, C. H., Chang, C. Y., Lee, P. L., & Yeh, T. K. (2016). Learning seismology through inquiry: Structured, guided, or both? *Seismological Research Letters*, *87*(4), 998–1007. https://doi.org/10.1785/0220150206
Christensen, R., Knezek, G., & Tyler-Wood, T. (2015). Alignment of hands-on STEM engagement activities with positive STEM dispositions in secondary school students. *Journal of Science Education and Technology*, *24*(6), 898–909. https://doi.org/10.1007/s10956-015-9572-6
Courboulex, F., Berenguer, J. L., & Courboulex, A. (2012). Sismos a l'Ecole: A worldwide network of real-time seismometers in schools. *Seismological Research Letters*, *83*(5), 870–873. https://doi.org/10.1785/0220110139
Darling-Hammond, L., & Adamson, F. (2014). *Beyond the bubble test: How performance assessments support 21st century learning*. John Wiley & Sons.
Davies, M., Lamb, S., & Doecke, E. (2011). *Strategic review of effective re-engagement models for disengaged learners*. Centre for Research on Education Systems – University of Melbourne.
DeJong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, *340*, 305–308. https://doi.org/10.1126/science.1230579
DeLaet, D. L. (2016). A pedagogy of civic engagement for the undergraduate political science classroom. *Journal of Political Science Education*, *12*(1), 72–84. https://doi.org/10.1080/15512169.2015.1063434
Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., Phillips, T., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291–297. https://doi.org/10.1890/110236
Duran, M., & Dökme, I. (2016). The effect Of The inquiry-based learning approach On student's critical thinking skills. *Eurasia Journal of Mathematics, Science And Technology Education*, *12*(12), 2887–2908. https://doi.org/10.12973/eurasia.2016.02311a

Epstein, J. L., Sanders, M. G., Sheldon, S. B., Simon, B. S., Salinas, K. C., Jansorn, N. R., Rodriguez, N., Van Voorhis, F. L., & Hutchins, D. J. (2018). *School, family, and community partnerships: Your handbook for action*. Corwin.

European Commission. (2015). *SCIENCE EDUCATION for responsible citizenship*. Publ. Office of the European Union. https://doi.org/10.2777/13004

Facer, K. (2011). *Learning futures: Education, technology and social change*. Routledge.

Felder, R. M., & Brent, R. (2024). *Teaching and learning STEM: A practical guide*. Jossey-Bass.

Finn, J., & Zimmer, K. (2012). Student engagement: What is it? Why does it matter? In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 97–131). Springer US.

Flanagan, C., & Levine, P. (2010). Civic engagement and the transition to adulthood. *The Future of Children*, *20*(1), 159–179. https://doi.org/10.1353/foc.0.0043

Forestiere, C. (2015). Promoting civic agency through civic-engagement activities: A guide for instructors new to civic-engagement pedagogy. *Journal of Political Science Education*, *11*(4), 455–471. https://doi.org/10.1080/15512169.2015.1066684

Furco, A., Muller, P., & Ammons, M. (1998). *Pre-post civic responsibility survey*. Service Learning Research and Development Center.

Glover, R. W., Lewis, D. C., Meagher, R., & Owens, K. A. (2021). Advocating for engagement: Do experiential learning courses boost civic engagement? *Journal of Political Science Education*, *17* (sup1), 599–615. https://doi.org/10.1080/15512169.2020.1831932

Goddard, R., Goddard, Y., Sook Kim, E., & Miller, R. (2015). A theoretical and empirical analysis of the roles of instructional leadership, teacher collaboration, and collective efficacy beliefs in support of student learning. *American Journal of Education*, *121*(4), 501–530. https://doi.org/10.1086/681925

Hamedani, M. G., Zheng, X., Darling-Hammond, L., Andree, A., & Quinn, B. (2015). *Social emotional learning in high school: How three urban high schools engage, educate, and empower youth*. Stanford Center for Opportunity Policy in Education.

Hamilton Associates. (2015). *School autonomy. Building the conditions for student success. A research project commissioned by the western Australian department of education*. Western Australian Department of Education.

Hart, D., Donnelly, T. M., Youniss, J., & Atkins, R. (2007). High school community service as a predictor of adult voting and volunteering. *American Educational Research Journal*, *44*(1), 197–219. https://doi.org/10.3102/0002831206298173

Hoffmann, R., & Muttarak, R. (2017). *Learn from the past, prepare for the future: Impacts of education and experience on disaster preparedness in the Philippines and Thailand*. World Development.

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of "STEM education" in K-12 contexts. *International Journal of STEM Education*, *5*(1), 1–18. https://doi.org/10.1186/s40594-018-0127-2

Illich, I. (1971). *Deschooling society*. Harper & Row.

Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education*, *7*(1), 1–13. https://doi.org/10.1186/s40594-020-00211-w

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International*, *25*(3), 246–258.

Klaassen, R. G. (2018). Interdisciplinary education: A case study. *European Journal of Engineering Education*, *43*(6), 842–859. https://doi.org/10.1080/03043797.2018.1442417

Kloser, M. (2014). Identifying a core set of science teaching practices: A Delphi expert panel approach. *Journal of Research in Science Teaching*, *51*(8), 1185–1217. https://doi.org/10.1002/tea.21171

Kottmeier, C., Agnon, A., Al-Halbouni, D., Alpert, P., Corsmeier, U., Eshel, A., Geyer, S., Haas, M., Holohan, E., Kalthoff, N., Kishcha, P., Krawczyk, C., Lati, J., Laronne, J. B., Lott, F., Mallast, U., Merz, R., Metzger, J., Mohsen, A., … Weber, M. (2016). New perspectives on interdisciplinary earth science at the Dead Sea: The DESERVE project. *Science of the Total Environment*, *544*, 1045–1058. https://doi.org/10.1016/j.scitotenv.2015.12.003

Lebedev, S., Bonadio, R., Gómez-García, C., de Laat, J. I., Bérdi, L., Chagas de Melo, B., Farrell, D., Stalling, D., Tirel, C., Collins, L., McCarthy, S., O'Donoghue, B., Schwenk, A., Smyth, M., & Bean, C. J. (2019). Education and public engagement using an active research project: Lessons and recipes from the SEA-SEIS North Atlantic Expedition's programme for Irish schools. *Geoscience Communication*, *2*(2), 143–155. https://doi.org/10.5194/gc-2-143-2019

Levine, P. (2007). *The future of democracy: Developing the next generation of American citizens*. Tufts University Press.

Lin, A., & Hess, J. L. (2021). Developing a framework for civic responsibility in engineering education. *ASEE Annual Conference and Exposition, Conference Proceedings, Virtual Conference*. https://doi.org/10.18260/1-2--36933

Liou, P.-Y. (2020). Students' attitudes toward science and science achievement: An analysis of the differential effects of science instructional practices. *Journal of Research in Science Teaching*, *58* (3), 1–25.

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799–822. https://doi.org/10.1002/sce.21522

Mavromanolakis, G., Papaevripidou, M., Luigi, C., Pavlou, Y., Zacharia, Z., Chouliaras, G., Cavas, B., Oral, O., & Karagoz, E. (2019). *School networks alert citizens protection-training programme for teachers and school heads*. Retrieved September 22, 2024, from https://snac-project.ea.gr/wp-content/uploads/2019/09/SNAC_IO2_EN.pdf

Moirano, R., Sánchez, M. A., & Štěpánek, L. (2020). Creative interdisciplinary collaboration: A systematic literature review. *Thinking Skills and Creativity*, *35*, 100626. https://doi.org/10.1016/j.tsc.2019.100626

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education*, *31*(2), 199–218. https://doi.org/10.1080/03075070600572090

Organization for Economic Co-operation and Development (OECD). (2004). *Second forum on schooling for tomorrow*. Retrieved January 2024, from https://www.oecd.org/fr/education/scolaire/secondforumonschoolingfortomorrowtorontocanada6-8june2004.htm

Organization for Economic Co-operation and Development (OECD). (2006). *Think scenarios, rethink education: Schooling for tomorrow*. OECD Publishing.

Organization for Economic Co-operation and Development (OECD). (2018). *The future of education and skills: Education 2030*. OECD Publishing. https://www.oecd.org/education/2030

Organization for Economic Co-operation and Development (OECD). (2020). *Back to the future of education: Four OECD scenarios for schooling, educational research and innovation*. OECD Publishing.

Paton, D. (2019). Disaster risk reduction: Psychological perspectives on preparedness. *Australian Journal of Psychology*, *71*(4), 327–341. https://doi.org/10.1111/ajpy.12237

Pennington, D., Ebert-Uphoff, I., Freed, N., & Martin, J. (2020). Bridging sustainability science, earth science, and data science through interdisciplinary education. *Sustainability Science*, *15* (2), 647–661. https://doi.org/10.1007/s11625-019-00735-3

Rudolph, J. L., & Horibe, S. (2016). What do we mean by science education for civic engagement? *Journal of Research in Science Teaching*, *53*(6), 805–820. https://doi.org/10.1002/tea.21303

Rumberger, R. W., & Rotermun, S. (2012). The relationship between engagement and high school dropout. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 491–513). Springer.

Sachs, J. (2001). Teacher professional identity: Competing discourses, competing outcomes. *Journal of Education Policy*, *16*(2), 149–161. https://doi.org/10.1080/02680930116819

Sanders, M. (2009, December/January). *STEM, STEM education, STEMmania. The Technology Teacher*. https://www.teachmeteamwork.com/files/sanders.istem.ed.ttt.istem.ed.def.pdf

Schneider, C. G. (2010). Civic learning and democratic engagement: The challenge for higher education. *Journal of College & Character*, *11*(1), 1–6.

Schreiner, C., & Sjoberg, S. (2004). Sowing the seeds of ROSE. Background, rationale, questionnaire development and data collection for ROSE (The Relevance of Science Education) – A comparative study of students' views of science and science education. *Acta Didactica*. http://urn.nb.no/URN:NBN:no-14449

Schulz, W., Ainley, J., Fraillon, J., Kerr, D., & Losito, B. (2010). *ICCS 2009 international report: Civic knowledge, attitudes, and engagement among lower-secondary school students in 38 countries*. International Association for the Evaluation of Educational Achievement (IEA).

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2017). STEM learning through engineering design: Impact on middle secondary students' interest towards STEM. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(5), 1189–1211.

Sharples, M., Adams, A., Alozie, N., Ferguson, R., Gaved, M., Herodotou, C., Koh, E., Kukulska-Hulme, A., Lool, C. K., McAndrew, P., Rienties, B., & Weller, M. (2015). *Innovating pedagogy 2015: Open university innovation report 4*. Open University.

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist*, *50*(1), 1–13.

Skilling, K., Bobis, J., & Martin, A. J. (2021). The "ins and outs" of student engagement in mathematics: Shifts in engagement factors among high and low achievers. *Mathematics Education Research Journal*, *33*(3), 469–493. https://doi.org/10.1007/s13394-020-00313-2

Smith, G. A., & Sobel, D. (2010). *Place- and community-based education in schools*. Routledge.

Sotiriou, S., & Bogner, F. X. (2023). Bridging informal science learning with schools: The open schooling model. In *Amplifying informal science learning* (pp. 222–230). Routledge.

Sotiriou, S., Cherouvis, S., Zygouritsas, N., Giannakopoulou, A., Milopoulos, G., Mauer, M., Stockert, A., Bogner, F., Verboon, F., & de Kroon, S. (2017). *Open schooling roadmap: A guide for school leaders and innovative teachers*. Retrieved September 22, 2024, from https://rri-tools.eu/-/open-schooling-roadmap-a-guide-for-school-leaders-and-innovative-teachers

Sotiriou, M., Sotiriou, S., & Bogner, X. F. (2021). Developing a self-reflection tool to assess schools' openness. *Frontiers in Education*, *6*, 1–16. https://doi.org/10.3389/feduc.2021.714227

Strauss, A., & Corbin, J. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (3rd ed.). SAGE Publications.

Subedi, S., Hetényi, G., & Shackleton, R. (2020). Impact of an educational program on earthquake awareness and preparedness in Nepal. *Geoscience Communication*, *3*(2), 279–290. https://doi.org/10.5194/gc-3-279-2020

Sumy, D. F., Jenkins, M. R., Crayne, J., Olds, S. E., Anderson, M. L., Johnson, J., Magura, B., Pridmore, C., & de Groot, R. M. (2022). Education initiatives to support earthquake early warning: A retrospective and a roadmap. *Seismological Research Letters*, 3498–3513. https://doi.org/10.1785/0220220159

Tataru, D., Zaharia, B., Grecu, B., Tibu, S., & Brisan, N. (2016). Seismology in Romanian schools: Education, outreach, monitoring, and research. *Romanian Reports in Physics*, *68*(4), 1589–1602.

Tsai, M. H., Chang, Y. L., Shiau, J. S., & Wang, S. M. (2020). Exploring the effects of a serious game-based learning package for disaster prevention education: The case of Battle of Flooding Protection. *International Journal of Disaster Risk Reduction*, *43*, Article 101393. https://doi.org/10.1016/j.ijdrr.2019.101393

Tytler, R., Mulligan, J., Prain, V., White, P., Xu, L., Kirk, M., Neilsen, C., & Speldewinde, C. (2021). An interdisciplinary approach to primary school mathematics and science learning. *International Journal of Science Education*, *43*(12), 1926–1949. https://doi.org/10.1080/09500693.2021.1946727

UNESCO. (2015). *Rethinking education. Towards a global common good?*. Retrieved April 6, 2024, from http://unesdoc.unesco.org/images/0023/002325/232555e.pdf

van Wijk, K., Channel, T., Viskupic, K., & Wells, J. (2013). *Outreach and education with a school-built seismometer*. SEG Technical Program Expanded Abstracts.

Wang, M. T., & Degol, J. (2014). Staying engaged: Knowledge and research needs in student engagement. *Child Development Perspectives*, *8*(3), 137–143.

Wang, M., Zhang, R., Abdulwase, R., Yan, S., & Muhammad, M. (2022). The construction of eco-system and collaboration platform for Enterprise Open Innovation. *Frontiers in Psychology*, *13*, 935644. https://doi.org/10.3389/fpsyg.2022.935644

Wenner, J. A., & Campbell, T. (2017). The theoretical and empirical basis of teacher leadership. *Review of Educational Research*, *87*(1), 134–171. https://doi.org/10.3102/0034654316653478

Winthrop, R., McGivney, E., & Barton, A. (2017). *Can we leapfrog? The potential of education innovations to rapidly accelerate progress. Skills for a changing world project*. Center for Universal Education. Brookings.

Zaff, J. F., Malanchuk, O., Michelsen, E., & Eccles, J. S. (2003). Socializing youth for civic engagement: The role of the family and significant others. *The Journal of Civic Commitment*, *9*(1), 57–73.

Zaharia, B., Serbu, F., Tataru, D., Grecu, B., & Brisan, N. (2016). "Hands on activity" - building your own seismometer in classroom. *International Multidisciplinary Scientific GeoConference: SGEM*, *3*, 1085–1092.

Zhang, D., & Shen, J. (2015). Disciplinary foundations for solving interdisciplinary scientific problems. *International Journal of Science Education*, *37*(15), 2555–2576. https://doi.org/10.1080/09500693.2015.1085658

Zollo, A., Bobbio, A., Berenguer, J. L., Courboulex, F., Denton, P., Festa, G., Sauron, A., Solarino, S., Haslinger, F., & Giardini, D. (2014). The European experience of educational seismology. In V. Thong (Ed.), *Geoscience research and outreach: Schools and public engagement.* Innovations in science education and technology series (pp. 145–170). Springer.