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Diversity and Inclusion in Science Education: Why? A Literature Review

Rachel Mamlok-Naaman[1]

In the last twenty years, there has been a consensus around the world that effective science education is vital to economic success in the emerging knowledge age. It is also suggested that knowledge of science and scientific ways of thinking is essential to participation in democratic decision-making. Students may recognise differences and advocate diversity, but assimilating those ideas requires the creation of conditions in which students can think deeply about situations that require tolerance. Schools in many countries and regions of the world are places shaped by cultural diversity. One may observe that in many schools there are social developments like migration and demographic and value change, consequently increasing the diversity of students. The issue of diversity in science education is therefore tackled according to many aspects, e.g., culture, language, scientific literacy and gender. The aim of the present literature review is to align the ERASMUS+ project Diversity in Science towards Social Inclusion with studies and views regarding diversity and inclusion in science education. The main goals of this project were to promote inclusive education and to train and foster the education of disadvantaged learners through a range of measures, including supporting education staff in addressing diversity and reinforcing diversity among education staff. Practices dealing with dimensions of diversity and inclusion in science education are developed and the partners shared the good practices that they developed.

Keywords: diversity, inclusion, chemistry language, culture, scientific literature

1 Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel; rachel.mamlok@weizmann.ac.il.

Raznolikost in inkluzija v naravoslovnem izobraževanju: zakaj – pregled literature

Rachel Mamlok-Naaman

V zadnjih dvajsetih letih je bilo po vsem svetu doseženo soglasje, da je učinkovito naravoslovno izobraževanje ključnega pomena za gospodarski uspeh v nastajajoči dobi znanja. Prav tako se domneva, da je poznavanje naravoslovja in znanstvenih načinov razmišljanja bistveno za sodelovanje pri demokratičnem sprejemanju odločitev. Učenci lahko prepoznavajo razlike in zagovarjajo raznolikost, vendar je za usvajanje teh idej treba ustvariti pogoje, v katerih lahko učenci poglobljeno razmišljajo o situacijah, ki zahtevajo strpnost. Šole v številnih državah in regijah sveta so kraji, ki jih oblikuje kulturna raznolikost. Opazimo lahko, da v veliko šolah prihaja do družbenih dogajanj, kot so: migracije ter demografske in vrednostne spremembe, kar posledično povečuje raznolikost učencev. Vprašanje raznolikosti v naravoslovnem izobraževanju se zato obravnava glede na številne vidike, npr. kulturo, jezik, naravoslovno pismenost in spol. Namen tega pregleda literature je uskladiti projekt ERASMUS+ DiSSI (Diversity in Science towards Social Inclusion) s študijami in pogledi na raznolikost in inkluzijo v naravoslovnem izobraževanju. Glavni cilji tega projekta so bili: spodbujanje inkluzivnega izobraževanja ter usposabljanje in spodbujanje izobraževanja prikrajšanih učencev z različnimi ukrepi, vključno s podporo izobraževalnemu osebju pri obravnavanju raznolikosti in krepitvi raznolikosti med izobraževalnim osebjem. Razvite so bile prakse, ki obravnavajo razsežnosti raznolikosti in inkluzije v naravoslovnem izobraževanju, partnerji pa so delili dobre prakse, ki so jih razvili.

Ključne besede: raznolikost, inkluzija, kemijski jezik, kultura, znanstvena literatura

Introduction

Diversity in Science towards Social Inclusion (DiSSI) was an ERASMUS+ project initiated by Professor Silvija Markic from LMU in Germany. The main objective of the project was to promote inclusive education and training, with an emphasis on enhancing educational opportunities for disadvantaged students. This involved providing support to education staff to effectively address and strengthen diversity within education staff.

Researchers from Ireland, Germany, the UK, Slovenia and Macedonia developed a teaching approach that considers the needs of students:

- from low socioeconomic status backgrounds;
- from ethnic minorities or with cultural backgrounds that differ from the mainstream culture;
- with low linguistic skills;
- who are considered as gifted students.

The aim of the present paper is to align the DiSSI project with studies and views regarding diversity and inclusion in science education. The partners shared the good practices that they developed dealing with diversity and inclusion in science education.

There is a global consensus that effective science education is crucial for economic success in the emerging knowledge age (Mansour, 2013). Furthermore, it is believed that a grasp of scientific knowledge and thinking is crucial for active participation in democratic decision-making. Although students may acknowledge differences and support diversity, assimilating these ideas necessitates establishing conditions that enable students to engage in profound reflection on situations requiring tolerance (Mamlok, 2013).

In their 2009 publication, Lee and Luykx conducted a comprehensive study analysing the impact of racial, ethnic, cultural, linguistic and socioeconomic variability on science achievement among K–12 students, a demographic group traditionally underserved by the education system. The book starts by addressing science achievement gaps within diverse racial, ethnic and socioeconomic groups. It then outlines the methodological and other criteria employed in the research, concluding with a presentation of findings. These findings explore the correlation between science achievement gaps and various factors, including the science curriculum, instruction, assessment, teacher education, school organisation, educational policies, and students' home and community environments. The authors propose a research agenda aimed at strengthening areas where a knowledge base is urgently needed.

In many countries and regions of the world, schools have their own cultural diversity (Rüschenpöhler & Markic, 2019). In many schools, there are social developments such as migration and demographic and value change, consequently increasing the diversity of students (Stinken-Rösner et al., 2020; Lee, 2003). Rüschenpöhler and Markic (2019) investigated the concept of science capital as it relates to chemistry education. They introduced the term 'chemistry capital' to capture the characteristics that contribute to individuals' success in the chemistry domain. These characteristics may include parental knowledge of chemistry content and engagement in chemistry-related activities at home. The authors conducted a study in which they interviewed 48 secondary school students in Germany using thematic analysis. The findings indicate that chemistry capital within the home environment is not uniformly distributed. Students lacking familial connections with the mainstream conception of chemistry tend to be located in schools with lower entry requirements. However, the research also identified cases where students independently acquired chemistry capital, despite the absence of familial support. To address these entrenched inequalities, the authors advocate teaching methodologies that prioritise identity formation and that actively involve students and their parents in a dialogue about chemistry.

Considering individual science/chemistry capital, there is a concerted effort to make science education inclusive and accessible to all students, with the aim of attaining scientific literacy for every student, beyond the preparation of those inclined towards academic careers in the sciences (Holbrook & Rannikmae, 2009). The key idea is to foster scientific literacy for all students, acknowledging that environmental, political, social or historical contexts can contribute to shaping active and reflective citizens. Accordingly, the initial step towards achieving 'scientific literacy for all' involves identifying stimulating and pertinent scientific issues, contexts, problems and questions.

The PISA Framework (OECD, 2013), established by the Organization for Economic Co-operation and Development (OECD), emphasises scientific literacy as the primary objective of science education. Scientific literacy is defined as "the ability to engage with science-related issues and with the ideas of science as a reflective citizen" (p. 7). A scientifically literate individual is expected not only to possess the ability, but also the interest in engaging in informed discussions about science and technology (Eilks et al., 2014). The PISA Framework recommends skills such as the following:

- *Explain phenomena scientifically:* recognise, offer and evaluate explanations for a range of natural and technological phenomena.
- *Evaluate and design scientific inquiry*: describe and appraise scientific studies and/or experiments and propose ways of addressing questions scientifically.

- *Interpret data and evidence scientifically*: analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions.

Scientific literacy in our contemporary world is a multifaceted concept consisting of media literacy and the ability to use information and communication technology (ICT) (Rodrigues, 2010). Media literacy, particularly in the context of digital media, has emerged as an essential cross-curricular goal in modern society, significantly influencing educational reforms (Belova et al., 2017).

The establishment of standards in science and mathematics education is often inspired by the AAAS (1993) Benchmarks for Scientific Literacy report. The science education standards articulated by the National Research Council (1996) serve as recommendations for 'best practices'. These practices encapsulate the current vision of the content, classroom environment, teaching methods and support needed to deliver a high-quality science education to all students. More recently, the Next Generation Science Standards (NGSS, Lead States, 2013) have been developed to outline 'the best practices' for teaching K–12 science content in the United States.

Attaining scientific literacy for all has evolved into a national education goal in numerous countries (Marks & Eilks, 2009). This objective poses a challenge for science teachers and those responsible for professional development (Lee, 2004). Its achievement necessitates a reform in the way chemistry is taught in schools (Norris & Phillips, 2003). Furthermore, the shift towards incorporating socio-scientific issues (SSIs) and education for sustainable development (ESD) in the chemistry curriculum reflects a broader reshaping of goals for science education, aiming for a more critical perspective of scientific literacy (Sjöström et al., 2017).

All of the above is based on the assumption that teachers are the best professional partners to develop lesson plans that combine issues related to chemistry content knowledge (CK) and its associated professional content knowledge (PCK). Teachers are more aware than others of the diversity of students' needs, interests and abilities.

Stinken-Rösner et al. (2020) stated that environmental, political, social and historical contexts play a crucial role in fostering students' development into active and reflective citizens. Consequently, the initial stride toward achieving 'scientific literacy for all' involves identifying stimulating, captivating and pertinent scientific issues.

To sum up, it is clear that teachers are at the centre of the sphere of influence. It is therefore recommended that 'top-down' curricular procedures be avoided or reduced. Teachers need time to develop as policy-makers and to make appropriate changes (Mamlok-Naaman et al., 2018). If our aim is to achieve effective science education, we should therefore tackle the issue of diversity in science education according to many aspects, e.g., culture, language, scientific literacy and gender.

Effective science education

Saet (2021) defined inclusive education as the practice of having all children, irrespective of their differences or special needs, studying together in the same school and within the same classrooms:

> Inclusive schooling does more than teaching children maths and language skills; it provides them with a safe space to grow and learn basic life skills, such as cooperation, responsibility, and respect. (p. 1)

The consideration of student diversity is meaningful for teaching and learning science (Markic & Abels, 2014). Teachers often treat their classes as belonging to homogeneous learning groups (Taber & Riga, 2016). However, the diversity of a group should be regarded as an opportunity for every student to develop. Diverse ideas and learning strategies may serve as a source of enrichment for every student (Florian & Spratt, 2013). According to Stinken-Rösner et al. (2020):

> In order to address the diversity and different needs of all students and enable full and equal participation, barriers must first be minimised or avoided. Additionally, in an educational sense, participation is about collaboration and creating different ways or approaches to a particular learning object. (p. 31)

The barriers may be aspects such as culture, language, gender (as mentioned above) or lack of scientific literacy (Lee, 2005). Concepts and phenomena should therefore be clarified for all students, acknowledging their personal, sociocultural, affective and cognitive learning diversity (Stinken-Rösner, 2020). Erduran (2003) claimed that ineffective communication between students and teachers can result in a gap between what is taught and what is learned. In the context of science lessons, achieving alignment between teachers' understanding of a specific science topic and students' ideas about it is crucial. Such alignment indicates the accurate transmission and reception of scientific knowledge in the classroom. For instance, ensuring the incorporation of key aspects such as macroscopic/microscopic relationships and the role of modelling in establishing these relationships is essential.

Bianchini et al. (2002) claim that issues of inclusion in science and remedying inequities in the science classroom can be facilitated by integrating the history, philosophy and sociology of science into professional development programmes. Education policy and teacher education should support teachers regarding these issues. Hilferty (2008) suggests that policy changes connect teachers' work to a larger citizenship agenda. Mamlok (2021) wrote that we should:

> Strive for the attainment of a common good, which involves constant interaction among people from diverse communities and political agents who work for the betterment of the public. (p. 14)

It has been suggested that the model of professional development is one of the most effective methods to overcome the challenges that teachers face. It enables teachers to reflect on and learn about how new practices can be evolved or shaped from existing classroom practice. This is not simple, as it requires teachers to re-examine what they do and how they might do it differently. In addition, attaining challenging learning goals in science according to students' needs represents a significant change in teachers' roles. Thus, teachers must enhance their ability to cope with diversity and the inclusion of students from different cultural and socioeconomic backgrounds by using diverse teaching strategies, inter alia (Mamlok-Naaman et al., 2013). Mamlok-Naaman et al. (2007) claim that diverse teaching and instructional strategies, combined with aligned assessment tools, may address as many students as possible in a heterogeneous classroom.

In summary, teachers need to receive guidance and support throughout various teaching and implementation stages involving changes in the curriculum (Harrison & Globman, 1988; Loucks-Horsley & Matsumoto, 1999). On the one hand, it is not easy for teachers to undergo modifications that include changes in content and in the way they teach (Mamlok-Naaman, et al., 2013); on the other hand, it has been noted that teachers are typically excellent learners who are interested in trying to teach a new curriculum, as well as in improving and enriching their teaching methods (Joyce & Showers, 1983).

Cultural aspects

Pomeroy (1994) claims that there have been numerous studies dealing with the needs of diverse learners in science education that addresses multicultural, intercultural or cross-cultural education. In her paper, she mentions the two main issues in American science education, as identified by scientists, science educators and stakeholders:

a. The growing gap between the racial, ethnic and gender demographics of the population as a whole and those demographics within the scientific establishment at all levels.
b. The inability of the education system to produce students who are scientifically literate.

The major concern is the lack of policy-makers and researchers who represent the increasingly diverse interests and needs of contemporary society. Hora et al. (2019) claimed that:

One problematic feature of the influential student employability discourse in both K-12 and higher education is the widespread conception of "skills" as decontextualized bits of knowledge, ability and disposition that alone will determine a students' success (or failure) in the labor market […] This approach is evident in the ubiquitous lists of skills that college students should acquire in order to be competitive in the rapidly automating and evolving labor market of the 21st century—a narrative that we call the skills discourse in this paper […] As a result, researchers, policymakers, and postsecondary educators are increasingly focused on integrating these competencies into the college experience via curriculum, instruction, and assessment. (p. 2221)

Referring to climate and culture, Friedman (1991) examined the differences between high-burnout and low-burnout primary schools. In addition, he aimed to investigate the components of organisational climate and culture, as well as social and professional support, in order to elucidate the burnout process. Nevertheless, teachers play a key role in any change, and as such, their beliefs, attitudes and culture should be considered within the socio-cultural framework of their work (Mansour, 2013).

In another study, Lareau and Weininger (2003) attempted to evaluate the outcomes of using the cultural capital concept in English-language educational sociology. They formulated an approach emphasising the significance of scrutinising micro-interactional processes, whereby individuals strategically engage in knowledge, skills and competence, together with institutionalised standards of evaluation. The authors claim that these skills are transferable across generations and may constitute a component of the competences that students and parents draw on in their institutional encounters.

One of the conclusions that can be drawn from the literature is that political decision-makers and educational reformers must consider teachers' beliefs about the subject matter, the pedagogy in the respective domain, and the cultural norms, values and traditions – a systemic view (Markic, et al., 2016).

Language

Science educators at all levels are challenged by increasing cultural and linguistic diversity, which is a consequence of globalisation. Mortimer and Scott (2003) stated that learning science requires students to develop linguistic competence in order to participate in subject-specific discourse and engage in the social language of science using a specific vocabulary (e.g., Aikenhead & Ogawa, 2007).

Effective teaching and learning necessitate a common language for communication. As Lemke (1990) stated, learning the language of science is akin to acquiring a second language. Selinker (1972) introduced the 'Interlanguage' theory, which is a framework for understanding psycholinguistic structures and processes aimed at meaningful performance using a second language. Chemistry students must comprehend the distinctions between the macroscopic, sub-microscopic and symbolic levels (Johnstone, 1991; Talanquer, 2011; Slapničar et al., 2018).

The same terms frequently have different meanings in the academic, teaching and daily language of students (Childs et al., 2015). The language of chemistry is prevalent in chemistry lessons. Marcik and Childs (2016) coined the term 'chemish' to describe this unique language of chemistry:

> The alphabet in chemish is expressed in the symbols for the chemical elements, words are the formulae of chemical substances and sentences and syntax are chemical equations and the rules of chemical combination. (Editorial, p. 434)

Rees et al. (2021) investigated the development of chemical language usage among six non-traditional students for one to four years. In their interviews, these students were asked about their understanding of macroscopic and sub-microscopic scientific language, particularly regarding explaining specific chemical reactions. The transcribed interviews were analysed, revealing the challenges faced by students in integrating sub-microscopic language into their explanations. The students revealed a chemical interlanguage involving the blending of everyday language with scientific terminology, the interchange of terms, and the omission of terms and conversational phrases. One of the conclusions was that combining everyday language with scientific language may foster an understanding of the latter, provided that the everyday language conveys an appropriate meaning.

As previously mentioned, language may be a major hindrance to many students (Wellington & Osborne, 2009). The language of chemistry, including verbal, symbolic and diagrammatic elements, is often somewhat daunting for students to recognise, employ and interpret (Osborne, 2002). Students also struggle with understanding symbols that convey additional information, and iconic symbols are often challenging due to their representation of abstract concepts (Marais & Jordaan, 2000). Learning to understand and balance a chemical equation is similar to learn a foreign language. Actually, it is even more difficult, since the language of chemistry is abstract (Taber, 2009, p. 101).

Taber (2013) recommends exercising the use of science language in science classes, so that the students will get used to it during the learning process. In addition, textbooks that serve as curricular materials should consider this issue and be more explicit regarding abstract representations in their content (Niaz & Maza, 2011).

Laszlo's claim (2013) may be a good way to summarise this section:

> Chemistry ought to be taught in like manner to a language, on the dual evidence of the existence of an iconic chemical language, of formulas and equations; and of chemical science being language-like and a combinatorial art. (p. 1)

Gender

Significant strides have been made in advancing the empowerment of women (Mamlok-Naaman, 2021). However, persistent gender-science stereotypes in mathematics and science continue to exert an influence on this issue, potentially negatively affecting the motivation of young women to pursue STEM majors in college (Makarova et al., 2019). Women still encounter discrimination and unconscious bias, as well as contending with family demands (Mamlok-Naaman et al., 2015). The analysis of a survey entitled 'A Global Approach to the Gender Gap in Mathematical, Computing, and Natural Sciences: How to measure it? How to reduce it?' identified various contributing factors. Recommendations stemming from this survey are directed at a range of stakeholders, including teachers and parents of girls in primary, secondary and higher education, as well as educational organisations, scientific unions and other global entities (Chiu & Cesa, 2020).

Blickenstaff (2005) claimed that women are still underrepresented in science disciplines, particularly in technology, engineering and mathematics (STEM), not only in the United States but also in most other countries globally. Women continue to represent a small proportion of faculty members in science and technology programmes, particularly in prestigious research institutions. Female STEM faculty members' academic careers often coincide with their child-bearing years, thus presenting challenges such as limited lab space, inadequate resources, lower salaries and fewer prestigious opportunities. According to UNESCO, these challenges make their professional lives particularly challenging, especially in the early stages of their academic careers, forcing them to grapple with discrimination, unconscious bias and family demands (Mamlok-Naaman, 2021).

There is a collective view that women in the sciences have difficulties in balancing both work and home obligations, without receiving proper support (Barnard et al., 2010). This is a huge challenge for women, so help derived from supportive sources enables them to 'gain' acceptance from male-dominated scientific fields (Mamlok-Naaman et al., 2011).

Fung et al. recently conducted a study in which they analysed existing programmes that aim to promote gender equity and inclusion in chemistry. Some 47 programmes were selected and analysed regarding their goals, the strategies used and their impact. The findings indicate that female scientists: (1) should be better recognised, and (2) should get funding for sustained networking with colleagues, e.g., conferences. The outcomes of the study were submitted to a peer-reviewed journal.

In summary, the gender gap is a societal problem (for both women and men). Female scientists can serve as role models and can inspire young female researchers. Nevertheless, narrowing the gender gap poses a significant challenge for the entire scientific community, spanning both developed and developing countries. This issue affects everyone, regardless of gender (Mamlok-Naaman, 2021).

Good practices shared by the partners

As mentioned above, the partners in the DiSSI project shared the good practices that they had developed dealing with the dimensions of diversity and inclusion in science education. The development of teaching and learning materials refers to non-formal education settings, which enable teachers to try different approaches. The teaching was based on inclusion, allowing cooperative learning while supporting the learning progress of the four disadvantaged groups of students listed in the introduction above. Each partner focused on different aspects of diversity and inclusion while referring to cultural plurality.

The partners conducted a pilot study in order to investigate the science capital of students from backgrounds with 'low' socioeconomic status. The study included inquiry-based activities, hands-on workshops, group discussions on the nature of science, and debates centred on the ethics of science.

Based on the findings, they developed and implemented learning materials aimed at increasing the science capital of these students in both formal and non-formal formats. Various sets of science outreach activities were conducted as part of the project. These activities, characterised by both formal and non-formal education, were intentionally designed to be adaptable for use in various settings beyond the traditional school environment, but they differed in terms of cultural context, the degree of open-endedness in the tasks, and the focus on the individuals involved in or affected by the science.

The activities developed included inquiry-based chemistry activities within a non-formal educational setting designed for gifted students. The main objective was to illustrate the development of learning modules and their adjustments for teaching chemistry using the Inquiry-Based Learning (IBL) approach in non-formal educational settings. After the activities were enacted, it was observed that gifted students initially held a more favourable attitude towards IBL before the module was adapted. Conversely, the non-gifted students exhibited no difference in their attitudes towards IBL, regardless of whether they had participated in the lab work before or after the Forensics Science module was adapted.

The focus of one team was on ethnically diverse students. Two types of activities were used: (1) game-based learning (escape room activities), and (2) inquiry-based learning (5E model activities). These activities were chosen because they were based on the following: (1) previous positive experiences, (2) learning through play, (3) thinking outside the box, and (4) opportunities for cooperation and socialising, including deepening friendship topics. The topics referred to ecology, gases and electrical circuits. The team developed examples of escape room puzzles, 5E (Engage Explore Explain Elaborate/Extend Evaluate) and lesson plans.

The development and implementation of the learning materials was followed by teachers' professional development and preparation, e.g., according to the Action Research model (Mamlok-Naamam & Eilks, 2012). The teams enacted their ideas through workshops with students, pre-service teachers and in-service teachers, as well as developing evaluations: pre- and post-questionnaires for students and teachers.

Table 1 summarises the good practices shared by the partners. As the table shows, each partner focused on a different component of the project.

Table 1
Good practices shared by the partners

Name of Institution	Activities
Ludwigsburg University of Education	Developing and implementing innovative concepts for language-sensitive student laboratories, with a specific emphasis on enhancing students' linguistic skills, including non-formal education, such as student laboratories.
University of Limerick	Investigating and addressing the science capital of students with a 'low' socioeconomic status at an Irish middle school, and then planning inquiry-based activities, hands-on workshops, group discussions on the nature of science, and debates centred on the ethics of science.
University of Strathclyde	Developing science interventions centred on cultural plurality and implemented by formal and informal students. The activities were designed to be adaptable for use in various settings beyond the traditional school environment.
University of Ljubljana	Developing inquiry-based chemistry activities within a non-formal educational setting designed for gifted students. The main objective was to illustrate the development of learning modules and their adjustments for teaching chemistry using the Inquiry-Based Learning (IBL) approach in non-formal educational settings.
Cyril and Methodius University, Skopje	The focus of the Macedonian team was on ethnically diverse students. They used two types of activities: (1) game-based learning (escape room activities), and (2) inquiry-based learning (5E model activities). The topics referred to ecology, gases and electrical circuits.

Summary

Addressing diversity and inclusion in science education represents a substantial challenge for teachers, who need to cultivate competencies such as personalised teaching to meet the individual needs of all students within a single classroom. Stocklmayer et al. (2010) stated that fundamental learning should occur at a pace tailored to each individual, allowing for diverse approaches. Utilising a range of both formal and informal strategies can ensure that the intellectual demands, which include an extensive array of topics in modern science, align with the learning preferences of young people in both formal and informal educational settings. Furthermore, it is anticipated that curricular materials will incorporate relevant components to cater to diverse learners' needs, potentially influencing science education and teaching practices (Belova et al., 2015).

The DiSSI project started during the Covid-19 pandemic and the corresponding restrictions for traveling. In the project meetings, which were usually short, one could notice the development of relationships of trust between partners who did not know each other very well. In addition, the ASANA project's platform management enabled an exchange of documents as well as sharing all of the other information organised by the coordinator, which was presented to and discussed with the partners during the initial meeting. The cooperation among the partners was enacted monthly by ZOOM video online meetings. Later, there were a few successful face-to-face meetings.

Pre-service and in-service teacher preparation on using the DiSSI approach for inclusive science teaching was provided to implement the concept's non-formal education. In addition, the DiSSI approach was implemented in different school curricula and beyond, through strong partnerships and networks with teachers, school principals and policy-makers.

It is suggested that the main impact aimed for was better social inclusion of different disadvantaged groups in science. The goal was to engage these groups with science and to convince more students to consider science as part of their self-identity. It is suggested that the present project managed to develop and implement good practices to deal with diversity in science education, using an approach targeting multiple cultures with a variety of needs. All of the partners referred to diversity and inclusion in developing and implementing their diversity programme.

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Biographical note

Rachel Mamlok-Naaman, PhD, is a scientist at the Department of Science Teaching, Weizmann Institute of Science; chair of EuCheMS DivCED; CCE national representative; a co-editor of CTI; and member of editorial boards of science education journals. She was the head of: (1) the National Center for Chemistry Teachers, (2) the chemistry group, (3) the chemistry teachers' Master program in the framework of the Rothschild-Weizmann, and (4) projects in the framework of the European Union. Her awards consist of two from the Weizmann Institute – 1990-Bar-Ner (for teaching), and 2006-Maxine Singer for professional development of chemistry teachers; ACS award (2018) for incorporation of sustainability into the chemistry curriculum; IUPAC award for 2020 distinguished women in chemistry and chemistry engineering.