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A Rising Tide Lifts All Boats? The Model of Differentiation As a Tool for Diversity in Science toward Social Inclusion

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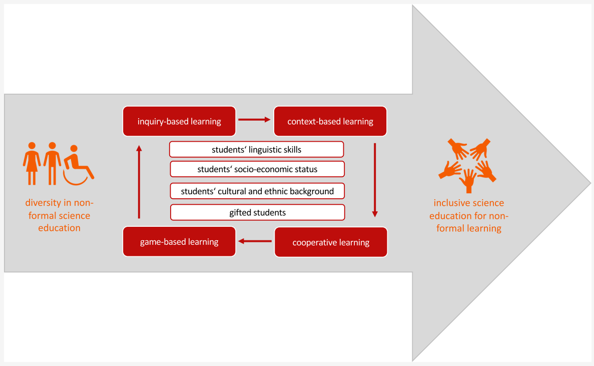
ABSTRACT: Approaches for inclusive science teaching currently tend to focus on only one dimension of diversity at a time. This neglects the fact that diversity is multidimensional in nature, and the consideration of only one dimension of diversity can yield inclusive practices with limited scope. Therefore, the goal of the project "Diversity in Science toward Social Inclusion—Non-formal Education in Science for Students' Diversity" (DiSSI) is to promote inclusive teaching practices for dealing with several dimensions of diversity simultaneously for non-formal education. Researchers from Ireland, Germany, the United Kingdom, Slovenia, and North Macedonia are developing a teaching approach that considers the needs of (i) students with a low socioeconomic status, (ii) students of ethnic minorities or with cultural backgrounds that differ from those of the mainstream culture, (iii) students with different linguistic skills, and (iv) gifted students. For this purpose, the Pedagogical Model of Differentiation was developed. In addition, the approaches of inquiry-based learning, context-based learning, game-based learning, and cooperative learning were reviewed in regard to their suitability for inclusive learning settings for non-formal science education. Conclusions were drawn about the mentioned dimensions of diversity. An innovative combination of pedagogical approaches that benefits all learners and thus is truly inclusive is presented. The teaching is inclusive in the sense that it allows for cooperative learning while simultaneously supporting the learning progress of the four differentiated groups of students. Thus, in this paper, the model of differentiation is presented and explained, and a summary of the approaches is discussed, which are applicable for inclusive teaching.



KEYWORDS: *Inclusion, Diversity, Differentiation, Chemical Education Research*

■ INTRODUCTION

Classroom insights as well as the results of numerous studies (e.g., PISA)[1] show that the composition of learning groups is complex, and thus, groups of students cannot be considered homogeneous. Students in one learning group differ in their learning requirements, attitude, linguistic competences, motivation, and interests.[2] They also differ in their ethnicity, religion, culture, and socioeconomic status. These aspects have a significant influence on the individual use of learning opportunities.[3]

The professional action of a teacher in an educational context requires that students' diversity characteristics need to be noticed and recognized. It needs to be reflected upon and considered in various ways.[2] In this way, all students get the opportunity to participate in educational offers, which enables them to have adequate learning conditions.[4] According to Sliwka,[2] inclusive teaching offers a response to this diversity. Inclusion is not only based on different levels of achievement and barriers to learning; it also considers all of the individual needs and characteristics of each child and adolescent.

However, the research of and approaches to socially inclusive chemistry education currently tend to focus on only one dimension of diversity at a time.[5] This often causes exclusion rather than inclusion in the classroom. For example, students and groups of students are excluded by using different or additional materials or by learning in separate learning groups instead of being included through this.[6] Students are often addressed as homogeneous learning groups, and lessons are planned for a group, although it is obvious that every student has a unique personality, which is influenced by his/her individual biography and everyday experiences and determines his/her individual learning conditions and pathways at the same time.[7] According to Schumann,[4] the

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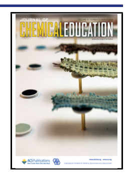

avoidance of exclusion and separation of certain groups of students and individuals because they cannot meet the requirements of the school is the focus of inclusion. Schools and teaching must therefore improve their offerings and frameworks in response to the needs and characteristics of their students. In terms of inclusive science education, goals of scientific literacy should be taught, taking into account the educational needs and requirements of every single student and their prior knowledge.[4]

However, science education for all can only be achieved if both perspectives—inclusive and scientific—are considered and interwoven.[8] In doing so, an inclusive science education assumes an adaptation of the teaching and learning materials as well as the learning environment to the students and their needs, which does not focus on their weaknesses. Practices should be found in which students' differences can be used positively for collaboration so that differences have a positive connotation in the context of active participation. This means designing learning environments, supporting students in their learning, and providing assistance to ensure equal participation in the classroom for everyone.[9] The diversity of a group is to be seen as a resource and a chance for individual and mutual learning processes as well as an essential aspect of human development since this productive viewpoint opens up new perspectives for action.[10,2] Thereby, learning and the experiences of individual students can be enriched in the sense of constructivism, as they profit from each other's experience in cooperative activities.[10]

Non-formal and informal activities are positively related to science learning.[11] The Organization for Economic Co-operation and Development (OECD) report in 2012 showed that, after participating in science-related non-formal activities, students often show better student performance, a stronger belief in their abilities to handle science-related tasks, greater enjoyment of learning science,[11] and greater career interest in science, technology, engineering, and mathematics (STEM).[12] Non-formal learning is situated between out-of-school informal learning, which is strongly characterized by voluntariness, and formal learning, which is involuntary, highly structured, and organized school-based learning. Thus, non-formal and informal educational offerings lend themselves particularly well to integrative science instruction because of its open and free, yet structured and educational, curriculum-oriented framework.[13]

The project "Diversity in Science toward Social Inclusion—Non-formal Education in Science for Students' Diversity" (DiSSI) focuses on the development and implementation of innovative methods, instruments, and activities in the form of best-practice examples of inclusive science education in general, and chemistry in particular, that aim to improve the educational opportunities of various groups of students in non-formal settings that are underrepresented in science. Special attention is paid to the targeted promotion of inclusive teaching methods, which take several dimensions of diversity into account simultaneously. Researchers from Ireland, Germany, the United Kingdom, Slovenia, and North Macedonia develop a shared learning and teaching approach that takes into account the needs of (i) students with low socioeconomic status, (ii) students from different ethnic minorities or with a cultural background different from the dominant culture, (iii) students with low language skills, and (iv) gifted students. In parallel, an evaluation framework for assessing inclusive practices in non-formal and informal science education is in the process of development and will be implemented in the project. A secondary aim is to support teachers in teaching science in diverse classes through in-service training.

■ THEORETICAL BACKGROUND

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) Commission[14] reacted to the growing diversity of students with the requirement for education for all, which must be achieved. This demand includes equal opportunities for all students to participate in education. Comparative studies such as PISA have shown very clearly that this is currently not being achieved in science education.[1] The results have indicated that participation in education is not possible for some groups. Research has also shown that there are specific dimensions of diversity that correspond to groups of students in particular who are disadvantaged and more often excluded than included.[1] Factors that hinder participation in education include students' linguistic skills, a low socioeconomic status, cultural and ethnic backgrounds that differ from the dominant culture and ethnicity, and giftedness.

Students with different language skills often have difficulties with the language of instruction and in developing specific technical language, especially in chemistry.[15] Socioeconomic background affects whether students can identify with science. It is more difficult for working-class students to identify with science than middle-class students.[16,17]

Another factor that tends to alienate students from science is the very narrow version presented in the curricula. This version is especially difficult for students whose culture is not the majority culture because they miss many of the common reference points shared by teachers and students.[18,19] In addition, students from nondominant ethnic groups tend to have a lower academic self-concept than those who belong to the dominant group.[20]

A further dimension of diversity that can prevent students from learning is giftedness. Here, giftedness in science education means students that have a great understanding of scientific problems, scientific phenomena, and scientific knowledge acquisition. A major problem in the education of gifted learners is the lack of challenge, which ensures that they make as much progress as they are capable of. The lack of challenge can also influence learner motivation and even lead to boredom. Meeting the needs of gifted learners is, therefore, a matter of matching task demand to their abilities to meet their emotional and cognitive needs.[21]

This results in a need for inclusive educational opportunities that enable all learners to participate in the learning process and, thus, in science education.

Inclusion and Chemistry Education

In order to talk about inclusion and present reflections on an approach to inclusive science teaching for non-formal education, a common context needs to be established. In the literature and research, the terms "inclusion" and "diversity" are interpreted differently.

The term "diversity" is a response to the thinking about plurality that the model "Dimensions of Diversity Wheel" by Gardenswartz and Rowe[22] summarizes. Gardenswartz and Rowe[22] group various aspects of diversity into four dimensions: those of personality, the internal dimension (age, gender, etc.), the external dimension (religion, education,

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income, etc.), and the organizational dimension (function and classification, place of work, management status, etc.). These aspects are consequently those that either connect individuals or differentiate them.[23] Starting from here, Sliwka defines the term "diversity" as the following (p 214): "Diversity: Learners are perceived to be different. Their difference serves as a resource for individual and mutual learning and development."[2] The term "diversity" has a positive connotation.[2] Following these definitions, Sliwka defines inclusion as "difference seen as an asset and opportunity" (p 214).[2]

It is through the perception of the varying aspects of diversity and a positive approach to them that inclusion becomes possible.[2]

According to Schumann,[4] inclusive teaching demands an active response to diversity and is based on the specificity and individual needs of each child. Therefore, inclusion must be defined broadly. Thus, the focus of inclusion is on avoiding exclusion and the separation of certain groups of students and individuals. Different learning opportunities (formal, non-formal, and informal) must therefore adapt and often improve their offers and frameworks to the needs and characteristics of their students while considering the diversity of all students.[8]

Differentiated learning and teaching is one way to deal with the differences among students; it is the opposite of one-size-fits-all teaching.[24] According to Tomlinson and Allan,[25] differentiated teaching addresses the learning needs of all students rather than teaching the class as if all individuals in it were fundamentally the same. Differentiation is an attempt to take into account differences within a learning group by using various methods, tools, and activities that change learning settings to deal with students' individual needs.[25] Differentiation does not only refer to the dimension of students' cognitive achievement; it instead takes all the dimensions of differentiation (content, classroom, instructional strategies, and products) into account.[24]

We know that these demands are not new. Worldwide, schools are obliged to introduce educational policy measures to make teaching and learning environments inclusive.[26]

One approach that responds to the diversity of learners and their multifaceted needs is the Universal Design for Learning (UDL). The Center for Applied Special Technology (CAST)[27] describes three principles to consider for inclusive learning. Three guidelines are listed for each of the principles, and examples of concretization are given for each. These principles include the following: (1) "provide multiple means of engagement", (2) "provide multiple means of representation", and (3) "provide multiple means of action and expression".[27] Baumann et al.[28] provide an example of how UDL can be used in the planning and delivery of science education with an experimental problem-based learning setting that is aligned with the basic principles of UDL and based on differentiated work materials.

However, the implementation of the more normative outcomes discussed in research is proving difficult in some areas. For example, research has shown that in the natural sciences, especially in chemistry, there is a particular difficulty in combining the often complex and abstract subject content and competencies with inclusive techniques and methods.[5] In order to be able to deal with the diversity of students in chemistry lessons, appropriate subject pedagogical approaches are needed. Research projects (e.g., ref 29) have shown that the "inclusive pedagogical approach", which enables the participation and self-determination of all students without prior categorization due to its open pedagogical design, is particularly suitable for inclusive chemistry teaching.[30]

The realization of the call for "science education for all" can only work if inclusive and scientific perspectives are interwoven.[8] Inclusive science education in general and in chemistry education in particular adapts teaching and learning materials to the needs of all students. The aim is to find practices and methods that positively unite the diversity of students in a common science classroom. This results in the task of designing learning settings, supporting students in their learning, and providing assistance to ensure equal participation in the classroom for everyone.[9]

Research on inclusive education is currently mainly related to science in general. In the following, the focus is more on science education. The findings presented here can be applied equally well to chemistry education.

Non-Formal Education

The OECD defines informal learning as learning outside of school without structure or curriculum.[31] Informal science learning includes activities in out-of-school settings that are not part of a formally assessable educational or curricular program of an educational institution.[31] Examples include voluntarily visiting museums, playing a computer game with science content, or watching a science program on television.[32] Formal learning is the highly structured and organized learning that takes place in schools.[11] Non-formal learning lies between voluntary informal learning and involuntary formal learning and uses characteristics from both extremes.[11] Usually, non-formal learning takes place outside of school in an open and free framework but is structured, organized, and oriented toward the education and curriculum.[13]

Anderson, Kisiel, and Storksdieck[33] showed in a study on teachers' perceptions of non-formal field trips that, in addition to the students, teachers are also crucial for the success of non-formal education offerings. Most teachers described a field trip as successful and beneficial if the students enjoyed themselves, and emotional or affective criteria were more important than, for example, specific learning objectives associated with the curriculum.[33] In contrast, an important point for teachers, to enable them to conduct an out-of-school learning offering, is the fit to the school curriculum. A fit with the curriculum thus plays an important role when it comes to selecting an out-of-school learning offering.[33] This point was also confirmed by the study of Garner, Siol, and Eilks.[34] This study explored the potential of non-formal learning environments and found that teachers were particularly interested in receiving news and innovative teaching and learning materials for science education that were oriented with the school curriculum.[34] Tried and tested projects on non-formal learning opportunities have already confirmed that there is potential for developing innovative teaching and learning ideas and materials. However, these innovative concepts have not yet found a permanent place in everyday science teaching (e.g., ref 35).

■ GUIDING QUESTIONS AND GOALS

Based on the situation and difficulties of education in relation to diversity, this paper focuses on the practical approaches of dealing with diversity as exemplified by non-formal chemistry education. Our guiding question to foster inclusive science education in which several dimensions of diversity are taken into account at the same time is the following: how can well-established pedagogical approaches in each dimension of

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diversity be connected in an inclusive approach for chemistry education? The Pedagogical Model of Differentiation is presented to support teachers in teaching inclusive chemistry education.

■ PEDAGOGICAL MODEL OF DIFFERENTIATION

To develop a multidimensional approach, in the frame of the project, the Pedagogical Model of Differentiation was developed (see Figure 1). By differentiation, we mean here the optimal support of all learners, independent of their requirements, within a learning group in the development of their competencies through appropriate pedagogical and didactic measures. Different ranges within a dimension of diversity can be supported, promoted, and fostered by offering various methods and tools, for example, in the form of support materials.

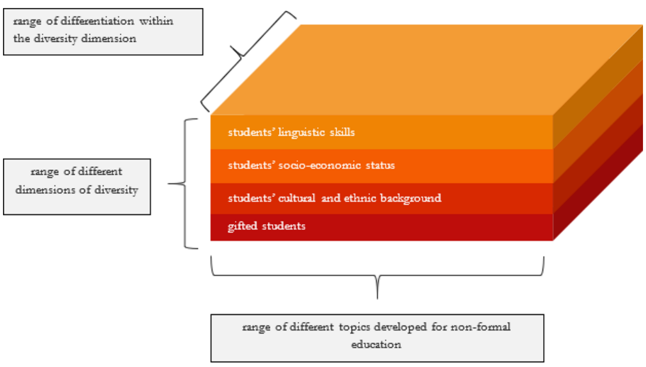

Figure 1. The Pedagogical Model of Differentiation.

The model of differentiation contrasts with common practice and enables the active participation of students in different dimensions of diversity. Thus, it can support the learning progress of all students in the mentioned disadvantaged groups at the same time.

The model shows how each teaching and learning material can be differentiated according to the range of diversity dimensions if needed and within the dimension itself. The range of different dimensions illustrates the four dimensions of diversity on which the model focuses on, which must be considered simultaneously through an inclusive approach. Additionally, the range of differentiation within each diversity dimension (from good to fewer language skills (referring to the language of instruction), from a low to a high socioeconomic status, an ethical and cultural background that is from more to less similar to the country of immigration, and from lower giftedness to higher giftedness) is acknowledged as well. Thus, each teaching unit is more flexible regarding the four dimensions of diversity. The range of different topics developed for non-formal education represents the diverse range of possible chemistry topics.

Following the named model and after the evaluation, collection, presentation, and discussion of best-practice examples for the dimensions named in Figure 1, DiSSI partners collected the following approaches, which are presented as best practices for each of the dimensions of diversity and, thus, are in common for all of the diversity dimensions:

- Context-based learning
- Inquiry-based chemistry teaching and learning
- Cooperative Learning
- Game-based chemistry teaching

In the following sections, each of the named approaches is discussed in the frame of inclusion.

Context-Based Learning

International studies have shown that students' interest in science is low and seems to be decreasing in several European countries.[36] It has often been identified among students at different levels of education that a rather negative attitude toward chemistry can cause a lower level of individual interest for learning chemistry, leading to a nonexistent intrinsic motivation for learning chemistry.[37] It is generally agreed that learning chemical concepts is a complex cognitive process due to the abstract nature of chemical concepts being particulate and symbolic.[38]

Keeping in mind this complexity of chemical concepts, chemistry teaching should emphasize learning in students' known contexts. Context-based teaching has been a long tradition in science, especially in chemistry. The development of this approach was stimulated by research that showed that students were not learning chemistry because they did not find it relevant.[39] Teaching chemistry in the context of real-world issues and implementing it in environmental and societal issues can be a promising way to help students close the gaps between school chemistry, applications of chemistry and technology, and their critical evaluation. The selection of such everyday-life contexts of chemistry and technology should be authentic and relevant to students' lives.[40]

Inquiry-Based Chemistry Teaching and Learning

It is important to have in mind that every context-based chemistry lesson should also comprise activities for students where they are engaged in constructing their own knowledge considering chemistry as a natural science. The most important principle that is common to all science while generating new knowledge is inquiry, and the teaching of science (including chemistry) must be based on this domain. Through inquiry and practice curriculum, students are expected to be able to apply their knowledge and skills of chemistry to authentic problems.[41] The inquiry-based science education (IBSE) approach follows a student-centered, constructivist perspective of learning. These IBSE methods provide students with a challenge or problem that they must overcome by learning the concepts without receiving previous explanations.[42] The international science education community[43,44] believes that an IBSE approach can offer a successful teaching method that stimulates students' interest and motivation in science and chemistry learning. Gilbert and Newberry[45] suggest connecting IBSE with specific contexts that have appropriate tasks that provide a personal challenge for each student and are interesting for the students and relevant to their own lives. Learning environments should be presented that are appropriate and support students' creativity in designing their research strategies for research problems. As Trna[46] concluded, the core principles of IBSE are involving students in discovering natural laws, linking information into a meaningful context, developing critical thinking, and promoting positive attitudes toward science, especially chemistry. As he indicates, IBSE is suitable for the education of all students.

In contrast, a review of research performed by Rizzo and Taylor[47] suggests that IBSE is not suitable exclusively for gifted students and students with disabilities. They concluded from the 12 studies included in the review that students with

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disabilities require support to participate in IBSE to demonstrate higher science achievement and that science achievement improves when components of explicit instruction are utilized in both the general and special education setting for students with disabilities.

Cooperative Learning

The benefits of cooperative learning have been empirically demonstrated many times (e.g., refs 48−50). Cooperative learning describes, like collaborative learning, a process in which students at all levels of ability work together in small groups to achieve a task.[51] Furthermore, cooperative learning is characterized by five aspects: (1) positive interdependence, (2) commitment and acceptance of responsibility, (3) face-to-face interaction, (4) social skills (e.g., active listening, asking for help), and (5) evaluation.[52] These aspects are demonstrated by learners in a cooperative group listening to each other, taking exact note of how things are said, giving and accepting help, looking for ways to solve difficulties, and actively participating in the development of new understandings and learning.[53]

The development and advancement of communication skills, problem-solving skills, and critical thinking are forced by the active participation of the students in the learning process through working in cooperative groups.[54−63] These aspects result in advantages and opportunities for learning science in general and learning chemistry in particular through the use of cooperative methods.

Studies have shown that cooperative learning has positive effects on understanding science[64−66] as well as on students' self-esteem and boosting their self-confidence.[67]

Cooperative learning can improve students' satisfaction and enjoyment.[68] Aydin[69] found positive effects in the promotion of academic knowledge, familiarity with the laboratory equipment, and the development of a positive approach to laboratory studies.

Game-Based Chemistry Teaching

It is easy to assume that games are interesting and fun because each of us has experienced games at some point in our lives. Of course, while entertainment is not the main goal in the educational process, game-based learning certainly helps in the acquisition of concepts and in bringing students together.

Perrotta et al.[70] refer to the key principles of game-based learning, which include intrinsic motivation, authenticity (contextualized and goal-oriented instead of abstract learning), self-reliance, autonomy, and experiential learning (learning by doing); they also discuss the mechanisms of this type of learning (simple rules, clear but challenging goals, interaction, student control, immediate and constructive feedback, a social element, etc.).

Learning by using games promotes the engagement of all students, active learning, logical connections of concepts, and fun at the same time. The significance of game-based learning is seen in the fact that it can be applied in diverse classrooms to support a variety of learning outcomes and to develop skills students will need in their future life in a friendly collaborative environment. More importantly, students have the opportunity to be directly involved in their own learning and engaged in the activities that meet their individual needs.[71]

From the benefits and effects of the presented approaches for learning chemistry in general and in regard to the disadvantaged groups mentioned in the Pedagogical Model of Differentiation, the potential for an inclusive approach to learning environments of different non-formal and informal education settings, which intend to enable all students to participate in the educational offer, arises from the combination of these approaches. To establish differentiation within the single dimensions of diversity and to keep the approach flexible, the inclusive approach is enhanced with appropriate methods, tools, and activities.

Methods, tools, and activities that address the diversity dimension of students' linguistic skills relate to supporting students who have difficulties with the language of instruction, the development of scientific literacy, or fostering communication skills. One example is the use of language-sensitive and language-supportive designed graded tip cards that support students in doing experiments or formulating their observations and findings.[72,73]

Furthermore, additional methods, tools, and activities that help students identify with chemistry, especially when students do not feel engaged by chemistry because of their socioeconomic background, culture, or ethnicity, demonstrate relevance to all students' lives and daily routines. One example is working with students' prior knowledge using concepts and mind maps.[74] Students are given the opportunity to integrate their prior experiences and knowledge through questions and tasks that can be answered in multiple ways.[75]

For gifted students, tasks are challenging and exciting when the solution is not easily predictable by just reading or using the knowledge they already have. Examples include open-ended questions and tasks that have more than one solution and when students learn through discussion rather than primarily through writing.[76] More practical examples can be found an the project homepage (dissi.org).

Within the framework of this project, the partners develop various teaching and learning settings for different informal and non-formal education offers (e.g., students laboratories, museums, botanical gardens, etc.) on different topics where approaches and methods can be tested. The concrete learning and teaching materials provide teachers with best-practice examples so that they can learn how to apply the strategies developed in DiSSI.

■ CONCLUSION AND IMPLICATIONS

To respond to diverse students in the education system, an inclusive science-chemistry approach is needed that addresses the interests and needs of all students. Therefore, developing inclusive learning settings and a set of pedagogical approaches that benefit all learners and thus are truly inclusive for non-formal education demands the consideration of different aspects of diversity simultaneously.

This paper discusses an approach to inclusive science/chemistry education for non-formal education based on four approaches: (1) context-based learning, (2) inquiry-based learning, (3) cooperative learning, and (4) game-based learning (Figure 2). As shown in the previous section, each approach is appropriate for learning and teaching chemistry and for the active participation of all students in general. According to the Pedagogical Model of Differentiation (Figure 1), the combination of these approaches seems to have positive effects concerning the four dimensions of diversity: (i) students' linguistic competencies, (ii) students' socioeconomic status, (iii) students' ethnical and cultural background, and (iv) students' giftedness.

The cooperation within the DiSSI project benefits, in particular, from the fact that the project members are experts in one of the named dimensions of diversity. This cooperation

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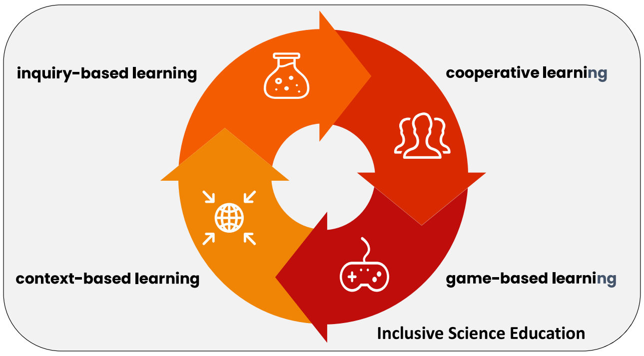

Figure 2. The DiSSI approach of inclusive science education.

results in parallels and similarities between the individual foci that can be used for an inclusive approach. The work with the Pedagogical Model of Differentiation shows one way to connect these different foci toward an inclusive approach. This connection is shown in a way that gives orientation and allows flexibility to make further differentiations within the dimensions for various informal and non-formal education offers and topics.

Figure 2 presents the common ground that results from different points of view on various dimensions of diversity and summarizes this common ground to the point.

The individual approaches of (1) context-based learning, (2) inquiry-based learning, (3) cooperative learning, and (4) game-based learning have shown positive effects on students learning science/chemistry, especially in regard to applying knowledge and skills to authentic problems,[41] fostering communication,[55−57] and using scientific working methods, e.g. experimentation for knowledge generation.[77,78] As discussed before, various studies have shown the advantages for students using the approaches for learning and teaching science in general and chemistry in particular. Thus, relevant contexts support students in seeing the relevance of chemical topics for their lives[41] and understanding complex chemical content.[39] Inquiry-based learning stimulates students' interest and motivation in learning science,[43] and inquiry-based learning supports students in linking information in meaningful contexts, developing critical thinking, and promoting positive attitudes toward science.[46] A cooperative and a game-based approach fosters the development and advancement of communication skills, problem-solving skills, and critical thinking.[59−63]

Based on these benefits related to science learning in general and to chemistry in particular, we suggest the combination of these approaches to promote inclusive science/chemistry education.

The integration of proven methods, tools, and activities that are positively related to each dimension of diversity allows for flexibility in referring to different learning groups. Learning environments that are developed according to the inclusive DiSSI approach can support, foster, and promote all four dimensions of diversity simultaneously by using the Pedagogical Model of Differentiation and taking all facets within the dimensions into account. While the Universal Design for Learning approach bases its inclusive claim primarily on its high flexibility and freedom of choice for learners in the three areas of working methods, learning content, and learning outcomes, which requires a very open design that leaves room for individual possibilities,[27] the inclusive DiSSI approach, together with the Pedagogical Model of Differentiation, proposes concrete approaches and connections.

Non-formal science education offers, such as out-of-school educational settings (i.e., museums, botanical gardens, zoos, institutes, university laboratories, etc.), should develop activities for students by focusing on an inquiry-based approach with an emphasis on context learning. In combination with cooperative and game-based approaches, communication among students can be promoted, as they are more often an active part of the learning process and are involved in solving scientific problems.

In non-formal education settings, students attending these activities may learn in a less stressful way compared to in formal learning settings in schools, where assessment is an important part of the process. With a view of the named dimensions of diversity, the connection of these approaches seems to be appropriate for fostering inclusive science/chemistry education in informal and non-formal education. As mentioned here in the title and in the words of John F. Kennedy, "a rising tide lifts all boats." Kennedy said this quote in regard to economic development, but we see that it also works for education as well. Here, we see that not only one dimension of diversity needs improvement; rather, all of the dimensions of diversity need to be improved in general, which will contribute to the benefit of all students in chemistry classes. The DiSSI approach could have positive effects on the active participation of disadvantaged groups in the dimensions of diversity as well as on the cooperative interaction of heterogeneous learning groups. Thus, the interventions presented here are in the first place developed for specific target groups. However, we see that they can be combined to be of benefit to all learners.

In conclusion, the combination of the chosen approaches to the DiSSI approach of science education enables the development of learning settings for non-formal education offers that not only include disadvantaged groups but also have a positive impact on all students in a learning group.[79]

We suggest that the approaches mentioned here are effective for promoting learning for diverse groups in non-formal chemistry education. This inclusive approach can be seen as a basis for non-formal education offerings. Furthermore, the arrangement is flexible for individual adaptations and further differentiation possibilities. We see high potential in this inclusive DiSSI approach because it is based on appropriate approaches that have been assessed as helpful by experts in the four dimensions of diversity. In addition, those approaches show similarities and potential for combination, especially for non-formal education offers.

At this point, we note that this inclusive approach results from theoretical considerations. Implementation in practice and a detailed evaluation will show in the next step how this approach works in different non-formal education offerings and learning groups.

Finally, we want to add that non-formal education offers enable all students to participate, foster better cooperation within a learning group, and further inclusive science/chemistry education.

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Notes

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REFERENCES

(1) OECD. In *PISA 2018 Results (Vol. II): Where All Students Can Succeed*; OECD Publishing, 2019. DOI: 10.1787/b5fd1b8f-en.

(2) Sliwka, A. From Homogeneity to Diversity in German Education. In *Educating Teachers for Diversity: Meeting the Challenge*; OECD Publishing, Paris, France, 2010; p 205−217.

(3) Zierer, K.; Seel, M. General Didactics and Instructional Design: eyes like twins A transatlantic dialogue about similarities and differences, about the past and the future of two sciences of learning and teaching. *SpringerPlus.* **2012**, *1*, 1−15.

(4) Schumann, B. Inklusion statt Integration - eine Verpflichtung zum Systemwechsel: Deutsche Schulverhältnisse auf dem Prüfstand des Völkerrechts. *PÄDAGOGIK.* **2009**, *2*, 51−53.

(5) Abels, S.; Koliander, B.; Plotz, T. Conflicting Demands of Chemistry and Inclusive Teaching—A Video-Based Case Study. *Education Sciences.* **2020**, *10* (3), 50.

(6) Sturm, T. In *Inklusion und Exklusion in Schule und Unterricht: Leistung - Differenz - Behinderung*; Kohlhammer Verlag, Stuttgart, Germany, 2023.

(7) Taber, K. S.; Riga, F. From each according to her capabilities; to each according to her needs: fully including the gifted school science education. In *Science education towards inclusion*; Markic, S., Abels, S., Eds.; Nova Science Publishers, Inc., New York, New York, U.S., 2016; p 195−219.

(8) Stinken-Rösner, L.; Rott, L.; Hundertmark, S.; Baumann, T.; Menthe, J.; Hoffmann, T.; Nehring, A.; Abels, S. Thinking Inclusive Science Education from two Perspectives: Inclusive Pedagogy and Science Education. *RISTAL.* **2020**, *3* (1), 30−45.

(9) Gudjónsdóttir, H.; Óskarsdóttir, E. Inclusive education, pedagogy and practice. In *Science Education towards Inclusion*; Markic, S., Abel, S., Eds.; Nova Science Publishers, Inc., New York, New York, U.S., 2016; p 7−22.

(10) Florian, L.; Spratt, J. Enacting inclusion: a framework for interrogating inclusive practice. *European Journal of Special Needs Education.* **2013**, *28*, 119−135.

(11) OECD. Are students more engaged when schools offer extracurricular activities? In *PISA in Focus*; OECD Publishing, 2012; Vol *18*, p 1−4. DOI: 10.1787/5k961l4ccczt-en.

(12) Dabney, K. P.; Tai, R. H.; Almarode, J. T.; Miller-Friedmann, J. L.; Sonnert, G.; Sadler, P. M.; Hazari, Z. Out-of-school time science activities and their assoziation with career interest in STEM. *International Journal of Science Education.* **2012**, *2* (1), 63−79.

(13) Coll, R. K.; Gilbert, J. K.; Pilot, A.; Streller, S. How to benefit from the informal and interdisciplinary dimension of chemistry in teaching. In *Teaching Chemistry - A Studybook: A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers;*; Eilks, I., Hofstein, A., Eds.; Sense Publishers: Rotterdam, The Netherlands, 2013; p 241−268.

(14) Deutsche UNESCO-Kommission e.V. Jahresbericht. 2010, 2011.

(15) Markic, S.; Broggy, J.; Childs, P. S. How to Deal with Linguistic Issues in Chemistry Classes. In *Teaching Chemistry - A Studybook*; Hofstein, A., Eilks, I., Eds.; Sense Publishers, Rotterdam, The Netherlands, 2013; p 127−152.

(16) Archer, L. ‘We Raised It with the Head’: The Educational Practices of Minority Ethnic, Middle-class Families. *Br. J. Sociol. Educ.* **2010**, *31* (4), 449−469.

(17) DeWitt, J.; Osborne, J.; Archer, L.; Dillon, J.; Willis, B.; Wong, B. Young Children’s Aspirations in Science: The Unequivocal, the Uncertain and the Unthinkable. *Int. J. Sci. Educ.* **2013**, *35* (6), 1037−1063.

(18) Aikenhead, G. S. The Humanistic and Cultural Aspects of Science & Technology Education. In *11th International Organization for Science and Technology Education (IOSTE) Symposium*; Lublin, Poland, 2004; p 1−16.

(19) Costa, V. B. When Science Is “Another World”: Relationships between Worlds of Family,Friends, School, and Science. *Sci. Educ.* **1995**, *79*, 313−333.

(20) Dean, L. M. Factors That Influence Minority Student Enrollment at Various Levels of Postsecondary Education. Ph.D. Dissertation, Old Dominion University, 2013. DOI: 10.25777/DYY2-SY91.

(21) Taber, K. S. Exploring the Language(s) of Chemistry Education. *Chem. Educ. Res. Pract.* **2015**, *16* (2), 193−197.

(22) Gardenswartz, L.; Rowe, A. In *Diverse teams at work: Capitalizing on the Power of Diversity*; Irwin Professional Pub., 1994.

(23) Gardenswartz, L.; Cherbosque, J.; Rowe, A. Emotional Intelligence and Diversity: A Model for Differences in the Workplace. *J. of Psych Issues in Org. Culture.* **2010**, *1* (1), 74−84.

(24) Reis, S. M.; Renzulli, J. S. Five Dimensions of Differentiation. *Gift. Educ. Press Q.* **2015**, *29* (3), 2−9.

(25) Tomlinson, C. A.; Allan, S. D. In *Leadership for Differentiating Schools & Classrooms*; Association for Supervision and Curriculum Development, Alexandria, Virginia, U.S., 2000.

(26) UNESCO. In *Policy Guidelines on Inclusion in Education*; UNESCO, Paris, France, 2009.
(27) Universal Design for Learning Guidelines version 2.2. CAST, 2018. https://udlguidelines.cast.org.
(28) Baumann, T.; Kieserling, M.; Struckholt, S.; Melle, I. Verbrennungen - Eine Unterrichtseinheit Für Inklusiven Unterricht. *CHEMKON.* **2018**, *25* (4), 160−170.
(29) Abels, S. Scaffolding Inquiry-Based Science and Chemistry Education in Inclusive Classrooms. In *New Developments in Science Education Research*; Yates, N. L., Ed.; Nova Science Publishers, Inc., 2015; p 77−95.
(30) Florian, L.; Black-Hawkins, K. Exploring inclusive pedagogy. *British Educational Research Journal.* **2011**, *37* (5), 813−828.
(31) European Centre for the Development of Vocational Training. In *Recognition and Validation of Non-Formal and Informal Learning for VET Teachers and Trainers in the EU Member States*; Office for Official Publications of the European Communities, 2007.
(32) Rennie, L. J. Learning science outside of school. In *Handbook of Research on Science Education*; Abell, S. K., Ledermann, N. G., Eds.; Taylor & Francis Group, New York, New York, U.S., 2014; Vol. *2*, p 120−144.
(33) Anderson, D.; Kisiel, J.; Storksdieck, M. Understanding Teachers' Perspectives on Field Trips: Discovering Common Ground in Three Countries. *Curator: The Museum Journal.* **2006**, *49* (3), 365−386.
(34) Garner, N.; Siol, A.; Eilks, I. The Potential of Non-Formal Laboratory Environments for Innovating the Chemistry Curriculum and Promoting Secondary School Level Students Education for Sustainability. *Sustainability.* **2015**, *7* (2), 1798−1818.
(35) Garner, N.; Hayes, S.; Eilks, I. Linking formal and non-formal learning in science education − a reflection from two cases in Ireland and Germany. *Sisyphus - Journal of Education* **2014**, *2* (2), 10−31.
(36) van Griethuijsen, R. A. L. F.; van Eijck, M. W.; Haste, H.; den Brok, P. J.; Skinner, N. C.; Mansour, N.; Savran Gencer, A.; BouJaoude, S. Global Patterns in Students' Views of Science and Interest in Science. *Research in Science Education* **2015**, *45* (4), 581−603.
(37) Holbrook, J. Education through science as a motivational innovation for science education for all. *Science Education International* **2010**, *21* (2), 80−91.
(38) Harrison, A. G.; Treagust, D. F. The Particulate Nature of Matter: Challenges in understanding the Submicroscopic World. In *Chemical Education: Towards Research-based Practice*; Gilbert, J. K., De Jong, O., Justi, R., Treagust, D. F., Van Driel, K. H., Eds.; Springer, Dordrecht, The Netherlands, 2002; Vol. *17*, p 189−212.
(39) Eilks, I.; Rauch, F.; Ralle, B.; Hofstein, A. How to Allocate the Chemistry Curriculum between Science and Society. In *Teaching Chemistry − A Studybook*; Eilks, I., Hofstein, A., Eds.; Sense Publishers, Rotterdam, The Netherlands, 2013; p 1−36.
(40) Mamlok-Naaman, R.; Mandler, D. Education for Sustainable Development in High School through Inquiry-Type Socio-Scientific Issues. In *Chemistry Education for a Sustainable Society Volume 1: High School, Outreach, & Global Perspectives*; Obare, S., Middlecamp, C., Peterman, K., Eds.; ACS Publications, 2020; Vol. *1*, p 69−78. DOI: 10.1021/bk-2020-1344.ch006.
(41) Chiu, M.-H.; Mamlok-Naman, R.; Apotheker, J. Identifying systems thinking components in the school science curricular standards of four countries. *J. Chem. Educ.* **2019**, *96*, 2814−2824.
(42) Prince, M.; Felder, R. The Many Faces of Inductive Teaching and Learning. *Journal of College Science Teaching* **2007**, *36* (5), 14−20.
(43) Abd-El-Khalick, F.; BouJaoude, S.; Duschl, R.; Lederman, N. G.; Mamlok-Naaman, R.; Hofstein, A.; Niaz, M.; Treagust, D.; Tuan, H. Inquiry in Science Education: International Perspectives. *Sci. Ed.* **2004**, *88* (3), 397−419.
(44) European Commission. *Science Education Now: A Renewed Pedagogy for the Future of Europe*; Office for Official Publications of the European Communities, 2007. https://www.eesc.europa.eu/sites/default/files/resources/docs/rapportrocardfinal.pdf (accessed 2021-03).
(45) Gilbert, J. K.; Newberry, M. The characteristics of the gifted and exceptionally able in science. In *Science Education for Gifted Learners*, 1st ed.; Taber, K. S., Ed.; Routledge, London, U.K., 2007; p 15−31.
(46) Trna, J. IBSE and Gifted Students. *Science Education International* **2014**, *25* (1), 19−28.
(47) Rizzo, K. L.; Taylor, J. C. Effects of Inquiry-Based Instruction on Science Achievement for Students with Disabilities: An Analysis of the Literature. *JSESD* **2016**, *19* (1), 1−16.
(48) Cooper, M. M. Cooperative learning. *J. Chem. Educ.* **1995**, *72* (2), 162−164.
(49) Gräber, W.; Kleuker, U. Entwicklung von Aufgaben für die Kooperation von Schülern, Erläuterungen zu Modul 8 des BLK - Modellversuch zur "Steigerung der Effizienz des mathematisch-naturwissenschaftlichen Unterrichts". 2001. https://fachportal.lernnetz.de/files/Projekte%20und%20Bildungspartner/SINUS-SH/SINUS-Module/Modul-8.pdf.
(50) Lazarowitz, R.; Hertz-Lazarowitz, R. Cooperative learning in the science curriculum. In *International Handbook of Science Education*; Fraser, B. J., Tobin, G., Eds.; Springer, Dordrecht, The Netherlands, 1998.
(51) Boehm, R. F.; Gallavan, N. P. Adapting Cooperative Learning to an Introductory Analysis Class. *J. Eng. Educ.* **2000**, *89* (4), 419−421.
(52) Johnson, D. W.; Johnson, R. T.; Holubec, E. J. In *The new circle of learning: Cooperation in the classroom and school*. ASCD, Alexandria, Virginia, U.S., 1994.
(53) Johnson, D. W.; Johnson, R. T. An Educational Psychology Success Story: Social Interdependence Theory and Cooperative Learning. *Educ. Res.* **2009**, *38* (5), 365−379.
(54) Bolling, A. L. Using group journals to improve writing and comprehension. *Journal on Excellence in College Teaching* **1994**, *5* (1), 47−55.
(55) Bowen, C. W. A Quantitative Literature Review of Cooperative Learning Effects on High School and College Chemistry Achievement. *J. Chem. Educ.* **2000**, *77* (1), 116.
(56) Eilks, I. Experiences and Reflections about Teaching Atomic Structure in a Jigsaw Classroom in Lower Secondary School Chemistry Lessons. *J. Chem. Educ.* **2005**, *82* (2), 313.
(57) Lin, E. Cooperative Learning in the science classroom. *Science Teacher.* **2006**, *73* (5), 35−39.
(58) Gardener, B. S.; Korth, S. D. Using reflection in cooperative learning groups to integrate theory and practice. *Journal on Excellence in Collage Teaching* **1996**, *7* (1), 17−30.
(59) Gillies, R. M. Teachers' and Students' Verbal Behaviours during Cooperative and Small-Group Learning. *British Journal of Educational Psychology.* **2006**, *76* (2), 271−287.
(60) Hennessy, D.; Evans, R. Small-group learning in the community college classroom. *Community College Enterprise* **2006**, *12* (1), 93−110.
(61) Levine, E. Reading your way to scientific literacy. *Journal of College Science Teaching* **2001**, *31* (2), 122−125.
(62) Prichard, J. S.; Bizo, L. A.; Stratford, R. J. The Educational Impact of Team-Skills Training: Preparing Students to Work in Groups. *British Journal of Educational Psychology.* **2006**, *76* (1), 119−140.
(63) Prince, M. Does Active Learning Work? A Review of the Research. *Journal of Engineering Education.* **2004**, *93* (3), 223−231.
(64) Foley, K.; O'Donnell, A. Cooperative learning and visual organisers: Effect on solving mole problems in high school chemistry. *Asian Pacific Journal of Education.* **2002**, *22*, 38−50.
(65) Hänze, M.; Berger, R. Cooperative learning, motivational effects, and student characteristics: An experimental study comparing cooperative learning and direct instruction in 12th grade physics classes. *Learning and Instruction.* **2007**, *17*, 29−41.
(66) Shachar, H.; Fischer, S. Cooperative learning and the achievement of motivation and perceptions of students in 11th grade chemistry classes. *Learning and Instruction.* **2004**, *14*, 69−87.

(67) Jenkins, J.; Antil, L.; Wayne, S.; Vadasy, P. How cooperative learning works for special education and remedial students. *Exceptional Children.* **2003**, *69*, 279−292.
(68) Raviv, A.; Cohen, S.; Aflalo, E. How Should Students Learn in the School Science Laboratory? The Benefits of Cooperative Learning. *Res. Sci. Educ.* **2019**, *49* (2), 331−345.
(69) Aydin, S. Effect of cooperative learning and traditional methods on students' achievements and identifications of laboratory equipments in science-technology laboratory course. *Educational Research and Reviews* **2011**, *6* (9), 636−644.
(70) Perrotta, C.; Featherstone, G.; Aston, H.; Houghton, E. In *Game-based learning: Latest evidence and future directions*; NFER, Slough, U.K., 2013.
(71) Shaffer, D. W.; Squire, K. R.; Halverson, R.; Gee, J. G. Video games and the future of learning. *Phi Delta Kappan* **2005**, *87* (2), 105−111.
(72) Affeldt, F.; Markic, S.; Eilks, I. Students' Use of Graded Learning Aids for Inquiry Learning. *Chem. Action.* **2019**, *114*, 28−33.
(73) Kieferle, S.; Markic, S. Development and Implementation of Innovative Concepts for Language-Sensitive Student Laboratories. *Chem. Educ. Res. Pract.* **2023**, *24*, 740.
(74) Osborne, J.; Simon, S.; Collins, S. Attitudes towards Science: A Review of the Literature and Its Implications. *Int. J. Sci. Educ.* **2003**, *25* (9), 1049−1079.
(75) Black, P.; Harrison, C.; Lee, C.; Marshall, B.; Wiliam, D. Working Inside the Black Box: Assessment for Learning in the Classroom. *Phi Delta Kappan* **2004**, *86* (1), 8−21.
(76) Jolliff, T. In *Chemistry for the Gifted and Talented*; Royal Society Of Chemistry, London, U.K., 2007.
(77) Eilks, I. Kooperatives Lernen im Chemieunterricht (Teil 1). *MNU.* **2003**, *56* (1), 51−54.
(78) Eilks, I. Kooperatives Lernen im Chemieunterricht (Teil 2). *Der Mathematische und Naturwissenschaftliche Unterricht* **2003**, *56* (2), 111−115.
(79) Kieferle, S.; Markic, S. Aktive Teilhabe und Forschendes Lernen ermöglichen − inklusive Lernumgebungen im SchülerInnen-labor der Sekundarstufe I - Enabling active participation and inquiry-based learning − inclusive learning settings for a student laboratory for lower secondary school. *CHEMKON.* **2024**, *31*, 21.

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