European Journal of Science and Mathematics Education, 2022, **10**(3), 338-351
ISSN: 2301-251X (Online)

OPEN ACCESS

Review Article

Science Education as a Human Right: A Systematic Review of the Literature

Patrick Schuck [1]
0000-0001-7303-4584

Markus Sebastian Feser [1*]
0000-0001-8503-0951

[1] Physics Education, Universität Hamburg, Hamburg, GERMANY
[*] Corresponding author: markus.sebastian.feser@uni-hamburg.de

Citation: Schuck, P., & Feser, M. S. (2022). Science Education as a Human Right: A Systematic Review of the Literature. *European Journal of Science and Mathematics Education, 10*(3), 338-14. https://doi.org/10.30935/scimath/11967

ARTICLE INFO

Received: 8 Feb 2022

Accepted: 22 Mar 2022

ABSTRACT

Basing school and university science education on an understanding of science education as a human right has been advocated by numerous authors. Broadly, the right to science education derives from the fundamental rights included in the Universal Declaration of Human Rights, namely the right to education and the right to science. The aim of the present study was to characterize the right to science education in greater detail and specify its conditions and barriers. To meet this aim, we conducted a systematic literature review entailing a bibliographic database search of the Web of Science and ProQuest and an article screening followed by a qualitative content analysis of the included publications. In doing so, we synthesized the findings of eight publications addressing the right to science education in various contexts. In this paper, we present the design and results of our analysis. The implications of our findings for future science education research are outlined at the end of this paper.

Keywords: science education, human rights, right to education, right to science, literature review

INTRODUCTION

Numerous authors have advocated that school and university science education should be based on an understanding of science[1] education as a human right (Porsdam Mann et al., 2020; Starl, 2021; Tajmel, 2019; Wyndham & Virtullo, 2018). For example, Chapman and Wyndham (2013) argued that the internationally recognized set of human rights includes that all humans have a right to science, implying that everyone also has a right to science education. Conversely, Milner (2015) considered that science education should also be considered a human right due to its status as a type of education, as education is a human right. Given that science education is often viewed as competitive, highly demanding, and elitist (e.g., Moravcsik, 1977; Sjøberg & Schreiner, 2005; Willems, 2007), framing science education as a human right could potentially help raise public awareness of the importance of making science education accessible to all students (Fensham & Harlen, 1999; Tajmel, 2017).

Unsurprisingly, the use of the right to science education as an analytic lens for contemporary challenges in school and university science education is a growing field of educational research (Tajmel et al., 2021). Nevertheless, it remains fairly unclear what characterizes the right to science education, what barriers exist

[1] In this paper the term "science" refers to what is considered as natural sciences (e.g., biology, chemistry, earth science, physics, etc.). However, in more general terms, science encompasses not only natural sciences, but also applied, social and formal sciences (Garai Díaz de Lezana, 2017). Therefore, it may be appropriate to extend the right to science education beyond the natural sciences. However, this question cannot be answered by the present literature review, as it solely focuses on publications addressing natural sciences education.

regarding this right, and what conditions must be met in formal and non-formal education to ensure this right. Therefore, to gain a better understanding of the right to science education, we conducted a systematic literature review informed by the following research questions:

1. In what ways does the existing literature characterize the right to science education?
2. What barriers to the right to science education can be identified in the existing literature?
3. What conditions are described in the existing literature that must be met to ensure the right to science education?

Before presenting the methodological approach and results of this study, we will first provide a brief overview of how to conceptualize science education from a human rights perspective.

HUMAN RIGHTS AND SCIENCE EDUCATION

The Right to Education

The Universal Declaration of Human Rights (UDHR) was adopted by the United Nations General Assembly on December 10, 1948, attributing inherent and inalienable fundamental rights to every human being. These fundamental rights include, among others, that "[e]veryone has the right to education[,] [e]ducation shall be free, at least in the elementary and fundamental stages[, and] [e]lementary education shall be compulsory" (United Nations, 1948, Art. 26). To ensure that a person's right to education is met, necessary conditions for the enjoyment of education (e.g., free elementary schools) must be met, the enjoyment of the right to education by one person must not interfere with the enjoyment of that right by others, and the enjoyment of the right to education by one person must not be interfered with by others (Lindahl, 2006). Moreover, since every learning process involves active co-construction by students (Matthews, 1998; Schnotz, 2011), the right to education cannot be ensured if it is understood as a guarantee of acquiring certain knowledge and skills (Hoffman, 1980). Instead, it is only possible to provide opportunities, especially within formal education, that could potentially trigger individual learning processes (Hoffman, 1980; Mandry, 2008). One way of evaluating whether a learning opportunity meets the essential requirements for ensuring the right to education is to use the 4-A scheme proposed by Tomasevški (2001). According to Tomasevški (2001), in order for a learning environment to be equitable—and thus enable enjoyment of the right to education—it must meet the criteria of availability, accessibility, acceptability, and adaptability (for a broader discussion on science education, see Starl, 2021; Stinken-Rösner et al., 2020).

The Right to Science

In addition to the right to education, the UDHR also names the fundamental human right to freely "share in scientific advancement and its benefits" (United Nations, 1948, Art. 27), also referred to as the right to science (Mancisidor, 2015). According to Chapman and Wyndham (2013), the right to science includes four core components:

1. Everyone should have access to the benefits of science and its applications, including scientific knowledge, without discrimination.
2. Everyone should have the opportunity to contribute to scientific enterprise and the freedom to conduct scientific research.
3. Everyone should have opportunities to participate in decision-making regarding science and thus the right to science-related information.
4. To ensure the right to science for everyone, it is essential to establish an environment that fosters scientific maintenance, development, and diffusion.

If science and the scientific community were structured according to these four core components, their resources and efforts could be distributed and used more equitably, potentially leading to a shift away from competitive or economic interests within academia (Garai Díaz de Lezana, 2017). Moreover, the right to science could potentially lead to enhanced societal quality of life, as it aims to promote access to technological achievements and scientific knowledge for all (Garai Díaz de Lezana, 2017; Wyndham & Virtullo, 2018). For example, improved access to scientific knowledge could enable individuals to base their views regarding

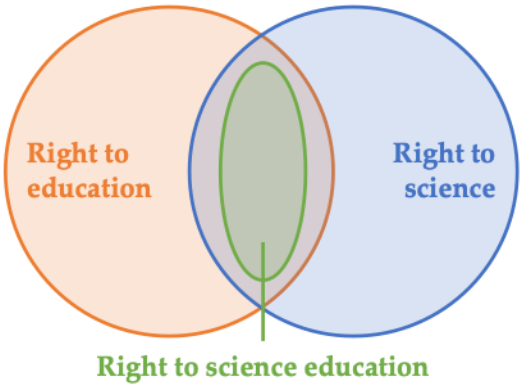


Figure 1. Relationship between the right to science, the right to education, & the right to science education

socio-scientific issues on scientific evidence, thus enabling them to make more informed decisions in everyday life (Garai Díaz de Lezana, 2017; Sadler, 2009). Nevertheless, it is important to note that the right to science may be limited, particularly in its capacity to protect society from the potentially harmful effects of abuses of science and technology (e.g., the use of nuclear physics to develop weapons; Garai Díaz de Lezana, 2017; Porsdam Mann et al., 2020).

The Right to Science Education

Despite the adoption of the right to science in the International Covenant on Economic, Social and Cultural Rights (United Nations, 1967), this right is still referred to as a "sleeping beauty" (Porsdam Mann et al., 2020), as it has been poorly implemented from a global perspective (Wyndham et al., 2017; Wyndham & Vitullo, 2018). To ensure enjoyment of the right to science for all, science education is of special importance (Chapman & Wyndham, 2013; Garai Díaz de Lezana, 2017; Porsdam Mann et al., 2020; Wyndham et al., 2017; Wyndham & Virtullo, 2018). Unsurprisingly, Shaheed (2012) noted a strong interconnection between the right to science and the right to education. This interconnection yields a fundamental right to be educated and informed about science, as illustrated in **Figure 1**. Furthermore, Shaheed (2012) emphasized that this right is not limited to school contexts. The provision of suitable non-school and post-school programs is equally important to ensure the right to science education for all. Therefore, in line with Shaheed (2012), the International Symposium on Human Rights and Equality in STEM Education (2021, p. 23) defined the right to science education, as follows:

> "[The right to science education is] an inherent aspect of the right to education, the rights to information and the right to enjoy the benefits of scientific progress including the right to contribute to scientific progress as enshrined in Art. 26 and 27 UDHR. [...] The right to science education pursues the goals of acquiring knowledge as an end in itself, of participating as a useful member in society and of the development of the full personality of learners."

Furthermore, Tajmel (2019) emphasized a specific focus on issues of diversity related to the right to science education. Given that science is typically perceived as only accessible to gifted people and given the masculine, heteronormative connotation carried by the culture of science (Bazzul & Sykes, 2011; Götschel, 2017), diversity issues (e.g., the underrepresentation of women in science) reflect barriers to the enjoyment of the right to science education. Consequently, in order to raise equitability, science and science education should meet certain conditions (e.g., Tomasevški's, 2001 4-A scheme) and reduce diversity barriers (Stinken-Rösner et al., 2020; Tajmel, 2019).

In summary, the right to science education derives from the fundamental rights included in the UDHR, namely the right to education and the right to science. To ensure this right, it is essential to meet several conditions and reduce barriers within formal science education and beyond. The aim of the present literature review was to characterize the right to science education in greater detail and to specify its conditions and barriers.

Table 1. Overview of the eight publications included in the qualitative content analysis

Publication	Addressed context		
	African context	Urban context	Miscellaneous contexts
Babaci-Wilhite (2017)	x		
Calabrese Barton (2002)		x	
Connor & Valle (2015)			x
Keane (2008)	x		
Leonard et al. (2016)		x	
Lerman (2017)			x
Milner (2015)			x
Tate (2001)		x	

METHODS

In line with our research questions, we conducted a systematic literature review encompassing two major steps of analysis:

1. A bibliographic database search followed by an article screening and
2. A qualitative content analysis of the included publications.

These steps of analysis are detailed in the following subsections.

Bibliographic Database Search and Article Screening

The bibliographic database search and article screening were conducted following the procedures outlined by Boland et al. (2017). After several scoping searches, a suitable search syntax (see **Appendix A** and **Appendix B**) of the Web of Science and all databases covered by ProQuest was used to identify publications on the right to science education. All searches were conducted from July 30 to August 1, 2021, and only publications published in academic journals or anthologies were included in the database search.

In total, 96 publications were yielded by the bibliographic database search (25 from the Web of Science and 71 from ProQuest). To identify publications related to our research questions, an article screening process was conducted with the following inclusion criteria:

- The right to science education is a major topic of the publication.
- The primary objects of the publication are individuals involved in (non-)formal science education.
- The scope of the publication is the right to education, the right to science, or (non-)formal science education.
- The publication is written in English or German.
- The publication is not a duplicate of another publication already included in the present study.

The screening process was conducted by the first author of this study. To ensure the reliability of the article screening, a second and third researcher independently repeated the screening process. The inter-rater agreement coefficient reached κ=0.92 between the first author and the second researcher and κ=0.86 between the first author and the third researcher, indicating very sufficient reliability (Wirtz & Caspar, 2002).

In total, eight publications met all the inclusion criteria of the screening process. All the included publications were published in English and in rigorously peer-reviewed journals. Furthermore, as illustrated in **Table 1**, on the one hand, the majority of these publications (five publications) can be categorized based on whether they address African or urban contexts of science education. Thus, it is reasonable to assume that issues related to the right to science education are particularly salient in African and/or urban science education. On the other hand, the remaining three publications address very specific and individual contexts, namely science education for students with special education needs (Connor & Valle, 2015), the use of project work in the science classroom to make science education more accessible (Lerman, 2017), and science education in the United States (Milner, 2015). Therefore, they were categorized as publications with miscellaneous contexts.

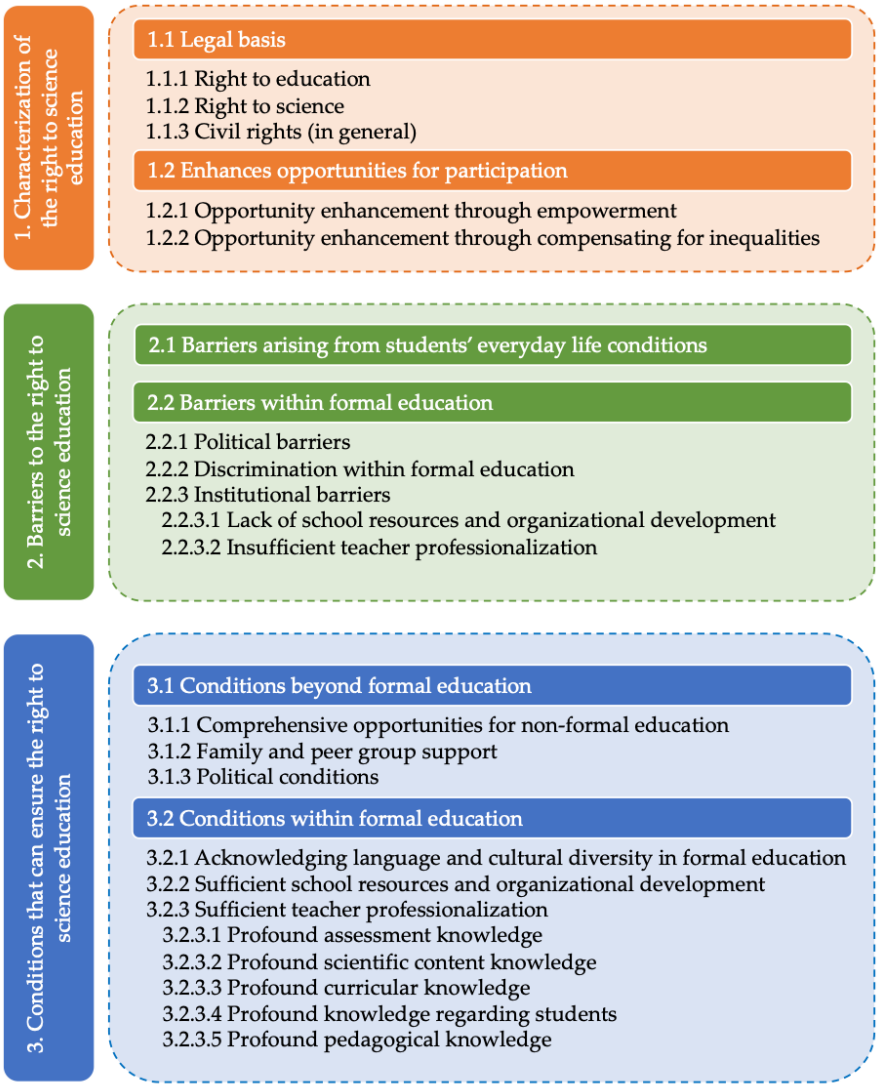


Figure 2. Illustration of the developed coding scheme. (Sub)-categories are numbered according to their hierarchical order

Qualitative Content Analysis

After the bibliographic database search and article screening, the eight publications were analyzed following the procedures of Schreier's (2012) qualitative content analysis. For this analysis, we developed a three-dimensional coding scheme based on our research questions. Furthermore, we used the sub-sumption strategy (Schreier, 2012, p. 88) to inductively generate valid subcategories for each dimension of our coding scheme.

The eight publications were coded in their entirety using the developed coding scheme, and the coding procedure was administered independently by two researchers, achieving excellent inter-coder agreement (κ=0.87) (Wirtz & Caspar, 2002). Finally, the included publications were summarized, compared, and evaluated in depth based on the results of the coding procedure.

RESULTS

The coding scheme illustrated in **Figure 2** emerged from the qualitative content analysis of the included publications. The main categories of this coding scheme were developed deductively based on our research questions, and the subcategories were derived inductively from the analyzed publications. In the following sections, each main category is discussed alongside its subcategories.

Table 2. Characterization of the right to science education within the included publications

1. Characterization of the right to science education	Babaci-Wilhite (2017)	Calabrese Barton (2002)	Connor and Valle (2015)	Keane (2008)	Leonard et al. (2016)	Lerman (2017)	Milner (2015)	Tate (2001)	Σ
1.1. Legal basis									
1.1.1. Right to education	x		x				x		**3**
1.1.2. Right to science		x			x	x			**3**
1.1.3. Civil rights (in general)		x			x			x	**3**
1.2. Enhances opportunities for participation									
1.2.1. Opportunity enhancement through empowerment	x	x			x		x		**4**
1.2.2. Opportunity enhancement through compensating for inequalities		x			x	x	x	x	**5**

Characterization of the Right to Science Education

As shown in **Table 2**, seven of the included publications explicitly addressed the characterization of the right to science education. One way of characterizing the right to science education is to relate it to its legal underpinnings. As expected, the included publications referred to either the right to education (Babaci-Wilhite, 2017; Connor & Valle, 2015; Milner, 2015) or the right to science (Calabrese Barton, 2002; Leonard et al., 2016; Lerman, 2017). Surprisingly, none of the publications referred to both the right to education and the right to science to characterize the right to science education. However, the three publications that addressed urban contexts (Calabrese Barton, 2002; Leonard et al., 2016; Tate, 2001) noted that the right to science education also arises from civil rights. In this regard, the term "civil rights" refers to the national implementation of internationally recognized human rights "which are enforceable by law and can be redressed by civil action [...] and especially [include] the right of personal liberty" (Tate, 2001, p. 1015).

Beyond the legal underpinnings of the right to science education, the included publications also characterized the right to science education by its potential to enhance opportunities for participation in science education and beyond. On one hand, the right to science enhances participation by compensating for inequalities. In particular, this includes accommodation for social disparities rooted in unequal dissemination of scientific knowledge, which disadvantages groups such as women, people of color, and LGBTQ* students (Calabrese Barton, 2002; Leonard et al., 2016; Lerman, 2017; Milner, 2015; Tate, 2001). On the other hand, participation is also enhanced through empowerment. For example, profound science education—and thus the enjoyment of the right to science education—is the first step toward a potential career in the scientific field (Calabrese Barton, 2002), enables a better understanding of natural phenomena within everyday life (Leonard et al., 2016), and enables more informed decisions regarding socio-scientific issues (Milner, 2015).

Barriers to the Right to Science Education

In total, seven of the included publications addressed barriers to the right to science education within and beyond formal education (see **Table 3**). Regarding barriers beyond formal education, five publications referred to students' everyday life conditions. Barriers of this type range from constraining family or peer influence (Leonard et al., 2016; Tate, 2001) to socially reproduced routines and cultural habits that conflict with the idea that everyone has a right to science education (Calabrese Barton, 2002; Keane, 2008). Furthermore, Lerman (2017) noted that many students lack access to science-related activities in everyday life, often because they (or their parents) cannot afford, for example, to visit a museum or science center.

Beyond students' everyday life conditions, the included publications also referred to barriers within formal education (see **Table 3**). For one, political barriers can be found within formal education. In this regard, Babaci-Wilhite (2017) highlighted the challenges of education policy in Africa, specifically that science teachers are not properly supported within the education system and that extracurricular and formal science education programs lack sufficient interconnection. The remaining publications that referred to political barriers dealt

Table 3. Barriers to the right to science education stated within the included publications

2. Barriers to the right to science education	Babaci-Wilhite (2017)	Calabrese Barton (2002)	Connor and Valle (2015)	Keane (2008)	Leonard et al. (2016)	Lerman (2017)	Milner (2015)	Tate (2001)	Σ
2.1. Barriers arising from students' everyday life conditions		x		x	x	x		x	**5**
2.2. Barriers within formal education									
2.2.1. Political barriers	x	x			x			x	**4**
2.2.2. Discrimination within formal education	x	x	x	x	x				**5**
2.2.3. Institutional barriers									
2.2.3.1. Lack of school resources & organizational development	x	x	x					x	**4**
2.2.3.2. Insufficient teacher professionalization	x	x	x	x	x			x	**6**

specifically with urban contexts (Calabrese Barton, 2002; Leonard et al., 2016; Tate, 2001). Therefore, it may be reasonable to assume that political barriers to the right to science education are particularly salient in urban science education. These publications argued that existing educational standards and guidelines in urban contexts primarily focus on reading, writing, and mathematics, placing little to no weight on science education. Moreover, Calabrese Barton (2002) noted that a lack of trust and reciprocal acknowledgement between policy actors and teachers is another potential source of barriers within urban science education. In addition, Tate (2001) emphasized that educational politics must increase the attractiveness of becoming a science teacher to address the shortage of science teachers in urban contexts.

Beyond the scarcity of enabling educational policies, discrimination within formal education constitutes a source of further barriers. In the included publications, two types of discrimination were frequently reported as barriers to the right to science education: (i) discrimination on the basis of students' language and culture and (ii) discrimination against groups that are underrepresented in science. Language and cultural discrimination was addressed by Babaci-Wilhite (2017) and Keane (2008). These authors concluded that the diversity of students' language and cultural backgrounds is insufficiently recognized within science education; this is particularly evident in that students from minority families experience distinctly limited opportunities to access high-quality science education (see Calabrese Barton, 2002; Leonard et al., 2016). This lack of recognition may lead students to grow disinterested in science or feel that they do not belong in the science classroom, thus interfering with their right to science education. Discrimination against groups that are underrepresented in science was addressed in three of the included publications (Calabrese Barton, 2002; Kane, 2008; Conner & Valle, 2015). More specifically, these publications referred to discrimination against women (e.g., stereotyped role images of women in science; Calabrese Barton, 2002), discrimination against students with special education needs or cognitive abilities (Conner & Valle, 2015), and discrimination against people of color (e.g., within "apartheid education [...] Black students were expected to become laborers who would have no need for academic science courses" Kaene, 2008, p. 609).

Finally, barriers to the right to science education also arise from disadvantageous institutional contexts within schools. In addition to a lack of school resources (Babaci-Wilhite, 2017; Calabrese Barton, 2002; Tate, 2001) and organizational development (Connor & Valle, 2015; Tate, 2001), insufficient professionalization of science teachers appears to be a significant issue, as six publications identified this problem as an institutional barrier to the right to science education. One major issue that emerged in the included publications related to teachers' knowledge regarding their students and how they manage this knowledge professionally. For example, Leonard et al. (2016) noted that science teaching that does not meet student needs can lead to a loss of interest in science. Furthermore, Calabrese Barton (2002) stated that some science teachers lack confidence in their students' abilities, which in turn may lead students to underestimate their own scientific abilities. Insufficient science teacher professionalization results from a lack of high-quality teacher education programs. Consequently, many teachers may wish to improve their science teaching but are unable to do so because they lack relevant professional training. For example, in some rural regions of Africa, many science

Table 4. Conditions that can ensure the right to science education stated within the included publications

3. Conditions that can ensure the right to science education	Babaci-Wilhite (2017)	Calabrese Barton (2002)	Connor and Valle (2015)	Keane (2008)	Leonard et al. (2016)	Lerman (2017)	Milner (2015)	Tate (2001)	Σ
3.1. Conditions beyond formal education									
3.1.1. Comprehensive opportunities for non-formal education	x			x	x			x	**4**
3.1.2. Family and peer group support						x			**1**
3.1.3. Political conditions		x						x	**2**
3.2. Conditions within formal education									
3.2.1. Acknowledging language & cultural diversity in formal education	x	x		x	x				**4**
3.2.2. Sufficient school resources & organizational development		x	x	x			x	x	**5**
3.2.3. Sufficient teacher professionalization									
3.2.3.1. Profound assessment knowledge			x		x				**2**
3.2.3.2. Profound scientific content knowledge		x	x		x				**3**
3.2.3.3. Profound curricular knowledge	x	x		x	x			x	**5**
3.2.3.4. Profound knowledge regarding students	x	x	x	x	x	x			**6**
3.2.3.5. Profound pedagogical knowledge	x	x	x		x	x	x		**6**

teachers struggle with a lack of proficiency in their language of instruction (English) and have no access to training in this language; this hinders them from providing high-quality science instruction for their students (Babaci-Wilhite, 2017).

Conditions that can ensure the Right to Science Education

Similar to barriers, the conditions that can ensure the right to science education can be classified as conditions within and beyond formal education. As shown in **Table 4**, seven publications addressed various conditions beyond formal education. Aside from supportive family and peer influence (Lerman, 2017) and enabling (school) policymaking (Calabrese Barton 2002; Tate, 2001), providing comprehensive opportunities for non-formal education appears to be the most prominent of these conditions. Babaci-Wilhite (2017) and Keane (2008) both argued that education should not be viewed as something that only takes place in school but that educational processes in everyday life are often equally as enriching as school-based educational processes. Similarly, Leonard et al. (2016) and Tate (2001) noted that non-formal education can potentially contribute to increased interest and participation in science-related activities. Particularly for students lacking formal science education, non-formal education provides opportunities to experience more autonomy and social inclusion through voluntary self-directed learning, which can also increase scientific literacy. However, it is essential to ensure that non-formal science education is accessible to everyone and not limited to those who already have a profound interest and literacy in science (Tate, 2001).

Conditions within formal education constitute the most important conditions that can ensure the right to science education, as evidenced by the fact that they were stated in all the included publications (see **Table 4**). The first of these conditions is the acknowledgment of language and cultural diversity in the science classroom (Babaci-Wilhite, 2017; Calabrese Barton, 2002; Keane, 2008; Leonard et al., 2016). To this end, Babaci-Wilhite (2017) highlighted the crucial role of language in science education, arguing that science teachers must teach in a language-sensitive manner to make scientific content accessible to all students. Furthermore, Keane (2008) referred to rural contexts in Africa, where the inclusion of indigenous knowledge of local cultures is essential for science education. Without this inclusion, students who grow up in non-westernized cultures but are taught science in a western-oriented way are always at a disadvantage. However, if teachers acknowledge that their students enter school science with individual understandings of nature strongly influenced by their cultural backgrounds, they may also possess the readiness to create learning opportunities that can strongly interconnect student understanding with the science curriculum, thus allowing students to develop a better understanding of nature and the relevance of science to their daily lives (Calabrese Barton, 2002). In line with this idea, Babaci-Wilhite (2017, p. 387) highlighted the following:

> "[Acknowledging language and cultural diversity in the science classroom] corrects a serious problem in much of science teaching in Africa today, in which universal science principles are taught to African students through a foreign language and using nonlocal contextualization and nonlocal examples."

Another condition within formal education that can ensure the right to science education is sufficient school resources and organizational development. In this regard, Calabrese Barton (2002) highlighted the need to equip science classrooms adequately in order to ensure high-quality science education. Additionally, Tate (2001) emphasized the necessity of providing an adequate amount of time for school science instruction. Furthermore, Connor and Valle (2015) advocated for more inclusive school cultures, particularly "to engage science educators to reject deficit notions of dis/ability in favor of understanding it as part of human variation, and consider the personal and professional benefits of this shift" (Connor & Valle, 2015, p. 1104).

Last but not least, the sufficient professionalization of science teachers—especially such that science teachers possess a profound professional knowledge base—is a significant condition to ensure the right to science education in formal education. Notably, only a minority of the included publications named teachers' assessment knowledge (Connor & Valle, 2015; Leonard et al., 2016) and scientific content knowledge (Calabrese Barton, 2002; Connor & Valle, 2015; Leonard et al., 2016) as conditions that can ensure the right to science education. Instead, the majority of the included publications stated that the profound pedagogical knowledge of science teachers (e.g., knowledge regarding classroom management or how to design student-centered instructions) is essential to ensure the right to science education (Babaci-Wilhite 2017; Calabrese Barton, 2002; Connor & Valle, 2015; Leonard et al., 2016; Lerman, 2017; Milner, 2015). Additionally, the majority of the included publications also referred to teachers' curricular knowledge (see **Table 4**). For example, Babaci-Wilhite (2017) and Leonard et al. (2016) stated that if teachers implement the science curriculum in an inquiry-based manner, it is more likely that their science teaching will promote interest in science among all their students and thus lead to a more equitable science classroom. Additionally, Tate (2001) emphasized the role of technology in science education, arguing that the incorporation of core ideas of engineering into science curricula has great potential to improve the accessibility of science instruction. Finally, the majority of the included publications stated that teachers' knowledge regarding their students is a condition that can ensure the right to science education (see **Table 4**). A basic prerequisite for this condition is that science teachers maintain positive expectations of their students' capabilities, regardless of their diverse backgrounds (Connor & Valle, 2015; Leonard et al., 2016). Accordingly, teachers must know how to address student diversity and include diversity as enrichment in the science classroom (Keane, 2008; Lerman, 2017). Furthermore, students' individual conceptions regarding scientific phenomena may deviate from what they learn in school, thus hindering their learning (Niedderer & Schecker, 1992). Therefore, it is essential that science teachers develop profound knowledge of their students' conceptions to develop instructional strategies that will adequately support all students in the science classroom (Babaci-Wilhite, 2017; Calabrese Barton, 2002).

DISCUSSION AND CONCLUSION

The present study revealed that the right to science education can be characterized by various legal underpinnings, including the right to education and the right to science explicitly outlined in the UDHR as well as civil rights (especially the right of personal liberty). In addition, the literature characterizes the right to scientific education in terms of its participation-enhancing effect, which occurs through empowerment and compensating for inequalities. Through effects such as the enhancement of participation through empowerment, it is clear that everyone could benefit from the right to science education. However, this has not yet been accomplished. Several barriers detailed in the literature continue to prevent students from claiming their right to science education. Some of these barriers, such as insufficient family or peer support or financial poverty, arise from students' everyday life conditions. Other barriers can be found in educational systems, including various kinds of discrimination, a lack of school resources, and insufficient teacher professionalization. However, conditions that can ensure the right to science education also exist both within and beyond formal education. In particular, the literature highlights the need for enabling (school) policy and extensive non-formal science education opportunities. Other conditions that can ensure the right to science

education within formal education include true acknowledgement of language and cultural diversity within the science classroom, sufficient school resources and organizational development, and (most significantly) a profound professional knowledge base among science teachers.

A search of the Web of Science and ProQuest databases identified a wide range of high-quality publications focused on the right to science education. However, the findings of this study should be interpreted in the context of three main limitations. First, it is possible that this search may have missed relevant studies due to the specific algorithms and ranking strategies provided by the Web of Science and ProQuest. Second, given that the two search engines used in this study cover only a fraction of the available academic literature, the inclusion of additional literature databases (e.g., Scopus or Google Scholar) may reveal additional publications not covered herein. Finally, additional publications on the right to science education might have been published in languages other than English or German, which were not included in this literature review.

With these limitations in mind, this study provides an initial overview of the existing literature on what characterizes the right to science education, what barriers exist regarding this right, and what conditions must be met to ensure this right in formal and non-formal education. Therefore, this literature review has important implications for future science education research. Above all, conceptualizing science education as a human right contributes a fresh perspective on the question of why it is important to ensure that everyone possesses at least a basic understanding of science. Some of the most frequent arguments made in favor of science education assert that science education benefits science itself, national economies, national power and influence, democratic government, and society as a whole as well as individuals on an intellectual, aesthetic, and moral level (for a more detailed discussion, see Stilgoe et al., 2014; Thomas & Durant, 1987). The right to science education is also based on its benefits (i.e., its potential to enhance opportunities for participation) but not exclusively. Instead, the right to science education is an equal and inalienable right for everyone, as it is a product of the strong interconnection between the right to science and the right to education. Consequently, the question of why the basic understanding of science should be promoted can be answered not only by referring to the benefits of science education but also by claiming that everyone has a right to opportunities that could potentially trigger a fruitful learning progression in science.

As revealed by the present literature review, sufficient teacher professionalization is a condition that can ensure the right to science education within formal education. Future research may explore common challenges faced by science teachers in the establishment of a learning environment that will meet the needs and backgrounds of all students equally. Given that discrimination based on student language and culture emerged as a critical barrier to the right to science education within formal education, the challenges involved in teaching science to culturally and linguistically diverse students should be a major emphasis of future research on teacher professionalization.

Finally, it is important to highlight that science teachers are not the only individuals responsible for ensuring students' right to science education. In particular, the present literature review revealed that sufficient school resources and organizational development are important as well. On the one hand, ensuring both is first and foremost a task which education policy obviously is accountable for. Therefore, it seems legitimate to call for education policy to live up to this accountability, meaning that education policy needs to provide the necessary resources as well as the conditions for effective organizational development in order to ensure the right to science education in formal education. On the other hand, however, it is essential for effective education policy to have clear information on what resources and support are required for this purpose. To generate such information is a task that science education research should fulfil. Consequently, future research in science education should also address the question of what resources and supports are needed by schools to ensure the right to science education for all students.

Author contributions: Shared lead authorship. Both authors were equally involved in the concept, design, data collection, data interpretation, writing, and critical revision of the present study. Both authors approved the final version of this article.

Funding: The research reported in this paper was supported in part by the project ProfaLe of the Universität Hamburg (Germany). ProfaLe is part of the Qualitätsoffensive Lehrerbildung, a joint initiative of the German Federal Government and the Länder, which aims to improve the quality of teacher training. This program is funded by the Federal Ministry of Education and Research (Germany).

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Babaci-Wilhite, Z. (2017). A rights-based approach to science literacy using local languages: Contextualising inquiry-based learning in Africa. *International Review of Education*, *63*(3), 381-401. https://doi.org/10.1007/s11159-017-9644-3

Bazzul, J., & Sykes, H. (2011). The secret identity of a biology textbook: Straight and naturally sexed. *Cultural Studies of Science Education, 6*(2), 265-286. https://doi.org/10.1007/s11422-010-9297-z

Boland, A., Cherry, G., & Dickson, R. (2017). *Doing a systematic review: A student's guide*. SAGE.

Calabrese Barton, A. (2002). Urban science education studies: A commitment to equity, social justice and a sense of place. *Studies in Science Education*, *38*(1), 1-37. https://doi.org/10.1080/03057260208560186

Chapman, A., & Wyndham, J. (2013). A human right to science. *Science*, *340*(6138), 1291-1291. https://doi.org/10.1126/science.1233319

Connor, D. J., & Valle, J. W. (2015). A socio-cultural reframing of science and dis/ability in education: Past problems, current concerns, and future possibilities. *Cultural Studies of Science Education*, *10*(4), 1103-1122. https://doi.org/10.1007/s11422-015-9712-6

Fensham, P. J., & Harlen, W. (1999). School science and public understanding of science. *International Journal of Science Education, 21*(7), 755-763. https://doi.org/10.1080/095006999290417

Garai Díaz de Lezana, M. (2017). *Science for all: Extraterritorial obligations for the realization of the human right to science* [Master's thesis, Maastricht University]. Global Campus Open Knowledge Repository. https://doi.org/20.500.11825/512

Götschel, H. (2017). Drehmomente fallender Pinguine. Queer-dekonstruktive Perspektiven in der Physik [Torques of falling penguins. Queer-deconstructive perspectives in physics]. In N. Balzter, F. C. Klenk, & O. Zitzelsberger (Eds.), *Queering MINT* (pp. 129-151). Verlag Barbara Budrich. https://doi.org/10.2307/j.ctvdf06ds.11

Hoffman, D. C. (1980). Can children have a right to education? In J. Merritt, B. Radebaugh, & W. Miranda (Eds.), *Proceedings of the Annual Conference of the Midwest Philosophy of Education Society 1978* (pp. 100-113). Midwest Philosophy of Education Society.

International Symposium on Human Rights and Equality in STEM Education (2021). Declaration on the human right to science education. In T. Tajmel, K. Starl, & S. Spintig (Eds.), *The human rights-based approach to STEM education* (pp. 23-24). Waxmann.

Keane, M. (2008). Science education and worldview. *Cultural Studies of Science Education*, *3*, 587-621. https://doi.org/10.1007/s11422-007-9086-5

Leonard, J., Chamberlin, S. A., Johnson, J. B., & Verma, G. (2016). Social justice, place, and equitable science education: Broadening urban students' opportunities to learn. *The Urban Review*, *48*(3), 355-379. https://doi.org/10.1007/s11256-016-0358-9

Lerman, Z. M. (2017). Making science education accessible to all. *Aula Abierta* [*Open Classroom*], *46*(2), 13-16. https://doi.org/10.17811/rifie.46.2.2017.13-16

Lindahl, R. (2006). The right to education in a globalized world. *Journal of Studies in International Education*, *10*(1), 5-26. https://doi.org/10.1177/1028315305283308

Mancisidor, M. (2015). Is there such a thing as a human right to science in international law? *ESIL Reflections, 4*(1), 1-6.

Mandry, C. (2008). Vom Wert der Bildung und dem moralischen Recht auf Bildung [On the value of education and the moral right to education]. In H. J. Münk (Ed.), *Wann ist Bildung erecht? [What makes education equitable?]* (pp. 73-89). Bertelsmann.

Matthews, M. (1998). *Constructivism in science education*. Springer Science+Business Media. https://doi.org/10.1007/978-94-011-5032-3

Milner, A. R. (2015). Universal human rights and STEM education: Editorial. *School Science and Mathematics*, *115*(6), 257-259. https://doi.org/10.1111/ssm.12134

Moravcsik, M. J. (1977). Is science elitist? A worldwide view. *Physics Bulletin, 28*(5), 205-205. https://doi.org/10.1088/0031-9112/28/5/011

Niedderer, H., & Schecker, H. (1992). Towards an explicit description of cognitive systems for research in physics learning. In R. Duit, H. Goldberg, & H. Niedderer (Eds.), *Research in physics learning—Theoretical issues and empirical studies* (pp. 74-98). Leibniz-Institut für die Pädagogik der Naturwissenschaften und Mathematik [Leibniz Institute for Science and Mathematics Education].

Porsdam Mann, S., Porsdam, H., & Donders, Y. (2020). "Sleeping beauty": The right to science as a global ethical discourse. *Human Rights Quarterly*, *42*(2), 332-356. https://doi.org/10.1353/hrq.2020.0020

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42. https://doi.org/10.1080/03057260802681839

Schnotz, W. (2011). *Pädagogische Psychologie kompakt [Educational psychology compact]*. Beltz.

Schreier, M. (2012). *Qualitative content analysis in practice*. SAGE.

Shaheed, F. (2012). Report of the special rapporteur in the field of cultural rights, Farida Shaheed: The right to enjoy the benefits of scientific progress and its applications. *United Nations*. https://digitallibrary.un.org/record/730844/files/A_HRC_20_26-EN.pdf

Sjøberg, S., & Schreiner, C. (2005). How do learners in different cultures relate to science and technology? *Asia-Pacific Forum on Science Learning and Teaching, 6*(2), 1-17.

Starl, K. (2021). The human right to science education re-examined. In T. Tajmel, K. Starl, & S. Spintig (Eds.), *The human rights-based approach to STEM education* (pp. 25-40). Waxmann.

Stilgoe, J., Lock, S. J., & Wilsdon, J. (2014). Why should we promote public engagement with science? *Public Understanding of Science*, *23*(1), 4-15. https://doi.org/10.1177/0963662513518154

Stinken-Rösner, L., Rott, L., Hundertmark, S., Baumann, Th., Menthe, J., Hoffmann, Th., Nehring, A., & Abels, S. (2020). Thinking inclusive science education from two perspectives: Inclusive pedagogy and science education. *Research in Subject-Matter Teaching and Learning, 3,* 30-45. https://doi.org/10.23770/rt1831

Tajmel, T. (2017). *Naturwissenschaftliche Bildung in der Migrationsgesellschaft [Science education in migration society]*. Springer. https://doi.org/10.1007/978-3-658-17123-0

Tajmel, T. (2019). Diversity, human rights and physics education: Theoretical perspectives and critical awareness. In M. Pietrocola (Ed.), *Upgrading physics education to meet the needs of society* (pp. 239-252). Springer. https://doi.org/10.1007/978-3-319-96163-7_16

Tajmel, T., Starl, K., & Spintig, S. (2021). Introduction. In T. Tajmel, K. Starl, & S. Spintig (Eds.), *The human rights-based approach to STEM education.* Waxmann. https://doi.org/10.31244/9783830992202

Tate, W. (2001). Science education as a civil right: Urban schools and opportunity-to-learn considerations. *Journal of Research in Science Teaching*, *38*(9), 1015-1028. https://doi.org/10.1002/tea.1045

Thomas, G., & Durant, J. (1987). Why should we promote the public understanding of science? *Scientific Literacy Papers: A Journal of Research in Science, Education and Research, 1*, 1-14.

Tomasevški, K. (2001). *Human rights obligations: Making education available, accessible, acceptable and adaptable*. Novum Grafiska AB.

United Nations. (1948). *Universal declaration of human rights*. https://www.un.org/sites/un2.un.org/files/udhr.pdf

United Nations. (1967). *International covenant on economic, social, and cultural rights*. https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights

Willems, K. (2007). *Schulische Fachkultur und Geschlecht. Physik und Deutsch—Natürliche Gegenpole? [Subject culture and gender within schools. Are physics and German classes like natural opposites?]*. Transcript. https://doi.org/10.1515/9783839406885

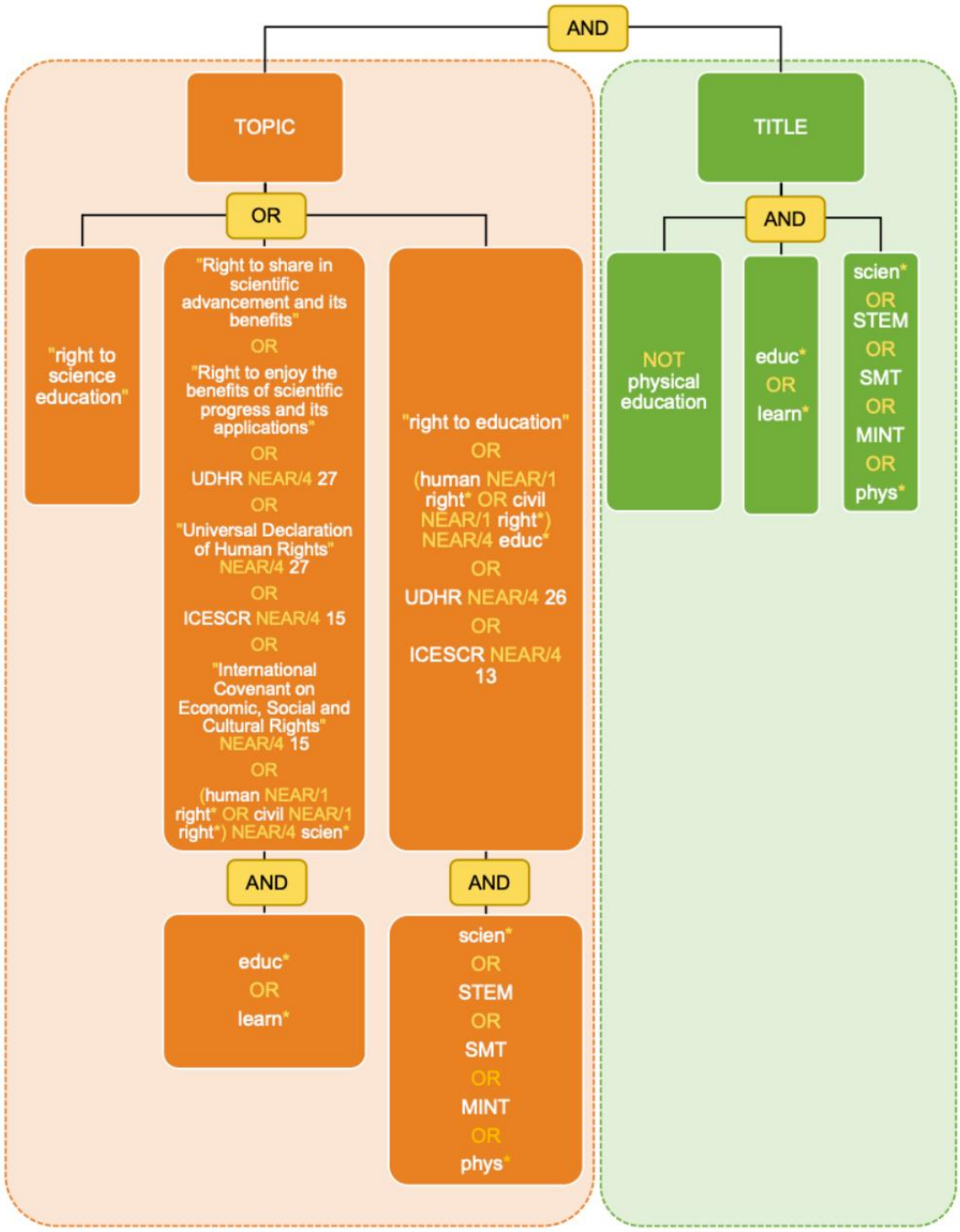
Wirtz, M., & Caspar, F. (2002). *Beurteilerübereinstimmung und Beurteilerreliabilität [Rater agreement and rater reliability]*. Hogrefe.

Wyndham, J. M., & Vitullo, M. W. (2018). Define the human right to science. *Science*, *362*(6418), 975-975. https://doi.org/10.1126/science.aaw1467

Wyndham, J. M., Vitullo, M. W., Kraska, K., Sianko, N., Carbajales, P., Nunez-Eddy, C., & Platts, E. (2017). Giving meaning to the right to science: A global and multidisciplinary approach. *American Association for the Advancement of Science*. https://www.aaas.org/sites/default/files/s3fs-public/reports/Right_to_Science_Report.pdf

APPENDIX A

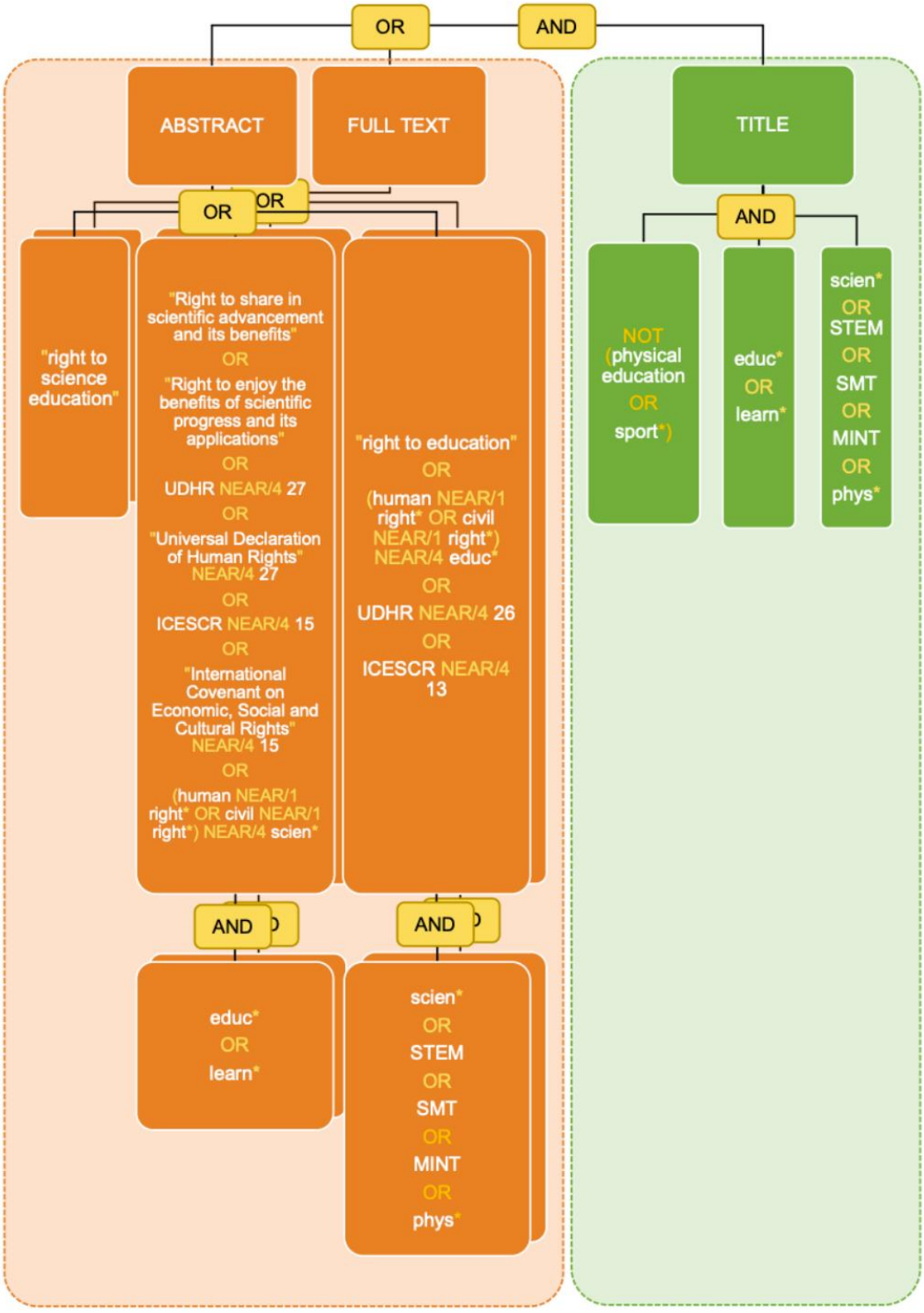
Illustration of the Search Syntax Applied in the Web of Science[2]



[2] Since both authors are physics education researchers, at an early stage of this study we were also interested whether there are publications on science education as a human right specifically within physics education research. Therefore, our search syntaxes also include the search term "phys*".

APPENDIX B

Illustration of the Search Syntax Applied in ProQuest[3]



[3] Since both authors are physics education researchers, at an early stage of this study we were also interested whether there are publications on science education as a human right specifically within physics education research. Therefore, our search syntaxes also include the search term "phys*".