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Review

The Role of Microscopes to Promote Sustainable Development Goals at School: A Literature Review

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Abstract: Microscopes are instruments usually associated with the field of Science Education. Unfortunately, despite their great potential for education, their use at school is not generalised. This implies fewer opportunities for students to understand the microscopic world, thus affecting the quality of their Environmental Education. In the present systematic literature review, proposals for Primary and Secondary (6–18 years) microscopy education are analysed, as well as their relation to the promotion of Sustainable Development Goals (SDGs). It has been carried out in the databases Web of Science and Scopus, followed by a content analysis of 82 journal articles. The main results show that non-formal educational contexts pay more attention to the relation between school microscopy and the SDGs than the formal ones, and, within these, basic education is the least represented in comparison to middle and high levels. Optical microscopes are the most used in relation to SDGs, in contrast to electron microscopes, while new digital, virtual and remote-controlled models are also mentioned. Within the Science and Technology fields associated with SDGs through school microscopy, 'Life Sciences' and 'Technological Sciences' stand out, and these fields are particularly varied in the case of SDG4 (Quality Education) and SDG3 (Good health and well-being). In conclusion, microscopes play a diverse and conspicuous role in promoting SDGs in school contexts at an international level, and their use should be encouraged in Environmental Education formal and non-formal Primary and Secondary Education.

Keywords: science education; environmental education; education for sustainable development; microscopy education; SDG4; primary education; secondary education; microscope; systematic literature review

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1. Introduction

The historical relevance of microscopes and their past and current importance in the scientific development of humanity is well established. Moreover, microscopes have great potential for education purposes. They are mostly associated with Science Education, but they may also be used in other disciplines, such as Arts Education [1–3]. However, despite their great potential for education at schools, their practical use in Primary and Secondary Education is not as widespread as would be expected. Proof of this fact is the constant efforts made by many and diverse institutions in order to establish programmes focusing on donations and the massive provision of microscopes to schools, mostly in the form of low-cost instrumentation [3–5].

Considering education as one of the main applications for microscopes, it is important to remark that education is essential not only as an end in itself but as a catalyst to achieve other objectives [6,7]. As an example, education is highlighted as a fundamental pillar of the promotion and achievement of the Sustainable Development Goals (SDGs from now on) by UNESCO [8]. These 17 goals comprise a broad range of challenges, and they represent an ambitious global plan to eradicate poverty, protect the planet and guarantee prosperity for everyone by 2030 (https://www.unesco.org/en/sdgs (accessed on 5 May 2024)).

Nevertheless, there is some criticism towards the SDGs, including claims that they are overambitious and lacking the effective mechanisms necessary in order to be implemented and monitored [9]. Some also argue that SDGs reinforce a neo-liberal approach to development and that they may be ignoring the structural causes of poverty and inequality [10–12]. The analysis of the SDGs also leads to a warning, as they often conceal trade-offs [13] that may have a negative impact if they are not adequately managed. Some examples of these conflicts are [9–14] the relation between agricultural production (SDG2) and the sustainable use of water (SDG6) and economic growth (SDG8) and environmental protection (SDG15) or the gender equity (SDG5) and cultural traditions (SDG16). Without a doubt, the implementation of the SDGs requires an unprecedented amount of cooperation a compromise among all parties involved in order to significantly transform society [14].

On a positive note, since the UN proclaimed the SDGs in 2015 [15], many international efforts have been made to design and tackle strategies leading to achieving them. In the case of education, there is a specific goal, SDG4, ‘Quality education’, that emphasises the need to ensure a good quality, inclusive and equitable education for everyone, as well as promoting learning opportunities throughout life. Thus, quality education may reduce poverty (SDG1), foster gender equality (SDG5) and promote peace and justice (SDG16). Moreover, education empowers people with the necessary knowledge and skills to actively contribute to communities and may inspire future generations to act in favour of a fairer, more sustainable world [16].

From this point of view, Environmental Education plays a fundamental role in achieving the SDGs, as it creates awareness and calls to action through individual responsibility [17–20]. Among other benefits, this approach may stimulate (i) the use of clean and renewable technologies by reducing the dependence on fossil fuels and the emissions of greenhouse gasses (SDG7); (ii) the increase of climate change awareness, highlighting the importance of reducing the carbon footprint (SDG13); (iii) the protection and restoring of degraded ecosystems and the sustainable use of natural resources (SDG15) and (iv) sustainable consumption patterns and the decrease of waste by teaching the importance of recycling, reusing and reducing waste (SDG12).

In this sense, Environmental and, in general, Scientific Education during Primary and Secondary Education plays a pivotal role in promoting the SDGs [21] and in forming students capable of accepting the challenges of sustainability. Firstly, scientific education fosters critical thinking and enhances problem-solving skills [22,23]. Students learn to issue hypotheses, to gather data through observation and experiments and to evaluate the results. This enables them to make evidence-based decisions to answer environmental questions. Secondly, scientific education involves studying the natural systems and the complex interactions among their components [24,25]. Learning about biogeochemical cycles (such as the water, carbon or nitrogen cycles) and ecosystems allows them to understand the interdependence of organisms and their environment. This is crucial to acknowledge how human actions such as deforestation or pollution may alter those cycles, leading to negative consequences for biodiversity, sustainability and the health of the planet. Thirdly, science projects at school prepare students to contribute to innovative solutions, not only providing them with technical knowledge but also supporting teamwork and creativity, which are essential skills to adapt to a constantly changing environment [26–28].

It has been proven that the use of microscopes in Primary and Secondary Education significantly enhances science teaching [29–34] through practical experiences combining inquiry, argumentation and modelling [35–38]. Moreover, they spark curiosity and a sense of wonder when students are faced with the physical, chemical, biological and geological nature of living or inert beings.

There is a large variety of microscopes [39], so they may be sorted depending on their use in different education levels at school. In lower educational levels, low magnification instruments may be used, such as hand lenses. In middle levels, other instruments with higher magnification may be progressively incorporated, such as stereomicroscopes and compound microscopes, and, in the highest education levels, experiences related to electron microscopes (transmission and scanning electron microscopes) may be included. Other options may be explored in parallel to these, such as DIY, remote-controlled, digital or virtual instruments.

Technological innovations in education, including those affecting microscopes, have had a significant impact on the improvement of the accessibility and effectiveness of scientific education at school. On the one hand, digital technologies, such as online learning platforms and interactive tools, allow broader and democratised access to Science Education [40]. Students from all over the world may access high-quality educational resources independently of their geographical location.

On the other hand, virtual labs and simulators allow students to perform complex experiments that would be difficult or costly to replicate in a traditional classroom [41,42]. Moreover, learning platforms may adapt to the individual needs of students and teachers, providing personalised content and instant feedback, which improves learning and motivation [43]. Nevertheless, it is important to notice that its impact also includes some negative aspects, such as inequality in access to technology, potential distractions and addictions, lack of true innovation [44,45] and a need for continuous formation [46].

The practical use of microscopes provides students with the a chance to experience a direct observation of natural phenomena, which promotes a deeper understanding of scientific context than a merely theoretical approach, in addition to awakening interest and curiosity for Science [31,42,47,48]. For example, analysing pond water samples under the microscope may help raise awareness among the students about the 'Clean water and sanitation' (SDG6) issue, as they will observe the presence of microorganisms that may pollute it and see the need for sanitising processes to produce drinkable water. When observing living cells from animals, plants and other beings, students may also learn about biodiversity and how ecological relationships work, which links with the goals 'Life below water' (SDG14) and 'Life on land' (SDG15). Moreover, when studying the structure and properties of new materials under the microscope, students may improve their understanding of the progress made in 'Industry, Innovation and infrastructure' (SDG9). As a final example, students may analyse samples of recycled products and waste, which in turn may lead to their exploration of sustainable consumption and production practices, linking with 'Responsible consumption and production' (SDG12).

No articles have been found explicitly linking school microscopy to the SDGs, and those references that at least relate school microscopy with Environmental Education are scarce: they focus on ecosystems conservation [49], green chemistry [1], technological innovations [50] and food sustainability [51]. Therefore, research about the practical use of microscopes in school activities, both formal and informal, related to the SDGs is identified as a knowledge gap.

The research question posed in this article is the following: What are the characteristics of the teaching proposals from the literature on microscopy in Primary and Secondary Education, and how do they relate to the promotion of the SDGs?

In order to answer this question, these four specific objectives are proposed:

1. To identify the types of microscopes involved in the activities, experiences, teaching units, etc., presented in journal articles on microscopy in Primary and Secondary Education.
2. To identify the scientific and technical disciplines corresponding with the content topics of the activities, experiences, teaching units, etc., presented in journal articles on microscopy in Primary and Secondary Education.
3. To catalogue those SDGs that are promoted in journal articles on microscopy in Primary and Secondary Education.
4. To relate the SDGs inferred from journal articles on microscopy in Primary and Secondary Education with the educational context (formal, non-formal) and specific level (basic, middle, high school) with the scientific and technical disciplines and with the types of microscopes.

The answer is provided through a systematic revision of the literature, analysing relevant studies on the relation of SDGs with the practice of school microscopy. The information may be useful for future research focusing on deeper aspects of these relationships. Moreover, it may be useful to identify the best practices and strategies to maximise the educational impact and promote SDGs effectively.

2. Materials and Methods

No previous reviews have been found on the same topic during the exhaustive literature review performed for this article. Therefore, this is a pioneering piece of work that, for the first time, links school Microscopy with SDGs. Its importance for the scientific community relies on the critical analysis of the selected publications, something that has not been performed before. Moreover, its interest stems from its focus on discerning which of the analysed articles could provide better evidence of the microscope as a tool to promote SDGs at school.

2.1. Search Strategies

A descriptive, systematic review of the literature is hereby presented, following the reporting guidelines of the PRISMA Statement 2020 [52]. Figure 1 shows the flow diagram of the process.

For the identification phase, the two main databases that are internationally recognised in the field of Education were used: Web of Science (WoS) and Scopus-Elsevier (Scopus).

In order to come up with a search equation including the most appropriate combination of key terms, the combination was divided into three blocks. In the first block, names of instruments for school microscopy were selected (*microscope* OR hand-lens* OR hand lens* OR 'magnifying glass*' OR binocular*). In the second block, the word education and its inflexions were used (*education*). The third block includes words referring to the education level (compulsory OR primary OR elementary OR secondary OR 'high school' OR 'middle school' OR 'basic school' OR 'K-12' OR K12) or to common ways in which referring to the students in non-formal contexts (child* OR kid* OR teenager* OR adolescent*).

This combination of search terms was applied to the title, abstract and keywords.

2.2. Inclusion and Exclusion Criteria

The Sustainable Development Goals (SDGs) published in 2015 by UNESCO stem from the eight Millennium Development Goals (MDGs) through Resolution A/54/2000 (https://www.un.org/en/conferences/environment/newyork2000 (accessed on 25 April 2024)), so that is the starting year used for the present revision. The selected time frame for the search was from January 2000 to April 2024, the last month of searching references for this study. Only publications with the format of journal articles were included.

Regarding the language, all references with the abstract in English, independently of the language of the main text, were considered.

In the screening phase, the use of key terms as metaphors (to avoid colloquial expressions like 'under the microscope') was excluded. Moreover, the scope of the articles was also used as an exclusion criterion: (1) those articles focusing on medical clinical contexts were not considered for this revision; (2) those directly related to educational levels different from Primary or Secondary education (especially those about Higher education) were not included in this review either. Finally, any other studies out of focus according to the purpose of this review were also excluded.

2.3. Review Procedure

The total gross number of records identified from both databases was n = 764 (WoS, n = 399; Scopus, n = 365). The resulting number after removing duplicated records was n = 532. After screening through the title, the abstract and the keywords and applying the abovementioned exclusion criteria, the number of reports decreased gradually to n = 113 and then to a final n = 82 (see Figure 1). All publications were located as PDFs through university library systems.

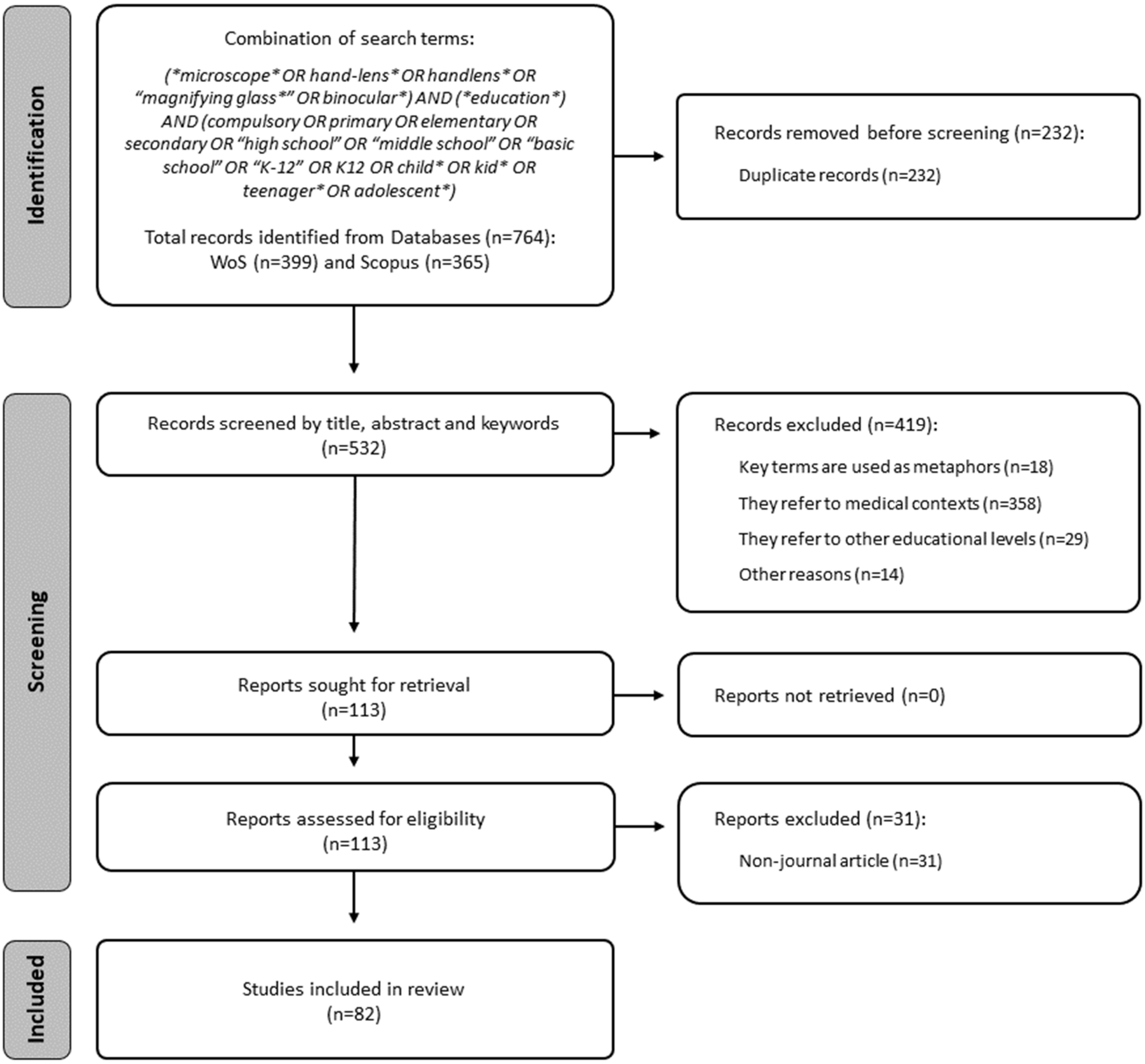

Figure 1. Flow diagram of the search process phases for this systematic literature review, considering the PRISMA 2020 statement [52].

2.4. Analysis Procedure

The 82 journal articles included in this review were analysed by two of the authors according to eight categories that were previously established: (a) Study type: experience or research; (b) Research method: not applicable, quantitative, qualitative or mixed; (c) Educational context: informal, non-formal or formal; (d) Educational level, referred to Primary and Secondary Education: basic, middle or high school; (e) Country; (f) UNESCO code for fields of Science and Technology [53]; and (g) type of microscope. For the last established category (h) related to the analysis of the associated SDGs, the artificial intelligence tools available as part of Web of Science and Scopus were used. All data are shown in Appendix A (Table A1), with authors ordered alphabetically.

Later analyses were carried out through the elaboration of comparative tables, calculation of relative and absolute frequencies and specific text searches with support of the software ©Microsoft Excel v2404, ©Microsoft Access v2410, ©MAXQDA v24.4 and Google Translator (used to translate the Japanese and French articles' main text). These steps have been applied starting from the RIS files of the databases and the PDFs of the complete publications.

3. Results

The results of the present study are structured in six blocks, linking to the specific objectives of the research: (1) General data; (2) Sustainable Development Goals; (3) Microscope type; (4) Fields of Science and Technology; (5) Educational context and level; (6) Interrelation among them. Tables summarising the obtained data are provided to facilitate their interpretation.

3.1. General Data

The general data included within this block are related to the language of publication, country of affiliation of the authors, number of authors, professional category of the authors, study type and research method.

3.1.1. Language of Publication

Given the established inclusion criteria, all the included articles have a title, abstract and keywords in English. The main text is also written in English in all but two articles. One of them is in French [30], and the other is in Japanese [54]. This situation was expected due to the international nature of the selected databases.

3.1.2. Country of Affiliation of the Authors

There are a total of 29 different countries represented in the studied articles. The USA is the most represented country (37 authors), followed by China (6), UK (6), Brazil (5), Israel (5), Turkey (5), France (4), Japan (4), Germany (2), India (2) and Slovenia (2). The less represented countries are Australia (1), Bolivia (1), Chile (1), Cyprus (1), Czech Republic (1), Indonesia (1), Italy (1), Malaysia (1), Mexico (1), Peru (1), Portugal (1), Romania (1), Russia (1), Spain (1), Sweden (1), Taiwan (1), Thailand (1) and the UAE (1).

Of the 82 included articles, most of them are by authors affiliated with institutions from the same country (71 articles), while a minority are collaborations among institutions from two countries (8), three countries (2) or four (1). Only one case has been identified in which the country of affiliation of the authors (USA, Austria, UK) differs from the country where the research was undertaken (Pakistan).

According to 'The World Bank' [55], almost all of the countries affiliated with the selected articles are currently considered 'high income' (17) and 'upper middle income' (10), with only two exceptions, Bolivia and India, which are considered as 'lower middle income' countries. There are no 'low-income' countries represented.

3.1.3. Number of Authors per Publication

The 82 articles analysed have been authored by a total of 354 researchers. The 96.6% authored just one article from the selected ones, with only 12 appearing in more than one: 11 signed two articles, and 1 coauthored three of them.

The number of authors in each article varies widely. There are usually two authors (18 articles), three (15), four (13) or just one (12). It is not infrequent to find articles with from five to twelve authors (22 articles), but it is uncommon to find more than ten authors signing the article (two articles).

3.1.4. Professional Category of Authors

Out of the 82 reviewed articles, 7 are authored by Secondary Education teachers in collaboration with other kinds of researchers [3,26,31,54,56–58], while 2 of them are exclusively authored by Secondary Education teachers [59,60]. The remaining 71 are authored by other kind of researchers. It is worth noticing that nine of them are collaborations between university Education departments and departments from scientific disciplinary fields [32,49,61–67].

3.1.5. Study Type and Research Method

Two general types of studies have been found within the selection: experience (E) or research (R). Experiences add up to 48, while there are 34 research-type studies. From this last type, the most frequent is the mixed-type research method (26 articles), followed by just qualitative (5) and just quantitative (3) research studies.

The variety of methodological approaches could favour a better understanding of the educational phenomenon observed and the development of more effective and scientifically based pedagogical strategies for microscopy education.

3.2. Sustainable Development Goals

The SDGs assigned to each study are shown in Table 1. The following elements have been itemised in the table in relation to each database: (a) presence or absence of the study in the database; (b) assignation or not of SDGs to the study; and (c) identification of the specific SDGs assigned.

The information is shown using different symbols:

1. The symbol ◸ means that the study only appears in Web of Science, and it has no SDGs assigned. Articles with these characteristics: 3.
2. The symbol ◤ means that the study only appears in Web of Science, and it has SDGs assigned. Articles with these characteristics: 6.
3. The symbol ◿ means that the study only appears in Scopus, and it has no SDGs assigned. Articles with these characteristics: 6.
4. The symbol ◢ means that the study only appears in Scopus, and it has SDGs assigned. Articles with these characteristics: 1.
5. The symbol □ means that the study appears in both databases, and it has no SDGs assigned. Articles with these characteristics: 5.
6. The symbol ◩ means that the study appears in both databases, and it has SDGs assigned only in Web of Science. Articles with these characteristics: 48.
7. The symbol ◪ means that the study appears in both databases, and it has SDGs assigned only in Scopus. Articles with these characteristics: 17.
8. The symbol ■ means that the study appears in both databases, and it has SDGs assigned in both of them. Articles with these characteristics: 6.

Therefore, a total of 14 of the reviewed articles do not have any SDGs assigned in these databases. In those that have them, most of the references are assigned to 'Quality Education' SDG4 (36) and 'Good Health and well-being' SDG3 (29). In second place are those assigned to 'Partnerships for the goals' SDG17 (9), 'Industry, innovation and infrastructure' SDG9 (5), 'Climate action' SDG13 (3) and 'Zero hunger' SDG2 (2). A minority of them are assigned to SDG1 (1), SDG6 (1), SDG7 (1), SDG12 (1), SDG14 (1), SDG15 (1) and SDG16 (1). There are no assignments for SDG5, SDG8, SDG10 and SDG11.

However, in order to correctly interpret these data, three circumstances should be mentioned: (a) there is a low percentage (7.3%) of coincidence between the assigned SDGs in both databases. This may be a consequence of the incipient development of the involved AIs; (b) the studies that are not assigned to any SDGs by the AIs could have been assigned to some of them if the assignation were made by a human. As an example, the authors believe that articles [34,68,69] should have been assigned at least SDG4, and (c) there is uncertainty about the ability of AIs to correctly detect all the SDGs, as happens with [70]. This article, which was found randomly during the search, contains the following chain search: 'Oral Health Education Context', but none of the databases have assigned SDG3 to it ('Good Health and well-being').

Table 1. Assignation of SDGs using AI tools of Scopus and Web of Science. Legend: Symbols ◸ and ◤ refer only to Web of Science; symbols ◿ and ◢ refer only to Scopus; symbols ◩ ◪ □ ■ refer to both databases.

	Sustainable Development Goals																	
References	×	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
[68,71,72]	◸																	
[34,43,48,54,73,74]	◿																	
[60,61,69,75,76]	□																	
[77]		◤	◤	◤														
[78]				◤														
[5,47,79,80]					◤													
[66]																		◢
[31,57,81–91]				◩														
[92]				◩			◩											
[26,29,32,33,51,62,63,70,93–104]					◩													
[59]														◩		◩		
[105]					◪													
[106]					◪													◪
[58]								◪										
[56]										◪								
[107]										◪			◪	◪				
[3]																	◪	
[108]																		◪
[109]			◩	◪										◩				
[50,110]				◩	◪													
[111]				◩	◪													◪
[112,113]				◩						◪								
[64,67,114,115]				◩														◪
[65]					◩					◪								
[1]					◪										◩			
[116]					◩													◪
[30,117]				■														
[2,41,42,49]					■													
TOTALS	14	1	2	29	36	0	1	1	0	5	0	0	1	3	1	1	1	9

3.3. Microscope Type

The types of microscopes mentioned in the analysed studies are shown in Table 2. When gathering this information, the specific terms used in each article for the different types were literally transcribed. The intention was to illustrate the variety of names associated with the same instrument, as well as the multiple technological options available within the field of school microscopy.

The results are grouped into three main types: (a) optical microscopes, subdivided into simple and compound; (b) electron microscopes, subdivided into transmission (TEM) and scanning (SEM) electron microscopes; and (c) other microscopes.

Optical microscopes are the most frequently mentioned (in 54 out of 82 articles). Among the optical microscopes, the following are cited: magnifying glasses [2,66,85,92] and simple DIY models, such as the Leeuwenhoek microscope, the Foldscope and the Smartphone Microscope [3,29,64,74,76,93,111,115,116]. Regarding the compound microscopes, the following ones are mentioned: brightfield microscope [2,5,30,31,41,59,61,66,70,72,75,77,80,82,92,94,96,97,99,100,103,106,108,109,112,114,117], phase contrast microscope [61,81,88], fluorescence microscope [56,86] and stereomicroscope [5,49,59,73,91,101]. Moreover, there are references to digital models [43,51,71,77,89,105], virtual reality and augmented reality models [34,47,78,79] and remote-controlled models [26].

Electron microscopes were mentioned more scarcely (in 15 out of 82 articles). These articles alluded to traditional desktop models, as well as remote and virtual versions, pointing out their adaptability and integration in learning environments with an internet connection. The Remote Scanning Electron Microscope [1,50,63,65,68,84,90,104,110] stands out against the Virtual Scanning Electron Microscope [42,62] and the Remote Transmission Electron Microscope [68].

Table 2. Types of microscopes mentioned in the analysed article. The specific terms used in each article for the different types were literally transcribed.

Type	Subtype	Terms	Digital/Remote/Virtual
Optical	Simple	DIY Leeuwenhoek Microscope DIY Simple Microscope Foldscope Loupe Magnifier Magnifying glass Mobile Microscope	Digital Hand Microscope Digital Microscope DIY Smart Microscope Smartphone Endomicroscope Smartphone Fluorescence Microscope Smartphone Microscope Virtual Loupe Virtual Magnifying glass
	Compound	Brightfield Microscope Compound Light Microscope Compound Microscope Fluorescence Microscope Fluorescence Synchronized Video Microscope Light Microscope Microscope Optical Microscope Optical Microscope (double headed) Optical Microscope (inverted) Phase Contrast Microscope Stereo Microscope Stereomicroscope Stereoscopic Dissecting Microscope Stereoscopic Microscope	Augmented Reality Microscope Remote-controlled Optical Microscope Virtual Optical Microscope Virtual Reality Microscope
Electron	Scanning	Scanning Electron Microscope Scanning Electron Microscope (desktop)	Remote SEM Virtual SEM
	Transmission	Transmission Electron Microscope	Remote TEM
Other		Atomic Force Microscope Scanning Probe Microscope Scanning Tunneling Microscope	Remote AFM Remote-controlled AFM

Lastly, other advanced types of microscopes are mentioned in 13 of the reviewed articles, such as the Atomic Force Microscope (AFM), including its remote version [32,33,57,68,83,95], the Scanning Probe Microscope [58,60,69,87] and the Scanning Tunneling Microscope [98]. These instruments highlight the progress towards the incorporation of high-level scientific tools in school environments to improve the learning experience of the students. It may be assumed that these additions would be recent, but references to these instruments are evenly spread out throughout the studied time span (2000–2024).

3.4. Field of Science and Technology

Given the international nature of the analysed studies and the diversity of educational systems involved, it has not been possible to apply a homogeneous method to identify and compare specific curricular contents within them. For this reason, a standardised classification has been used instead, using the four-digit code from the Fields of Science and Technology by UNESCO [53] to associate the different content fields to each article. Only the most prominent detected field has been associated. This offers a general vision with sufficient meaning within the context of the current research. The results are shown in Table 3.

Table 3. Main fields of science and technology [53] identified in the analysed studies.

Two-Digits Code	Number of Studies	Four-Digits Code
22 Physics	9	2203 Electronics (2) 2204 Fluids (1) 2209 Optics (2) 2211 Solid state physics (1) 2214 Units and Constants (2) 2299 Other specialties (1)
23 Chemistry	4	2303 Inorganic chemistry (1) 2306 Organic Chemistry (1) 2399 Other specialties (2)
24 Life Sciences	39	2401 Animal biology (6) 2403 Biochemistry (2) 2407 Cell biology (2) 2410 Human biology (4) 2411 Human physiology (1) 2413 Insect Biology (4) 2414 Microbiology (13) 2417 Plant Biology (4) 2420 Virology (1) 2499 Other specialties (2)
25 Earth and Space Sciences	1	2506 Geology (1)
32 Medical Sciences	4	3212 Public health (4)
33 Technological Sciences	24	3311 Instrumentation Technology (21) 3312 Materials Technology (3)
55 History	1	5506 Specialized histories (1)

The most frequent fields that appear associated with the different articles are 'Life Sciences' (39 articles) and 'Technological Sciences' (24 articles).

Within the 'Life Sciences' field, there are a high number of articles (13) associated with 'Microbiology' [32,59,64,70–72,76,79,81,92,95,106,116]. It is also interesting that there is a larger number of articles related to animals, classified as 'Animal Biology' [2,49,89,94,105,114] and 'Insect Biology' [50,63,65,101] than to plants ('Plant Biology') [29,51,96,109].

In those articles focusing on the UNESCO field of 'Technological Sciences', most of them (21 out of 24) are related to 'Instrumentation Technology' [3,34,43,48,56–58,60,62,69,73,78,83,84,86,87,90,110,112,113,115]. Those articles describe microscopy technological innovations within a wide range of economic costs, applicable to Primary and Secondary Education.

Apart from 'Life Sciences' and 'Technological Sciences', other fields appear in the reviewed studies, such as 'Physics' (9), 'Chemistry' (4), 'Medical Sciences' (4), 'Earth and Space Sciences' (1) and 'History' (1).

In addition, it should be noted that there are seven articles out of the total number that explicitly mention STEM in their title, abstract and/or keywords [2,26,51,66,68,96,113].

Finally, it is worth mentioning that some of the studies additionally include relations with the Arts Education field [1–3].

3.5. Educational Context and Level

Similarly to the previous section, due to the large quantity and heterogeneity of the international educational systems involved in the analysed articles, a simplification in subcategories has been applied for the educational context and level. Thus, the educational contexts are divided into two, formal and non-formal, and the educational levels within formal contexts into three, basic, middle and high.

The results show a predominance of studies that apply school microscopy in formal contexts (54 articles) as opposed to non-formal (18) and that there are some studies in which both contexts are involved (10).

Within formal contexts, the educational level of 'high school' (26) is the most frequent, followed by 'middle school' (9) and 'basic school' (6). In non-formal contexts, there are mentions of outreach activities in science museums [2,5,116], hospitals and clinics [30,81,111,114,117], foundations [77], companies [5,85,90,92,105], organisations [3,5,109,111] and universities [1–3,5,30,47,65,69,74,76,88,92,97,99,100,105,107–109,111,113,114,116].

3.6. Interrelation Among Results

In this section, all previous results are grouped in Table 4 and interrelated to the SDGs. It is important to remember that SDG5, SDG8, SDG10 and SDG11 were not assigned to any of the 82 selected articles.

In relation to the study type, there is a higher number of SDGs associated with articles that are only about experiences (E) than with articles involving research (R). For six of the SDGs (SDG1, SDG2, SDG7, SDG12, SDG14, SDG16), the studies are only type E; for two of them (SDG6, SDG15), only type R studies appear, and there are five SDGs (SDG3, SDG4, SDG9, SDG13, SDG17) for which both E and R types are observed. The low number of R studies may be interpreted as evidence of the incipient state of the relationship between SDGs and school microscopy.

Regarding the educational context, the non-formal context is associated with a larger number of SDGs (11) than the formal one (9). There are four SDGs that only relate to non-formal contexts (SDG1, SDG2, SDG6, SDG12) and two that are only related to formal ones (SDG7, SDG15). The rest of the SDGs appear associated with both contexts (SDG3, SDG4, SDG9, SDG13, SDG14, SDG16, SDG17).

When looking at the educational level within the formal context, the three sublevels (basic, middle and high) share their association with five of the SDGs (SDG3, SDG4, SDG9, SDG14, SDG17). Moreover, the middle and high schools also share SDG16 and are associated with another SDG each (the middle level is associated with SDG15 and the high level with SDG7). Thus, basic school is the educational level associated with the smallest number of SDGs in this analysis (5).

Regarding the types of microscopes (Table 4), they relate to the SDGs as follows: in most cases, optical microscopes (both simple and compound) appear associated to SDGs, specifically to 10 of them (SDG1, SDG2, SDG3, SDG4, SDG6, SDG9, SDG13, SDG15, SDG16, SDG17), while, in the case of electron microscopes, scanning electron microscopes appear associated with six SDGs (SDG3, SDG4, SDG9, SDG12, SDG13, SDG14). Other types of microscopes are related to three SDGs (SDG3, SDG4, SDG7). It is interesting to highlight that SDG3 ('Good health and well-being') and SDG4 ('Quality Education') are associated with all types of microscopes; SDG12 ('Responsible consumption and production') and SDG14 ('Life below water') are only associated with electron microscopes, and SDG7 ('Affordable and clean energy') just relates to other types of microscopes.

Finally, the Science and Technology fields associated with SDGs through school microscopy in the analysed articles are particularly varied in the case of SDG4 ('Quality Education'). This goal is associated with seven different fields: Physics, Chemistry, Life Sciences, Earth and Space Sciences, Medical Sciences, Technological Sciences and History. SDG3 and SDG17 also stand out, as they are associated with four fields: Physics, Life Sciences, Medical Sciences and Technological Sciences. The SGDs associated with two fields are SDG2 (Life Sciences, Medical Sciences), SDG9 and SDG13 (Life Sciences, Technological Sciences). There are seven SDGs that are just associated with one field: SDG1 (Medical Sciences); SDG6 and SDG15 (Life Sciences); SDG7, SDG12 and SDG16 (Technological Sciences); and SDG15 (Chemistry). These correspondences among disciplines, or the lack of them, may indicate the degree of collaboration and synergy that would be potentially involved in the achievement of each of the SDGs through school education using practical microscopy. However, most microscope types may be related to almost every field of science, so no specific pattern of educational relevance has been observed.

Table 4. Interrelation among all the analysed blocks of results. Study type is indicated as E (experience) or R (research).

SDG	Topic	Total Articles	Study Type	Research Method	Educational Context	Educational Level	Field of Science (UNESCO Code)	Microscope Type
SDG1	No poverty	1	E	n/a	Non-formal	-	Medical Sciences (3212)	Optical (simple, compound)
SDG2	Zero hunger	2	E	n/a	Non-formal	-	Life Sciences (2417) Medical Sciences (3212)	Optical (simple, compound)
SDG3	Good health and well-being	28	E, R	Mixed, Qualitative, Quantitative	Non-formal, Formal	Basic, Middle, High	Physics (2211) Life Sciences (2401, 2403, 2410, 2411, 2413, 2414, 2417) Medical Sciences (3212) Technological Sciences (3311)	Optical (simple, compound), Electron (scanning), Other
SDG4	Quality education	36	E, R	Mixed, Qualitative	Non-formal, Formal	Basic, Middle, High	Physics (2203, 2204, 2209, 2214) Chemistry (2306, 2399) Life Sciences (2401, 2403, 2407, 2410, 2413, 2414, 2417, 2499) Earth and Space Sciences (2506) Medical Sciences (3212) Technological Sciences (3311, 3312) History (5506)	Optical (simple, compound), Electron (scanning), Other
SDG5	Gender equality	0	-	n/a	-	-	-	-
SDG6	Clean water and sanitation	1	R	Mixed	Non-formal	-	Life Sciences (2414)	Optical (simple, compound)
SDG7	Affordable and clean energy	1	E	n/a	Formal	High	Technological Sciences (3311)	Other
SDG8	Decent work and economic growth	0	-	n/a	-	-	-	-
SDG9	Industry, innovation and infrastructure	5	E, R	Mixed	Non-formal, Formal	Basic, Middle, High	Life Sciences (2413) Technological Sciences (3311, 3312)	Optical (simple, compound), Electron (scanning)
SDG10	Reduced inequalities	0	-	n/a	-	-	-	-

Table 4. *Cont.*

SDG	Topic	Total Articles	Study Type	Research Method	Educational Context	Educational Level	Field of Science (UNESCO Code)	Microscope Type
SDG11	Sustainable cities and communities	0	-	n/a	-	-	-	-
SDG12	Responsible consumption and production	1	E	n/a	Non-formal	-	Technological Sciences (3312)	Electron (scanning)
SDG13	Climate action	3	E, R	Mixed	Non-formal, Formal	Middle	Life Sciences (2414, 2417) Technological Sciences (3312)	Optical (compound), Electron (scanning)
SDG14	Life below water	1	E	n/a	Non-formal, Formal	Basic, Middle, High	Chemistry (2306)	Electron (scanning)
SDG15	Life on land	1	R	Mixed	Formal	Middle	Life Sciences (2414)	Optical (compound)
SDG16	Peace, justice and strong institutions	1	E	n/a	Non-formal, Formal	Middle, High	Technological Sciences (3311)	Optical (simple)
SDG17	Partnerships for the goals	9	E, R	Mixed, Qualitative	Non-formal, Formal	Basic, Middle, High	Physics (2299) Life Sciences (2401, 2407, 2410, 2414) Medical Sciences (3212) Technological Sciences (3311)	Optical (simple, compound)

4. Discussion

The results of the present study show that formal educational contexts seem to pay insufficient attention to SDGs when working on school microscopy. However, the fact that 34.1% of the analysed references relate school microscopy with non-formal education contexts is considered relevant and positive for the adequate development of microscopy education. This situation is in agreement with other studies [118–120], which highlight the benefits of these synergies between schools and other institutions.

Most of the analysed articles are focused on 'Quality Education' (SDG4) and 'Good Health and well-being' (SDG3). From the perspective of school microscopy, these data may be interpreted as low attention paid during curricular design to include any questions related to sustainability, especially in basic education, as shown in other studies [7,121]. In contrast, it seems that, in non-formal contexts, more attention is paid, and there is more awareness regarding these aspects [122,123].

Life Sciences and Technological Sciences are the most represented fields in the reviewed articles. In contrast, Physics and Chemistry, considered the other two important fields in the curriculum, are noticeably scarcer. This may indicate a lower frequency of application of their contents in relation to school microscopy in real classroom situations, but further and more detailed studies would be required to support this. It is interesting to remark that the references to Animal Biology (including Insect Biology) almost triple the number of articles in comparison to those related to Plant Biology. This zoocentric situation is similar to the findings in other references [124,125] for in Primary and Secondary Education contexts, and it is also evident when analysing textbooks for these educational levels [126,127]. Due to the varied nature of scientific disciplines involved in school microscopy in this analysis, an explicit relation to STEM in most of the analysed articles was to be expected. However, only 8.5% of them show this relation. This is congruent with the results obtained by [128,129] about types of educational materials associated with STEM and the difficulties for teachers to implement them in the classroom. Moreover, similarly to the results of [129], most of the references are associated with the high school level.

Regarding the educational levels, the obtained results may be interpreted as a lower frequency of practical use of school microscopy in basic education in comparison with the other levels. However, it is worth noticing that, in general terms, published educational research on the basic education level rarely reaches the journals included in the used databases [130]. As has been indicated in the exclusion criteria, no publications on 'Higher Education' have been selected nor reviewed in this study, as this educational level is not included in the research question. However, it is relevant to mention that 19.5% of the analysed articles include this educational level as part of their target sample, which may have implications regarding the content level of the teaching proposals and the adaptation of the learning objectives. This is a common occurrence in other studies, such as [131–133].

The broad diversity of microscopy instruments shown in the analysed articles reflects the continuous innovation and increasing accessibility of sophisticated tools in educational contexts [134], thus supporting a more technologically appealing scientific education [135]. The fact that optical microscopes (simple or compound) are related to a larger number of SDGs than electron microscopes may suggest that the accessibility and versatility of optical microscopes allow for greater flexibility in the design of school activities, as this type of microscope is easier to adapt for different purposes than electron or other types of microscopes [39].

One of the analysed articles [73] deals with a novel aspect in relation to school microscopy: ergonomy. School microscope design is not optimised for the size and height of children. They often force their posture, especially due to the height of the eyepieces and the resulting angle for the upper arm and elbow. However, in other fields, such as medicine, the need to adapt these characteristics of the instrument to the user is taken into account in professional medical instruments [136,137] to avoid postural fatigue and to facilitate their use.

Finally, it is important to highlight two aspects of the authorship of the reviewed articles. Firstly, the fact that most authors only appear in one of the articles and their distribution in the different studies may be interpreted as a lack of stable research groups dedicated to the specific topic of school microscopy. The existence of such groups may be a good indicator of the maturity of this research field [138]. Secondly, the low presence of school teachers among the authors may be interpreted as the scarceness of collaborations in the studies of school microscopy between universities and schools, mainly Primary Education centres, but also Secondary Education. This situation does not help in closing the existing gap between educational research and classroom practice [139].

5. Conclusions, Limitations and Implications

After the abovementioned analysis of the results, it may be concluded that microscopes play a prominent and varied role as potential promoters of SDGs in school contexts, both in Primary and Secondary Education, at an international level. Their presence is profusely associated with Quality Education (SDG4).

The large number of scientific disciplines to which these instruments are associated reflects their potential to be included in a wide range of subjects in formal contexts.

Moreover, traditional optical microscope models from the end of the 20th century (both simple and compound) and electron microscope models (transmission and scanning ones) have evolved technologically and may coexist in the classroom with other types: digital, augmented reality, virtual or remote-controlled models. In this sense, internet availability is a critical issue for limited-resource schools to potentially access them.

The relationship of school microscopy with the goal of 'Good health and well-being' (SDG3) is outstanding. This is probably inherited from the historical importance of microscopes in the discovery of pathogenic organisms and the resulting improvement of hygienic conditions in modern societies. Visualising these pathogens under the microscope in educational contexts may trigger a behavioural change in the population that will positively impact their health.

Secondarily, it is also remarkable the number of studies that describe experiences of building innovative microscopes for their use at schools, clearly relating to SDG9 ('Industry, innovation and infrastructure'). It is gathered from these examples that it is possible to enhance engineering skills at the school level by performing activities related to building homemade microscopes.

School microscopy practice benefits from many initiatives within non-formal contexts, particularly in the form of outreach programmes offered by science museums, hospitals and clinics, foundations, companies, organisations and universities that often have access to some economic support for these purposes. It is clear that the connection between schools and other institutions is worth being nurtured, following SDG17 'Partnerships for the goals'.

Occasional relations have been found in the analysed articles between school microscopy and the goals 'No poverty' (SDG1), 'Zero hunger' (SDG2) and 'Peace, justice and strong institutions' (SDG16). This may indicate a potential for these activities to develop an ethical consciousness and to offer opportunities for reflection on social justice that is currently overlooked in the science classroom. This reinforces the importance of school microscopy as a complementary resource for the integral education of a person.

Relations with 'Climate action' (SDG13), 'Clean water and sanitation' (SDG6), 'Affordable and clean energy' (SDG7) and 'Responsible consumption and production' (SDG12) have also been occasionally identified. These could thus be relevant areas to investigate further on the role of school microscopy as a promoter of the SDGs. As an example, SDG6 could be especially useful to approach from the point of view of microorganisms as indicators of water quality. On the other hand, SDG12 could be tackled through the study of microplastics.

Finally, no articles have been assigned to 'Gender equality' (SDG5), 'Decent work and economic growth' (SDG8), 'Reduced inequalities' (SDG10) or 'Sustainable cities and communities' (SDG11). These are, therefore, identified as topics in which research related to school microscopy may provide new insights.

In this systematic literature review, the first limitation encountered is the fact that not all the experiences that may be relevant to answer the research question are published in peer-reviewed journals included in the used international databases. Although it is true that these databases guarantee a greater international spreading of the research, there may be cases in which the published information is more relevant locally. In addition, it is well known that successful experiences with positive results are the ones most frequently published [140], so the existence of unsuccessful cases may not be discarded.

Another limitation identified in this review is the probable inaccuracy of the AIs of the used databases (Web of Science and Scopus) involved in the assignation of SDGs. Several studies [141,142] point out the immaturity of these tools, although their rapid evolution is foreseeable. Apart from the comments on this regard in Section 3.2, it is striking that, for example, 'Life on water' (SDG14) and 'Life on land' (SDG15) goals do not appear more often in the reviewed articles, while the field Life Sciences is widely represented in the manual identification made by the authors.

The results and conclusions of the present study clearly reveal some future research lines for educational researchers: (1) in relation to the SDGs, there is a need for specific qualitative studies assigning SDGs to publications carried out by humans, as long as there are no better AIs to refine the assignation process; (2) regarding curricular contents, there is an evident lack of structure and specificity in their assignation to the established educational levels (basic, middle and high), so another line of research could focus on the sequencing of contents and the selection of samples when designing and implementing school microscopy activities; (3) with regards to the design and development of pre- and in-service teacher training programmes, it is necessary to investigate the reality of each country in order to propose strategies to promote school microscopy adapted to existing circumstances.

In summary, the use of practical microscopy in schools not only contributes to adequate scientific training but is also relevant in many other fields to achieve quality education. Its implementation is not free of challenges and difficulties that need to be studied in further detail.

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Appendix A

Table A1. Itemisation of categories established to analyse the selected articles. Study type is indicated as E (experience) or R (research).

Authors	Study Type	Research Method	Educational Context	Educational Level	Country	Field of Science (UNESCO Code)	Microscope Type/s Involved	SDG
Abdusselam & Kilis [47]	R	Mixed	Non-formal, Formal	Middle	Turkey	2407 Cell biology	*Augmented Reality Microscope*	4
Abdusselam et al. [79]	E	n/a	Formal	Middle	Turkey	2414 Microbiology	*Augmented Reality Microscope*	4
Abu-Much et al. [75]	E	n/a	Formal	High	Israel	2303 Inorganic chemistry	*Optical Microscope*	-
Acharya et al. [81]	R	Quantitative	Non-formal	-	India	2414 Microbiology	*Phase Contrast Microscope*	3
Akashi et al. [61]	E	n/a	Formal	High	Japan	2420 Virology	*Light Microscope, Phase Contrast Microscope*	-
Almendro Vedia et al. [82]	E	n/a	Formal	High	Spain, France	2403 Biochemistry	*(Inverted) Optical Microscope*	3
Angelini et al. [49]	R	Mixed	Formal	Middle	Brazil	2401 Animal biology	*Stereoscopic Microscope*	4
Ara et al. [48]	E	n/a	Non-formal, Formal	Basic, Middle, High	France, USA, UK	3311 Instrumentation Technology	*Scanning Electron Microscope*	-
Araújo-Jorge et al. [108]	E	n/a	Non-formal, Formal	High	Brazil	2407 Cell biology	*Light Microscope (SEM and TEM images)*	17
Baudin et al. [26]	R	Mixed	Formal	High	USA, Bolivia	2403 Biochemistry	*Remote-controlled Optical Microscope*	4
Beam et al. [114]	R	Mixed	Non-formal	-	USA, Peru	2401 Animal biology	*Light Microscope*	3, 17
Bennett et al. [92]	R	Mixed	Non-formal	-	USA, Austria, UK (Pakistan)	2414 Microbiology	*Magnifying glass and Microscope*	3, 6
Bergmann et al. [83]	E	n/a	Formal	High	Germany, USA	3311 Instrumentation Technology	*Atomic Force Microscope*	3
Bitencourt Wommer et al. [93]	E	n/a	Formal	Middle	Brazil	5506 Specialized histories	*DIY Leeuwenhoek Microscope*	4
Blasi & Alfonso [62]	R	Mixed	Formal	High	USA	3311 Instrumentation Technology	*Virtual Scanning Electron Microscope*	4
Blatti [1]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	2306 Organic Chemistry	*Remote Scanning Electron Microscope*	4, 14

Table A1. *Cont.*

Authors	Study Type	Research Method	Educational Context	Educational Level	Country	Field of Science (UNESCO Code)	Microscope Type/s Involved	SDG
Branning et al. [56]	E	n/a	Formal	High	USA	3311 Instrumentation Technology	*Fluorescence Microscope*	9
Bull et al. [43]	E	n/a	Formal	Basic, Middle	USA	3311 Instrumentation Technology	*Digital Microscope*	-
Chen et al. [73]	R	Qualitative	Formal	Basic	China, Japan	3311 Instrumentation Technology	*Optical Microscope, Stereoscopic Microscope*	-
Childers & Jones [63]	R	Mixed	Formal	High	USA	2413 Insect Biology	*Remote Scanning Electron Microscope*	4
Chou & Wang [29]	R	Qualitative	Formal	Basic	Taiwan	2417 Plant Biology	*Mobile Microscope*	4
Chumbley & Chumbley [84]	R	Mixed	Formal	Basic, Middle, High	USA	3311 Instrumentation Technology	*Remote Scanning Electron Microscope*	3
Chumbley et al. [110]	E	n/a	Formal	Basic, Middle, High	USA	3311 Instrumentation Technology	*Remote Scanning Electron Microscope*	3, 4
Cohen [59]	R	Mixed	Formal	Middle	USA	2414 Microbiology	*Stereoscopic Dissecting Microscope, Compound Light Microscope*	13, 15
Corradini et al. [30]	E	n/a	Non-formal	-	France	2410 Human biology	*Optical Microscope*	3
Crawford [74]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	2209 Optics	*DIY Simple Microscope*	-
Deakin [85]	R	Quantitative	Non-formal	-	UK	3212 Public health	*Magnifying glass*	3
Deccache-Maia et al. [77]	E	n/a	Non-formal	-	Brazil	3212 Public health	*Optical Microscope, Digital Hand Microscope*	1, 2, 3
Delgado et al. [41]	R	Mixed	Formal	Middle, High	USA	2214 Units and Constants	*Optical Microscope*	4
Dinescu et al. [42]	E	n/a	Formal	High	Romania	2203 Electronics	*Virtual Scanning Electron Microscope*	4
Eggleston et al. [31]	E	n/a	Formal	High	USA	2411 Human physiology	*Optical Microscope*	3
Fintschenko [86]	E	n/a	Formal	High	USA	3311 Instrumentation Technology	*Inverted Fluorescence Synchronized Video Microscope*	3
Flores & Marzullo [64]	E	n/a	Formal	High	Chile	2414 Microbiology	*DIY Leeuwenhoek Microscope*	3, 17

Table A1. *Cont.*

Authors	Study Type	Research Method	Educational Context	Educational Level	Country	Field of Science (UNESCO Code)	Microscope Type/s Involved	SDG
Gabdulinova & Kovrova [71]	R	Mixed	Formal	Basic, Middle	Russia	2414 Microbiology	*Digital Microscope*	-
Gardner at al. [76]	R	Mixed	Non-formal	-	USA	2414 Microbiology	*Foldscope*	-
Gerber et al. [112]	R	Mixed	Formal	Middle	USA	3311 Instrumentation Technology	*Optical Microscope*	3, 9
Goss et al. [57]	E	n/a	Formal	Basic, Middle, High	USA	3311 Instrumentation Technology	*Analog Atomic Force Microscope*	3
Hajkova et al. [87]	E	n/a	Formal	High	Czech Republic	3311 Instrumentation Technology	*Scanning Probe Microscope*	3
Hoover & Pelaez [94]	R	Mixed	Formal	High	USA	2401 Animal biology	*Optical Microscope*	4
Jones et al. [32]	R	Mixed	Formal	High	USA	2414 Microbiology	*Remote-controlled Atomic Force Microscope*	4
Jones et al. [95]	R	Mixed	Formal	Middle, High	USA	2414 Microbiology	*Remote-controlled Atomic Force Microscope*	4
Kaur et al. [111]	R	Mixed	Non-formal	-	India	3212 Public health	*Foldscope*	3, 4, 17
Koca et al. [88]	R	Quantitative	Non-formal	-	Turkey	3212 Public health	*Phase Contrast Microscope*	3
Koehler et al. [96]	E	n/a	Formal	High	USA	2417 Plant Biology	*Brightfield Microscope*	4
Korb & Thakkar [65]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	2413 Insect Biology	*Remote Scanning Electron Microscope*	4, 9
Lindsay [2]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	2401 Animal biology	*Loupes, Stereomicroscopes, Compound Microscopes (Virtual Photomicrograpies images)*	4
López Clinton [116]	E	n/a	Non-Formal	-	Sweden, Mexico	2414 Microbiology	*Foldscope*	4, 17
Loynachan [72]	E	n/a	Formal	High	USA	2414 Microbiology	*Optical Microscope*	-
Lupi & Seno [97]	R	Mixed	Non-Formal	-	Italy	2506 Geology	*Optical Microscope*	4
Mafra et al. [70]	E	n/a	Formal	Basic	Portugal	2414 Microbiology	*Optical Microscope*	4
Margel et al. [98]	R	Mixed	Formal	High	Israel	2399 Chemistry, other specialties	*Scanning Tunneling Microscope*	4
Marquez et al. [58]	E	n/a	Formal	High	USA	3311 Instrumentation Technology	*Scanning Probe Microscope*	7

Table A1. *Cont.*

Authors	Study Type	Research Method	Educational Context	Educational Level	Country	Field of Science (UNESCO Code)	Microscope Type/s Involved	SDG
Min et al. [68]	E	n/a	Formal	High	USA	2399 Chemistry, other specialties	*Remote Scanning Electron Microscope, Remote Atomic Force Microscope, Remote Transmission Electron Microscope*	-
Morgan [117]	R	Mixed	Non-formal	-	UK	2410 Human biology	*(Double headed) Optical Microscope*	3
Morin [60]	E	n/a	Formal	High	USA	3311 Instrumentation Technology	*Scanning Probe Microscope*	-
Ortug et al. [99]	E	n/a	Non-formal	-	Turkey	2410 Human biology	*Optical Microscope*	4
Parno et al. [66]	R	Mixed	Formal	High	Indonesia, Malaysia	2299 Physics, other specialties	*Magnifier, Optical Microscope*	17
Pires de Souza et al. [106]	E	n/a	Formal	Basic, Middle, High	Brazil	2414 Microbiology	*Optical Microscope*	4, 17
Potter et al. [50]	E	n/a	Formal	Basic, Middle, High	USA	2413 Insect Biology	*Remote Scanning Electron Microscope*	3, 4
Price et al. [100]	E	n/a	Non-formal	-	USA	2214 Units and Constants	*Light Microscope, (Desktop) Scanning Electron Microscope*	4
Quardokus et al. [69]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	3311 Instrumentation Technology	*Scanning Probe Microscope*	-
Raghs [107]	E	n/a	Non-formal	-	Turkey	3312 Materials Technology	*Scanning Electron Microscope (images)*	9, 12, 13
Sammet & Dreesmann [101]	R	Mixed	Formal	Middle, High	Germany	2413 Insect Biology	*Stereo Microscope*	4
Sarayuthpitak et al. [67]	R	Mixed	Formal	Basic	Thailand, USA	2410 Human biology	*Smartphone Endomicroscope*	3, 17
Schaefer et al. [113]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	3311 Instrumentation Technology	*Smartphone Fluorescence Microscope*	3, 9

Table A1. *Cont.*

Authors	Study Type	Research Method	Educational Context	Educational Level	Country	Field of Science (UNESCO Code)	Microscope Type/s Involved	SDG
Shams et al. [105]	E	n/a	Non-formal, Formal	Basic, Middle, High	USA	2401 Animal biology	*Digital Microscope*	4
Škorjanc & Belušič [89]	E	n/a	Formal	High	Slovenia	2401 Animal biology	*Digital Microscope*	3
Strgulc Krajsek & Vilhar [80]	E	n/a	Formal	High	Slovenia	2204 Fluids	*Light Microscope*	4
Suffert & Suffert [109]	E	n/a	Non-formal	-	France	2417 Plant Biology	*Optical Microscope*	2, 3, 13
Tanaka et al. [90]	E	n/a	Non-formal	-	Japan	3311 Instrumentation Technology	*Remote Scanning Electron Microscope*	3
Turner et al. [51]	R	Mixed	Formal	Basic	Australia	2417 Plant Biology	*Digital Microscope*	4
Valanides & Angeli [102]	E	n/a	Formal	Basic	Cyprus	2209 Optics	*Virtual Magnifying glass*	4
Vicente [5]	E	n/a	Non-formal	-	UK	2499 Life Sciences, other specialties	*Stereomicroscope, Compound Microscope, Digital Microscope*	4
Wang et al. [115]	R	Qualitative	Formal	Middle, High	China	3311 Instrumentation Technology	*DIY Smart Microscope*	3, 17
Whelan et al. [91]	E	n/a	Formal	High	UAE, China, USA, Israel	2211 Solid state physics	*Stereomicroscope*	3
Wicks et al. [3]	E	n/a	Non-formal, Formal	Middle, High	UK	3311 Instrumentation Technology	*Smartphone Microscope*	16
Yang & Zhou [103]	R	Qualitative	Formal	Middle	China	2499 Life Sciences, other specialties	*Optical Microscope*	4
Yasuda et al. [54]	E	n/a	Formal	High	Japan	2203 Electronics	*Scanning Electron Microscope*	-
Yonai & Blonder [33]	R	Qualitative	Formal	Middle	Israel	3312 Materials Technology	*Atomic Force Microscope*	4
Yonai & Blonder [104]	R	Mixed	Formal	Middle	Israel	3312 Materials Technology	*Remote Scanning Electron Microscope*	4
Zhang et al. [78]	R	Mixed	Formal	Middle	China	3311 Instrumentation Technology	*Virtual Optical Microscope*	3
Zhou et al. [34]	E	n/a	Formal	Basic, Middle, High	China	3311 Instrumentation Technology	*Virtual Reality Microscope, Augmented Reality Microscope*	-

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