Teacher Education and Curriculum Studies
2025, Vol. 10, No. 2, pp. 69-76
https://doi.org/10.11648/j.tecs.20251002.14

Research Article

Co-construction of Resources Integrating Health Education in Teacher Training in Mali: The Case of the Chemical Aspects of Water

Sidi Mohamed Tounkara[1, *], **Mohamed Soudani**[2]

[1]Physics and chemistry Department, Ecole Normale Supérieure de Bamako, Bamako, Mali
[2]S2HEP UR 4148, Universite Claude Bernard, Lyon, France

Abstract

The Co-construction of resources integrating health education (HE) in teacher training in Mali, concerning chemistry aspects of natural water resources, is the objective of this work. Generally, biomedical aspects predominate in health education. However, heavy metals elimination and organoleptic characteristics of drinking water will be given priority. The results of our survey of 80 primary school teachers and master's trainees, an analysis of iron(II) ions in water samples from 30 wells and a discussion of 40 preparation sheets for trainees on natural water, showed respectively: the predominance of hygiene and microbiological aspects (89.4%) against chemicals aspects (17.5%); the problem-situations (PS) texts appeared either as an introduction or as an evaluation question; and 80% of the well water samples had iron levels in excess of the standard value of 0.3mg/L, giving an objectionable reddish-brown colour to the water. As drinking water treatment is part of the teacher training institute "IFM" programme (limited to turbidity treatment and chlorination), we co-constructed PS in line with current curricula and official recommendations on competency-based approach (CBA). We used innovative pedagogical model combining Peirce's semiotics as an intermediary between the organoleptic characteristic's representations of water and Johnstone's triplet, for the conceptualization of chemistry as a curriculum requirement. Due to the proliferation of boreholes in Mali and in Sub-Saharan Africa countries, participants agree that chemical aspects of drinking water must be prioritized in health education and they are confidents to contextualize chemistry with real problems for a better adequation between official curriculum and real curriculum.

Keywords

Health Education, Resources, Training, Teachers, Chemistry

1. Introduction

The prevention of diseases and traffic accidents, the various addictions of young people (including exciting and new technologies), and the hygiene of the human body, food and homes are themes in health education, as are a healthy mind in a healthy body and ultraviolet radiation and sun protection measures [1-4]. These issues are transversal and involve multiple disciplines in school curricula in which health education is not a covered subject. In these disciplines, biology makes a significant contribution, as do civic and moral education [5-7]. However, chemistry is rarely included even

*Corresponding author: siditounka@gmail.com (Sidi Mohamed Tounkara)

Received: 8 May 2025; **Accepted:** 22 May 2025; **Published:** 20 June 2025

though it is used by health specialists for analysis, research and treatment. Indeed, many authors note that teachers still have a biomedical conception of health (i.e., biological and medical aspects of diseases and their prevention) [8, 9].

As a result, chemical aspects are virtually absent from the examples of health education modelling cited by many authors, which are generally related to behavioural change [10, 11]. The expected results may not be achieved by these approaches when chemical aspects, particularly those related to drinking water, are not taken into account in health education.

The quality of drinking water becomes a public health problem when large-scale infections caused by waterborne diseases, such as diarrhoeal diseases, occur [12]. In chemistry, the issue of health education appears specifically in laboratory work [13]. Chemistry also contributes to the identification and resolution of many public health problems, such as those related to drinking water quality [14]. Water and natural water resources are major themes in health education. In fact, water is essential to life, but it is also a vector for diseases and toxic substances (e.g., arsenic) or substances that cause intoxication with excessive exposure (e.g., fluoride).

Health education is not part of the chemistry syllabus at the general secondary level in Mali. The study of water, from the primary to the general secondary level, can be an ideal place to address public health issues. However, this requires teacher training and the development of resources such as those provided for teachers at teacher training institute "IFM", where natural water and drinking water treatment are included in the curriculum. This is the aim of this work, in line with current curricula and official recommendations on competency-based approach (CBA).

2. Issues and Theoretical Framework

2.1. Co-construction of HE Resources in General Secondary Education

Authors defined health as a state of complete physical, social and mental well-being that enables people to lead individually, socially and economically productive lives [15]. Health education contributes to well-being by preventing water-borne diseases, including those linked to the chemical aspects of water quality. However, there are several obstacles to health education, including a lack of teaching resources or learning, teaching and research materials in all formats and types of media [16, 17]. The advantage of resources for teachers is that they fit into the official curriculum in the context of the instrumentalization process from a documentational approach [18]. Hence, there is a need for the co-construction of resources.

IFM specialists and generalists are intended for teaching in grades 1-6 and 7--9, respectively. With regard to natural water, treatment methods are used to obtain drinking water (3rd class). Treatment depends on raw water characteristics, such as (1) turbidity or microorganisms (suspended) and (2) metal ions (dissolved). The first and second are referred to as the external and internal determinants of health, respectively [15]. Previous authors suggest that health can be influenced interactively by three determinants: endogenous determinants; exogenous determinants and the system of health care. The third group of determinants is related to water treatment methods.

The health concerns associated with the chemical constituents of drinking water differ from those associated with microbial contamination and arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure [14]. The World Health Organisation regularly publishes drinking water quality guidelines.

2.2. Chemical Aspects of Drinking Water Quality

Directives include guide values for several of these constituents. A guide value is the concentration of a constituent for which the risk to the consumer, assuming lifetime consumption of the water, does not exceed the tolerable health risk [14]. When drinking water contains toxic constituents in small doses, these may be tasteless, odourless and colourless beyond the imperative value that would normally lead to rejection of the water. Poisoning occurs as a result of regular and prolonged exposure to high levels of fluoride or arsenic in drinking water. Fluoride in low levels strengthens tooth enamel and contributes to the prevention of dental caries. However, excess fluoride leads to dental fluorosis when milk teeth are replaced by the transformation of the calcium hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) of the enamel into fluorapatite ($Ca_5(PO_4)_3F$) [19]. This is also the case for the oxidation of As(III) to As(V) under physiological conditions; this produces hydrogen peroxide (H_2O_2), which oxidises iron(II) ions to iron(III) ions and generates hydroxyl radicals ($OH^{\bullet}$) [20]. These compounds, in turn, react with DNA. Excess exposure to arsenic in drinking water may result in a significant risk of cancer, skin lesions, and peripheral vascular disease [14]. Fluoride and arsenic are found in Europe, Africa, Asia and America at especially high concentrations in groundwater [21-24]. This is why fluoride and arsenic are health concerns, with guide values of 1.5mg/L and 10μg/L, respectively. Metals also have a negative impact on health and are found at high levels in groundwater [25, 26].

Anaerobic groundwater may contain ferrous iron at high levels without discolouration or turbidity in the water when it is pumped directly from a well. Upon exposure to the atmosphere, however, ferrous iron(II) oxidises to hydroxide ferric iron(III) ($Fe(OH)_3$), giving an objectionable reddish-brown colour to the water.

There is usually no noticeable taste at iron concentrations below 0.3mg/L, although turbidity and colour may develop [14]. In general, biomedical aspects rather than chemical aspects are favoured in teaching practices at the general education level. With respect to teacher training, as a lever for HE, some authors suggest using teacher's conceptions.

2.3. Teachers' Perceptions of Health Education

On the one hand, these representations are related to teachers' subjects of investigation. For example, Soumahoro et al., interviewed 448 students (age 16) on the Ivory Coast about their food hygiene practices. The results revealed that 94.9% of the participants systematically washed their hands before each meal, but 53.6% had fallen ill after eating street food [7]. This biomedical aspect has also been described by other authors. Assimi et al., conducted a survey of 200 Moroccan schoolchildren (aged 6-12) and their mothers [5]. The results revealed that toothbrush use in this population was low and that the brushing method used was ineffective. Similarly, Koelen & Van den Ban suggested that a person cannot maintain good teeth simply by visiting a dentist on a regular basis; toothbrushing and eating less sugar are equally important [15].

On the other hand, these representations are related to the results of teacher surveys. Calas et al., focused on an analysis of 39 schoolteachers [8]. Of these, 83% said that they conducted health education in their classrooms via the biomedical model, and 34% considered health education to be the responsibility of medical staff. The results of a survey conducted by Clément and Carvalho with 11312 teachers in 31 countries in Africa and Europe as well as in Brazil and Australia showed that 50% had biomedical conceptions [9]. Recently, Lipták & Tarkó came to the same conclusion in their survey of 68 future teachers in Hungary [27]. When asked the open-ended question, 'What do you think when you hear the word health?', 95.2% of the respondents mentioned the physical aspect.

These results do not consider chemical aspects, including those linked to the organoleptic characteristics of drinking water. Hence, our research questions are as follows: Are the chemical aspects of drinking water quality addressed at the IFM level? How do master's student teachers understand these issues? How can chemistry contribute to health education based on drinking water in general secondary education?

As health education is not part of the chemistry syllabus at the general secondary level, it is expected that biomedical aspects will be given priority over chemical aspects. The integration of health education into chemistry courses can be achieved through the co-construction of resources that compare the determinants of health with the presence or absence of a drinking-water non-potability index. With regard to the conceptualisation of chemistry as a curriculum requirement, we use Peirce's semiotics as an intermediary between the organoleptic characteristics of water and Johnstone's triplet [28].

2.4. Peirce's Semiotics

Peirce defines a sign as 'something, A, which denotes some fact or object, B, to some interpreting thought, C' [28]. In Peirce's semiotics, a sign says something about the object; it may be real, imaginable or unimaginable, but the interpreter to whom the sign refers is not the object. The sign can be an icon (which maintains a resemblance relationship between the interpreter and the object), an index (which maintains a cause–effect relationship between the interpreter and the object), or a symbol (which maintains an arbitrary or conventional relationship between the interpreter and the object) (Fig. 1) [29, 30].

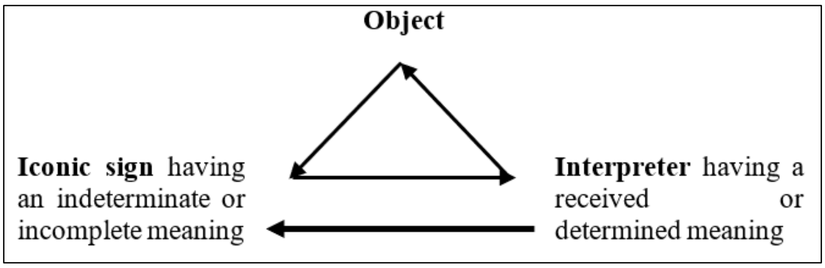

Figure 1. *Sequence of the Sign (a word visual image (or sound) like molecule), Object (referent), Interpreter (mental image associated with or without a word (particle or atom), (SOI), highlighting the semiotic process of the development of knowledge according to Peirce [29].*

Changes in the organoleptic characteristics of water are indices or physical symptoms in Peirce's sense, but the absence of indexical signs is not synonymous with potable water, just as the absence of pathological signs does not guarantee the absence of pathology itself. Hence, chemical testing and analysis are important for diagnosis before and after water treatment.

3. Methodology

To link chemistry to health education, we opted for the co-construction of resources: (1) a survey of 40 trainees (master's degree) in chemistry and physics and 40 physics-chemistry teachers (for grades 7-9) who had previously passed through the IFMs (Table 1) and (2) the co-construction of problem situations (PSs) in accordance with the official curriculum (Table 2). Our survey instruments are paper/pencil questionnaires. All questions are closed-ended, "Yes" or "No" (Table 1). The survey was carried out using the resources available: the forms handed in on site were collected three days later, while those sent by electronically were received a week after they had been sent. Well water samples had collected in plastic bottles. We used Hanna instruments for measuring iron(II) at the laboratory of “Ecole Normale Supérieure”, and the co-construction of problem situations (PSs) which involved 30 lessons plan took place in the same establishment (Table 2). Chemical and biomedical aspects were the dependent variables. The data were processed qualitatively and quantitatively.

Table 1. *Questions addressed to teachers and preservice teachers.*

Question 1: To maintain good teeth, is it necessary for children to:

Q1.1. Eat less sugar? yes ❑ no ❑

Q1.2. Brush their teeth regularly? yes ❑ no ❑

Q1.3. Drink potable water? yes ❑ no ❑

Question 2: To avoid skeletal deformation, is it necessary for children to:

Q2.1. Adopt good sitting posture? yes ❑ no ❑

Q2.2. Drink potable water? yes ❑ no ❑

Question 3: Does a healthy diet include the following:

Q3.1. Cooking food properly? yes ❑ no ❑

Q3.2. Keeping food clean? yes ❑ no ❑

Question 4 is about the content analysis of lesson plans. Are the following points included:

Q4.1 Problem situations?

Q4.2 Operational educational objectives?

Q4.3 Hypothetical experiments?

Q4.4 Chemical aspects of pollution?

Q4.5 Indications that water is not potable?

Q4.6 Do these indicators relate to chemical aspects of drinking water quality?

Table 2. *Stages of resource co-construction.*

Steps and process for each stage

Sampling

1) Involved 30 wells, by master's students
2) Samples taken the day before and stored in 1.5 L flasks
3) - Ferrous ions levels of samples: 0.00 to 4.5mg/L (guide value of 0.2mg/L)

Lesson plan preparation

1) Number: 30
2) Conception: by 30 master's students over 7 days
3) Theme: natural waters in the 3rd-year IFM class
4) Subject area: material sciences
5) Speciality: physics-chemistry
6) - Content: definition, composition, potability treatments

Elaboration of problem-solving strategy

1) Participants: searcher and 30 master’s trainees
2) Presentation of problem-solving strategies by each group
3) Pooling and discussion of the results
4) Validation
5) Proposal of hypothetical experiments by each group
6) Choice of Hanna instruments (fast, compact, reliable and inexpensive)
7) Didactic transposition of treatment practices
8) - Presentation of images of people affected

4. Results and Discussion

4.1. Results

The results of the water analyses revealed that 80% of the well water samples had iron levels in excess of the standard value of 0.3mg/L. Precipitates formed a few days later following aeration of four liters stored in plastic bottles. The participants attested to the disadvantages of ferruginous water in their area.

The results of the survey revealed that hygiene and microbiological aspects predominated, with 87.6% (Q1.1), 100% (Q1.2), 80% (Q3.1) and 90% (Q3.2) for yes, unlike the chemical aspects of drinking water, with 5% (Q1.3) and 30% (Q2.2). However, some teachers and preservice teachers (master’s degree) were aware of the importance of potable water (Q2.2). For results that were not expected, further investigations are necessary to justify the negative impact of non-potable water.

The results for the 30 lesson plans were as follows: 100% (Q4.1; Q4.2 and Q4.5), 90% (Q4.3) and 67.5% (Q4.4). The PS texts appeared either as an introduction or as an evaluation question (Q4.1), such as ‘drinking-water definition’, ‘natural water composition’, ‘how to obtain drinkable water’, or ‘the representation of the distillation process’. The planned experiments were based on the composition of natural water as a mixture, mineral removal by distillation and particle removal by decantation and filtration (Q4.3). Indications that water is non-potable relate only to suspended particles (Q4.5) and not to chemical aspects (Q4.6). The results related to co-construction are presented below (Figure 2 and Table 3).

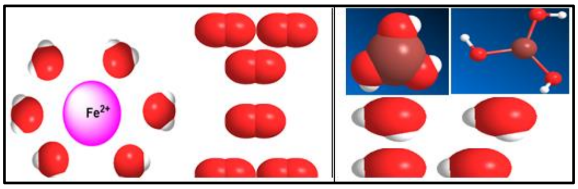

Figure 2. Iconic representations of: hydrated iron(II) ions, $[Fe(OH_2)_6]^{2+}$, and oxygen molecules (left); iron(II) hydroxide, $Fe(OH)_3$, and water molecules, H_2O (right), used to construct a stoichiometric relationship.

Table 3. Generating resources related to HE.

Problem situation
Q1. What is drinking water?
Q2. This is a sample of limpid groundwater (beaker 1). Can it contain iron(II) ions? Justify your answe?
Q3. This water, on exposure to the atmosphere, has become reddish-brown due to the formation of ferric hydroxide, $Fe(OH)_3$ (beaker 2). How do you explain this precipitate formation? Is it potable water?

4.2. Discussion

The results of the surveys of teachers and preservice teachers confirmed the importance of the biomedical aspects compared with the chemical aspects of drinking water. In West Bengal, Chowdhury et al., reported a maximum arsenic increase of 205% in samples of rice grains steamed with groundwater containing arsenic [31]. Saeed et al., established a link between excess fluoride and tooth decay and highlighted its impact on the intelligence of children aged 6 to 14 years [32]. In terms of health, the absence of signs is not synonymous with the absence of pathology [15]. Hygiene rules are not sufficient under these conditions.

The equations are as follows for the phenomenon of iron(III) precipitation, formed:

$$4\mathrm{Fe}^{2+}(\mathrm{aq}) + \mathrm{O}_2(\mathrm{aq}) + 2\mathrm{H}_2\mathrm{O}(l) \rightarrow 4F^{3+}(aq) + 4\,\mathrm{OH}^-(aq) \quad (1)$$

$$4\mathrm{Fe}^{3+}(\mathrm{aq}) + 4\mathrm{OH}^-(aq) + 8\mathrm{H}_2\mathrm{O}(l) \rightarrow 4\mathrm{Fe(OH)}_3(\mathrm{s}) + 8\mathrm{H}^+(\mathrm{aq}) \quad (2)$$

$$\text{Either: } 4\mathrm{Fe}^{3+}(\mathrm{aq}) + \mathrm{O}_2(\mathrm{aq}) + 10\mathrm{H}_2\mathrm{O}(l) \rightarrow 4\mathrm{Fe(OH)}_3(\mathrm{s}) + 8\mathrm{H}^+(\mathrm{aq}) \quad (3)$$

$$\frac{-\mathrm{d}[\mathrm{Fe(II)}]}{\mathrm{dt}} = k[\mathrm{Fe(II)}]p_{O_2}[OH^-]^2 \quad (4)$$

In practice, water acidification (1) reduces the rate of precipitate formation (4), which becomes significant above pH 7. Recent studies on this law of kinetics (Stumm and Lee law) show the catalytic role of the iron(III) ions formed, i.e., a heterogeneous mixture.

The method of identifying and measuring iron(II) ions in our experiment, like engineering practices in teacher education, was used by students to identify and measure nitrate ions in water [33, 34]. In the body, nitrate ions produce nitrite ions, which cause methemoglobinemia in infants.

Lesson planning and group discussions about promote the development of pre-service teachers' skills [35, 36]. With respect to sequence plans, difficulties arise in formulating problem situations because the presence of operational educational objectives leads to inductivism [37, 38]. This makes it impossible to anticipate the formulation of hypotheses and their validation by experience. Hence, there is a need for training in these aspects [39, 40].

The student teachers used dots as signs of turbidity to represent non-potable water. Turbidity is a source of bacterial proliferation and hides microbes from disinfection. This phenomenon is exacerbated by the sale of water sachets [41]. The chemical treatment methods used in practice have advantages, disadvantages, and limitations. Although ozonation and chlorination were mentioned, the trainees did not associate these methods with the chemical reactions that precipitate metal ions. However, due to public health problems, boreholes have been abandoned in Mali and other countries because of high levels of manganese, iron or arsenic. Çalış obtained the same results in his survey of 60 preservice physics and chemistry teachers [42]. The latter had difficulty formulating and integrating real-life problems into secondary school lesson plans.

We used iconic signs in the form of simplified molecular models (mental constructions) to represent iron(II) ions, hydrated counterions and oxygen molecules (Figure 2). The hydrated ion representation is a simplification of the Stern double layer. It is related to limpid ferruginous water that may or may not be drinkable depending on the guide value. For reddish-brown, nondrinkable ferruginous water, we used crosses to avoid confusing them (visible particles) with gas particles (mental constructions). The relationships among the macroscopic iron(III) hydroxide precipitate, as an index or physical symptom in Peirce's sense, the rearrangement of atoms (microscopic interpretation) and the chemical equation (symbolic level) were established. According to Johnstone's triplet, these interrelations promote an understanding of chemistry [28]. Savec et al., described the interrelationship of the three levels of chemistry using a real-life problem: the softening of hard water that forms a grey deposit at the bottom of containers after boiling [43]. In this case, our work on health education focuses on preventing kidney stones caused by hard water.

We did not multiply the PS in accordance with instrumentalisation rather than instrumentation [18]. The dissolution of metal oxides is due to oxygen gas depletion and excess carbon dioxide in groundwater (Q1). The possible confusion between crystallisation (a physical phenomenon) and the precipitation of ferric hydroxide (a chemical transformation) (Q2) are obstacles to be overcome [44]. It is possible to go further in the

PS by imagining or evoking (in the sense of Peirce), for safety reasons, the presence of As(III) ions instead of iron(II) ions.

5. Conclusion

This research has shown that it is possible to integrate health education into IFM chemistry courses. The co-constructed and proposed PS must be implemented by volunteer teachers in classroom situations. This study could be extended to an analysis of the resources used by teachers. The use of both Peirce's triadic model and Johnstone's triplet as well as model images (iconic signs) shows that such integration is not without difficulties. Cirkony & Kenny used cross signs to designate molecules in a study of molar concentrations to lead to chemical reaction equations [45]. Teachers must keep in mind that these signs, as well as molecular models, are only representations and supports. In-service teacher training and the development of resources for instrumentation and instrumentalization are therefore essential [16, 18]. This methodology of didactic engineering can be used in teacher training and for teachers, the chemistry contextualization using real-life problems and Peirce's and Johnstone's models.

Abbreviations

CBA	Competency-based Approach
HE	Health Education
PS	Problem Situation
SOI	Sign Object Interpreter
IFM	Teacher Training Institute

Author Contributions

Mohamed Soudani: Supervision, validation
Sidi Mohamed Tounkara: Conceptualization, Investigation, Methodology and Analysis

Funding

No funds for this project.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Guiet-Silvain, J., Jourdain, D., Parayre, S., Simar, C., Pizon, F., Berger D. (2011). Education à la santé, mise en perspective historique et internationale. *Carrefours de l'Edication*, 32, 105-127.

[2] Gelinas, I. (2007). Un esprit sain dans un corps sain ou le sport en milieu d'éducation. *Education Canada-Toronto*, *47*(2), 12.

[3] Renier, S. (2020). Traduction inédite du texte Le corps et l'esprit de John Dewey. *Les Sciences de l'éducation-Pour l'Ère nouvelle*, *53*(4), 103-119.

[4] Scott, J. J., Johnston, R. S., Bear, N., Gregory, S., Blane, S., Strickland, M., Darby, J., & Gray, E. S. (2021). Targeted Teacher Education to Improve Primary Preservice Teachers' Knowledge and Understanding of UV and Effective Sun Protection Measures for Children. *Australian Journal of Teacher Education*, 46(3). https://doi.org/10.14221/ajte.2021v46n3.4

[5] Assimi 1, S., Tajmouti 2, R., & Ennibi 3, O. K. (2016). Hygiène bucco-dentaire d'enfants scolarisés marocains et de leurs mères. *Santé publique*, *28*(2), 245-250.

[6] Duijster, D., Buxton, H., Benzian, H., Dimaisip-Nabuab, J., Monse, B., Volgenant, C., & Dreibelbis, R. (2020). Impact of a school-based water, sanitation and hygiene programme on children's independent handwashing and toothbrushing habits: a cluster-randomised trial. *International journal of public health*, *65*, 1699-1709. https://doi.org/10.1007/s00038-020-01514-z

[7] Soumahoro, S. I., Coulibaly, M., Kouassi, D. P., Irika, O., Goua, B. I., Ouaga, J. M., & Angbo-Effi, O. (2018). Connaissance, Attitudes et pratiques des élèves sur l'hygiène alimentaire et l'alimentation de la rue. *Revue Malienne d'Infectiologie et de Microbiologie*, *2*(2). https://doi.org/10.53597/remim.v2i2.1195

[8] Calas, F., Reynaud, C., & Caussidier, C. (2012). "Éducation à la santé et pensée complexe: une approche globale pour la formation des enseignants", *RDST*, 5 | 2012, 106-130. https://doi.org/10.4000/rdst.575

[9] Clément, P., & Carvalho, G. S. (2017). "Les conceptions d'enseignants de 31 pays sur la santé, entre approches biomédicale et socio-écologique", *RDST*, 16 | 2017, 33-56. https://doi.org/10.4000/rdst.1545

[10] Godin, G. (1991). L'éducation pour la santé: les fondements psycho-sociaux de la définition des messages éducatifs. In: Sciences sociales et santé. 1(9). 67-94.

[11] Manderscheid, J-C. (1994). Modèles et principes en éducation pour la santé. In: *Revue française de pédagogie*, (107), 81-96.

[12] Melese, B., Paulos, W., Astawesegn, F. H., & Gelgelu, T. B. (2019). Prevalence of diarrheal diseases and associated factors among under-five children in Dale District, Sidama zone, Southern Ethiopia: a cross-sectional study. *BMC public health*, *19*, 1-10. https://doi.org/10.1186/s12889-019-7579-2

[13] Papadopoli, R., Nobile, C. G. A., Trovato, A., Pileggi, C., & Pavia, M. (2020). Chemical risk and safety awareness, perception, and practices among research laboratories workers in Italy. *Journal of occupational medicine and toxicology*, *15*, 1-11. https://doi.org/10.1186/s12995-020-00268-x

[14] World Health Organization. (2022). *Guidelines for drinking-water quality: incorporating the first and second addenda*. Available From: https://iris.who.int/bitstream/handle/10665/352532/9789240045064-eng pdf (accessed 20/04/2025).

[15] Koelen, M. A., & Van den Ban, A. W. (2023). *Health education and health promotion*. BRILL.

[16] UNESCO (2023). The teachers we need for the education we want: the global imperative to reverse the teacher shortage; factsheet. Available from: https://unesdoc.unesco.org/ark:/48223/pf0000387001 (accessed 20/11/2024).

[17] UNESCO (2019). Recommandation on open educational resources (OER). Retrieved on unesdoc.unesco.org/ark:/48223/pf0000383205/PDF/383205eng.pdf.multi (accessed 20/01/2025).

[18] Gueudet, G., & Trouche, L. (2008). Du travail documentaire des enseignants: genèses, collectifs, communautés: Le cas des mathématiques. *Education et didactique*, *3*, 7-33. https://doi.org/10.4000/educationdidactique.342

[19] Johnston, N. R., & Strobel, S. A. (2020). Principles of fluoride toxicity and the cellular response: a review. *Archives of toxicology*, *94*(4), 1051-1069. https://doi.org/10.1007/s00204-020-02687-5

[20] Jomova, K., Jenisova, Z., Feszterova, M., Baros, S., Liska, J., Hudecova, D.,... & Valko, M. (2011). Arsenic: toxicity, oxidative stress and human disease. *Journal of applied toxicology*, *31*(2), 95-107. https://doi.org/10.1002/jat.1649

[21] Abdul, K. S. M., Jayasinghe, S. S., Chandana, E. P., Jayasumana, C., & De Silva, P. M. C. (2015). Arsenic and human health effects: A review. *Environmental toxicology and pharmacology*, *40*(3), 828-846. https://doi.org/10.1016/j.etap.2015.09.016

[22] Cury, J. A., Ricomini-Filho, A. P., Berti, F. L. P., & Tabchoury, C. P. (2019). Systemic effects (risks) of water fluoridation. *Brazilian dental journal*, *30*, 421-428. http://dx.doi.org/10.1590/0103-6440201903124

[23] Edmunds, W. M., & Smedley, P. L. (2012). Fluoride in natural waters. In *Essentials of medical geology: Revised Edition* (pp. 311-336). Dordrecht: Springer Netherlands.

[24] Irunde, R., Ijumulana, J., Ligate, F., Maity, J. P., Ahmad, A., Mtamba, J.,... & Bhattacharya, P. (2022). Arsenic in Africa: potential sources, spatial variability, and the state of the art for arsenic removal using locally available materials. *Groundwater for sustainable development*, *18*, 100746. https://doi.org/10.1016/j.gsd.2022.100746

[25] Thimmappa, B. H. S. (2023). Perspectives on general aspects of pollution toxicology. *African Journal of Chemical Education*, AJCE 13(1), 240-292.

[26] Wang, Y., Yuan, S., Shi, J., Ma, T., Xie, X., Deng, Y.,... & Jiang, G. (2023). Groundwater quality and health: making the invisible visible. *Environmental Science & Technology*, *57*(13), 5125-5136. https://doi.org/10.1021/acs.est.2c08061

[27] Lipták, Z. M., & Tarkó, K. (2020). Health education-health misconceptions-teacher training lessons learnt from a hungarian pilot study. *European Journal of Education*, *3*(2), 90-97.

[28] Taber K. S., (2013), Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, 14(2), 156–168. https://doi.org/10.1039/C3RP00012E

[29] Soudani, M., Soudani-Bani, O., Roletto, E., & Regis, A. (2014). Fonctionnement sémiotique et construction des modèles en chimie. Un cadre d'analyse peircien. *RDST. Recherches en didactique des sciences et des technologies*, (9), 179-208. https://doi.org/10.4000/rdst.881

[30] Pinillos, AS. (2023). Silence as a Cognitive Tool to Comprehend the Environment. *Foundations of Science*, 1-27. https://doi.org/10.1007/s10699-023-09925-w

[31] Chowdhury, N. R., Ghosh, S., Joardar, M., Kar, D., & Roychowdhury, T. (2018). Impact of arsenic contaminated groundwater used during domestic scale post harvesting of paddy crop in West Bengal: arsenic partitioning in raw and parboiled whole grain. *Chemosphere*, *211*, 173-184. https://doi.org/10.1016/j.chemosphere.2018.07.128

[32] Saeed, M., Malik, R. N., & Kamal, A. (2020). Fluorosis and cognitive development among children (6–14 years of age) in the endemic areas of the world: A review and critical analysis. *Environmental Science and Pollution Research*, *27*, 2566-2579. https://doi.org/10.1007/s11356-019-06938-6

[33] García-Carmona, A., & Toma, R. B. (2024). Integration of engineering practices into secondary science education: Teacher experiences, emotions, and appraisals. *Research in Science Education*, 54, 549–572. https://doi.org/10.1007/s11165-023-10152-3

[34] Gawankar, S., & Masten, S. J. (2023). Development of an Inexpensive, Rapid Method to Measure Nitrates in Freshwater to Enhance Student Learning. *Journal of Chemical Education*, *100*(6), 2141-2149. https://doi.org/10.1021/acs.jchemed.2c00381

[35] Marangio, K., Carpendale, J., Cooper, R., Mansfeld, J. (2024). Supporting the Development of Science Pre-service Teachers' Creativity and Critical Thinking in Secondary Science Initial Teacher Education. *Research in Science Education*, 54, 65–81. https://doi.org/10.1007/s11165-023-10104-x

[36] Altan, E. B., & Ucuncuoglu, İ. (2019). Examining the development of pre-service science teachers' STEM-focused lesson planning skills. *Eurasian Journal of Educational Research*, *19*(83), 103-124.

[37] Kang, J. (2022). Interrelationship between inquiry-based learning and instructional quality in predicting science literacy. *Research in Science Education*, *52*(1), 339-355. 5 https://doi.org/10.1007/s11165-020-09946-6

[38] Tounkara, S. M., Diawara, M., & Soudani, M. (2020). Appropriation par des enseignants du secondaire de la situation-problème dans le cadre de la réforme curriculaire au Mali. *European journal of education studies*, 7(3), 187-198. https://doi.org/10.5281/zenodo.3756196

[39] Chadha, D. (2022). How do we prepare to teach? Exploring science lecturers' authentic approaches to teaching in higher education. *Research in Science Education*, *52*(2), 635-653. https://doi.org/10.1007/s11165-020-09972-4

[40] Tounkara, S. M., Mohamed, S. (2022). Titolazioni acido-base e soluzioni saline come supporto per lo sviluppo di competenze scientifiche, epistemologiche e didattiche. *La Chimica nella Scuola*, 5, 53-61.

[41] Sahirou, B. M., Laouali, M. S., Mahamane, A. A., Adamou, H. H., Amadou, H., Manzola, A. S., & Hassane, B. G. (2020). Evaluation of the quality of" pure water" sold in Niamey, Niger. *International Journal of Biological and Chemical Sciences*, *14*(9), 3412-3427. https://dx.doi.org/10.4314/ijbcs.v14i9.35

[42] Çalış, S. (2020). Physics-chemistry preservice teachers' opinions about preparing and implementation of STEM lesson plan. *JOTSE, 10*(2), 296-305. https://doi.org/10.3926/jotse.971

[43] Savec, V. F., Sajovic, I., & Wissiak Grm, K. S. (2009). Action research to promote the formation of linkages by chemistry students between the macro, submicro, and symbolic representational levels. In *Multiple representations in chemical education* (pp. 309-331). Dordrecht: Springer Netherlands.

[44] Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2009). Linking the macroscopic, sub-microscopic and symbolic levels: The case of inorganic qualitative analysis. In *Multiple representations in chemical education* (pp. 137-150). Dordrecht: Springer Netherlands.

[45] Cirkony, C., & Kenny, J. D. (2022). Using Formative Assessment to Build Coherence Between Educational Policy and Classroom Practice: A Case Study Using Inquiry in Science. *Australian Journal of Teacher Education*, 47(10). https://doi.org/10.14221/ajte.2022v47n10.5