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Pernaa, Johannes

Multidisciplinary Digital Publishing Institute
2022-05-20

Pernaa, J.; Kämppi, V.; Aksela, M. Supporting the Relevance of Chemistry Education through Sustainable Ionic Liquids Context: A Research-Based Design Approach. Sustainability 2022, 14, 6220.

http://hdl.handle.net/10138/349342

sustainability

Article

Supporting the Relevance of Chemistry Education through Sustainable Ionic Liquids Context: A Research-Based Design Approach

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Abstract: By introducing the sustainable nature of chemistry to students—makers of the future—teachers, and teacher students we can promote their scientific literacy and increase understanding of the relevance of chemistry research and studies in sustainability. Ionic liquids are a topical example of innovation of green chemistry research offering many possibilities for sustainable chemistry education. This article describes how to develop research-based learning materials on ionic liquids using educational design research as a design strategy. The design process included two cycles and the initial design solution was iterated via a qualitative case study conducted with future chemistry teachers. The main result of this research is the designed context-based activity that engages learners with individual, vocational, and societal levels of relevance. In addition, the study produced new insights into future chemistry teachers' perceptions of ionic liquids' possibilities in a chemistry learning context. According to future chemistry teachers, ionic liquids are an interesting new context for laboratory learning and can increase interest in chemistry studies.

Keywords: relevance; chemistry education; sustainable chemistry; design-based research; context-based; ionic liquids; teacher education

Citation: Pernaa, J.; Kämppi, V.; Aksela, M. Supporting the Relevance of Chemistry Education through Sustainable Ionic Liquids Context: A Research-Based Design Approach. *Sustainability* **2022**, *14*, 6220. https://doi.org/10.3390/su14106220

Academic Editor: Pedro Guilherme Rocha dos Reis

Received: 6 April 2022
Accepted: 17 May 2022
Published: 20 May 2022

1. Introduction

Promoting scientific and sustainability literacy through future-oriented and transformational education is of utmost importance [1]. The role of chemistry as a science and its education are vital in building a healthy sustainable future [2]. There is a great need to promote scientific chemistry literacy for all people [3]. In addition, we need more chemistry specialists in various fields to solve global sustainability challenges [4]. As research has shown, young people—makers of the future—are not necessarily interested enough in chemistry [5,6] and they often do not find chemistry studies as relevant [7]. There is a need to get relevant pedagogical innovations/solutions into practice in chemistry education. This paper describes how to meet these needs and develop research-based learning materials through collaboration. Sustainability chemistry education has been a main goal of our research group, and this study is an example of it [8].

To engage and inspire young people to study chemistry, it is important to consider the relevance perspective [9]. This can be done by developing learning materials that are experienced as relevant by learners [10]. One approach to increase relevance is to use contexts that learners can relate to [7]. Another suggestion made by Blonder and Mamlok-Naaman [11] is to use contemporary research cases as context. The contemporary approach teaches about the nature of science by showing learners how scientific knowledge is generated. Many authors consider that it is important to promote the understanding of the nature of science and scientific literacy in school teaching and teacher education [12,13]. This gives an understanding of the connections between chemistry and society as well as chemistry and technology, which are in constant interaction [14]. In this regard, there is a need for developing new context-based learning materials based on novel chemistry research.

To contribute to the relevance challenge described above, the aim of this research is to develop a context-based learning activity emphasizing the relevance of chemistry through a sustainable contemporary research context—ionic liquids. The context of ionic liquids was chosen because it is a topical example of innovation of green chemistry offering many possibilities for sustainability [15,16].

Therefore, the topic is also important from the sustainable chemistry education perspective which has received a lot of attention in recent years. For example, Mahaffy et al. [17] proposed that sustainable and green chemistry can be addressed via systems thinking. The systems approach aims to offer a more holistic perspective to chemistry learning than a traditional concept approach. The medium for fostering a more comprehensive perspective can be anything from smaller lab experiments to open-ended projects [18]. Even though this research is conducted in the context of sustainable chemistry education, we do not directly address systems thinking which is linked to sustainability education in many research articles [17–23]. To promote the comprehensive approach, we will design the activity around chemistry laboratory work [18].

However, the challenge is that designing holistic learning materials is difficult because it demands both expertise in pedagogical planning and high content knowledge. To solve this challenge, many authors encourage engagement with multiple different stakeholders in the design process [24,25].

The material will be developed for pre-service chemistry teacher education purposes. The aim of the designed activity is to inspire future chemistry teachers through an activity based on recent chemistry research and show an example of how materials can be developed using a research-based approach. The development is carried out using a design-based research (DBR) approach, which is a widely used methodology in research-based learning environment design [26,27]. To emphasize the holistic approach, the project is carried out collaboratively including both the content specialists and pedagogical experts [25].

The structure of the paper is based on the DBR approach. A DBR can be reported by describing the design process in chronological order. In this regard, first, we will introduce DBR as a research methodology. This is usually done in the beginning because the structure of the DBR guides the formulation of research questions (RQ) (see Section 2) and answering the RQs guides the progress of the overall project. Therefore, after stating the RQs, they will be answered in the next section (see Sections 3–5).

2. Implementation of Design-Based Research

DBR is a research methodology that enables an iterative systematic approach to complex learning environment development projects [26]. As mentioned, it is nowadays a widely used strategy in educational research [25,27]. According to Edelson [26], DBR is at the same time a practical and research-driven development strategy. This means that the development is based on a solid theoretical framework, and it will produce concrete design solutions (e.g., learning materials) validated through scientific research. This approach enables contributing to scientific discussions and not just focusing on designing new artifacts [26]. To ensure the systematic research-oriented demand set for DBR, this research consists of three phases (see Figure 1) each guided by a research question.

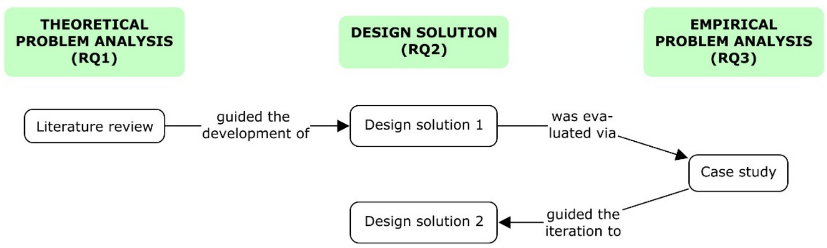

Figure 1. Structure of the conducted DBR.

Phase 1: Theoretical problem analysis

DBR always begins with a need analysis, where the design needs, possibilities, and challenges are analyzed [26,28]. In this research, the needs were mapped via reviewing earlier research literature. Therefore, this phase forms the theoretical framework of the research.

RQ1: What kind of possibilities does the ionic-liquids context offer for supporting relevance? (see Section 3)

Phase 2: Design solution

The design solution is the concrete ionic liquid activity that is being developed. In this DBR the first version of the design solution is developed based on the need analysis. However, since DBR is a cyclic process the design solution will be iterated via the empirical phase leading to design solution 2 [26].

RQ2: What kind of practical work activity enables chemistry learning in the context of ionic liquids? (see Section 4)

Phase 3: Empirical problem analysis

As Edelson [26] emphasizes, development should include a formative evaluation that is used in iterating the design solution. In this DBR, the design solution is developed for pre-service teacher education. Therefore, the case study used in evaluating design solution 1 was conducted with future chemistry teachers. As expected from a DBR, the aim of this phase is both to develop a practical solution (RQ3a) and contribute to relevant research via future chemistry teachers' perceptions in an ionic-liquids context (RQ3b) [26,29,30]. The findings of empirical problem analysis are used in redeveloping the design solution and contributing to scientific relevance discussion.

RQ3: What kind of perceptions do future chemistry teachers have on (a) the functionality and (b) relevance of an activity related to ionic liquids? (see Section 5)

Validity and Reliability of Design-Based Research

Even though DBR is widely applied in educational research, it has been criticized for its reliability. DBR projects are often complex including multiple steps and stakeholders producing various kinds of data [29]. In this DBR, the complex nature of DBR has been controlled by accurate documentation.

Another critique is aimed toward research settings. First, there is no unified methodology how to conduct DBR studies [31]. This critique is correct, but currently, there is no better model to apply research-based methods to designing educational artifacts. The selection of methods depends on the design focus, and the selected methods will define the reliability and validity criteria [32]. Second, empirical phases are often qualitative, which is the case in this research too. This makes it difficult to produce generalized results, which is one of the aims of contributing to theories via empirical problem analyses [26,27,29,31]. However, many authors remind us that DBR can be used in producing best practices on a local scale [27,30]. In this DBR the local scale is pre-service chemistry teacher education at the University of Helsinki, enabling the development of the activity in an authentic end-user setting [29].

3. Theoretical Problem Analysis: The Possibilities of the Ionic-Liquids Context for Supporting Relevance (RQ1)

In this section, we answer RQ1 by analyzing the possibilities that the ionic-liquids context offers for supporting relevance. The analysis is conducted via a literature review. First, we define the term relevance and then use it as a tool for mapping out the possibilities.

According to many studies, making chemistry studying more relevant may act as a key factor in increasing interest in studying chemistry [7,33]. However, there is no clear consensus on the definition of relevance. It can be a synonym for interest or necessity, or it can be thought to refer to students' view of relevance [9,34]. Stuckey et al. [33] have defined relevance through a model, where relevance is divided into individual (IR), vocational

(VR), and societal relevance (SR). The relevance perspective can be intrinsic or extrinsic, referring to present or future needs (see Figure 2).

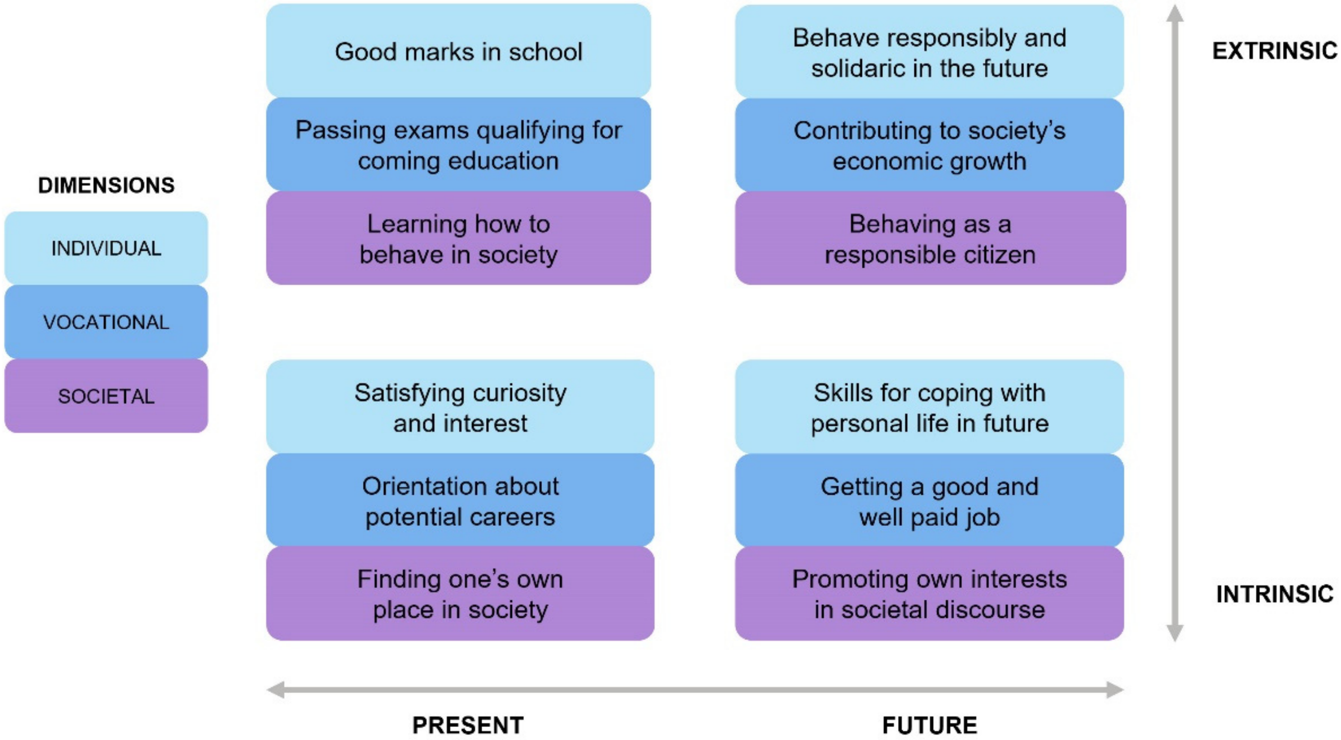

Figure 2. The dimensions of Stuckey et al.'s (2013) relevance model.

Individual relevance includes students' personal interests and needs in the present and future. The individual dimension addresses things that are relevant to the students themselves. Individually relevant teaching offers the students useful skills for coping with the challenges of daily life and develops a student's intellectual skills. Vocational relevance refers to skills that are needed in present studies, in a future entrance exam, or in a future profession. Societal relevance includes the understanding of the connection between society and science, and skills that are necessary for behaving responsibly. Societally relevant teaching gives the capacity to act as a responsible citizen and to function according to sustainable development [33,34].

Ionic liquids were chosen as the chemistry context because it is a current research topic with a clear societal role. Ionic liquids have also been present in the Finnish media lately, where several articles and news about the latest Finnish ionic liquids innovations have been published via national level mass media. Public support for the innovation strengthens its societal relevance [24]. This encouraged us to assume that ionic liquids might be a high-relevance chemistry context (see an overview from Table 1), which are important for chemistry education. According to research, contexts help learners to understand the connection between science and daily life [7]. When learning contents are looked at from the viewpoint of everyday contexts, students learn why chemistry is important, and where it influences.

Ionic liquids are organic salts that have a melting point below 100 degrees Celsius. Ionic liquids have many useful properties, such as chemical, thermal, and electrochemical stability, nonflammability, low vapor pressure, and solubility in many compounds. Because of these properties, they have a wide range of use cases [35]. For example, ionic liquids have applications in fields like analytics, biotechnology and biomedicine, catalysis and synthesis, extraction, electrochemistry, etc. [36,37]. Ionic liquids are also researched at our home institution University of Helsinki, where the research focuses especially on their possibilities for cellulose dissolution [15]. This determined the chemistry context for the designed activity—ionic liquids in the dissolution of cellulose looked from the viewpoint of sustainable development. Sustainable development is related to the topic for example through the need for cellulose and growing cotton. Ionic liquids can be regarded as a sustainable option in processing cellulose, and processed innovation acts as one solution to this problem related to natural resources [38]. From the sustainable green chemistry perspective, ionic liquids offer possibilities, especially for more sustainable solvent options [39]. However, even though ionic liquids are considered a green solvent option, they have some toxic effects that cause harm for many types of organisms if exposed to nature. The toxic effects of ionic liquids depend on their structure, test conditions, and morphology of the organisms. Therefore, more research is needed in order to evaluate the comprehensive sustainability of using ionic liquids as solvents [40,41].

Table 1. The summary of relevance possibilities of ionic liquids according to the literature review.

	Intrinsic	Extrinsic
Present	Can be used as a context in teaching many chemistry concepts. (IR) Sustainable solutions have a strong vocational and societal role. (VR, SR)	Ionic-liquid solutions contribute to the current sustainable thinking. (SR) Ionic liquids can be used in teaching the nature of science. (SR)
Future	Sustainability know-how may secure a job in the future. (VR) Ionic liquids may engage societal awareness. (SR)	Ionic-liquid solutions inspire us to invent more sustainable practices. (SR)

Ionic liquids are a topical example of innovation of green chemistry, made possible by science and technology [16]. Hernani et al. [16] also suggested that the context includes many opportunities for teaching about chemistry subject matter and for developing thinking skills. Mudzakir et al. [42] have noted that ionic liquids are also useful in teaching about the philosophy of chemistry, for example, by bringing out the epistemological nature of chemistry. They highlight in their study that ionic liquids are a good context for illustrating connections between science and technology, and a context that influences attitudes towards chemicals. Based on their research, ionic liquids can be used especially alongside teaching about topics such as chemical bonds, organic compounds, acid and base theory, and the internal interaction of polymers and molecules.

4. Design Solution 1: Supporting the Relevance via Practical Work in the Ionic-Liquids Context (RQ2)

The context-based approach has been developed to solve intrinsic chemistry educational challenges derived from content overload [7]. The challenge is that often curricula are overloaded with concepts to address the rapidly developing chemistry research. Learners experience chemistry as an overwhelming number of isolated facts, which leads to poor basic knowledge of chemistry, a lack of transfer, and a lack of relevance. Students can solve problems that are given to them, but they cannot transfer knowledge to another setting [7,43]. As a solution, Gilbert [7] suggested that the content overload must be decreased by identifying central concepts and concentrating on them. Basic chemistry should be learned through contexts which students can relate to. This would promote the ownership of learning and support interest, relevance, and transfer effect. Additionally, Schwartz [44] rationalizes that contexts should be the center of the curriculum. Chemical phenomena and concepts are introduced when needed to understand the real-world societal issues selected in the designed contexts.

However, the use of contexts includes some challenges. It is difficult to design context-based learning because there is no clear definition for the term "context". For example, context can be understood as a setting that includes content-specific language used in a social community that forms a behavioral environment where learning occurs. In addition, context needs relevant extra-situational background information that learners can relate to events organized by the community [7,43]. De Jong [45] defines contexts as more student-centered and defines them as practices that help students to build meaning around topics that are being studied. Contexts can be classified into categories depending on their perspectives. Contexts can engage through different domains such as personal (e.g., everyday life connection), social and society (e.g., the role of science in society), professional (e.g., future career), and scientific and technology (e.g., scientific and technologic literacy) [45].

In this research, context is understood as the chemistry topic of ionic liquids, and the aim was to design a learning activity around the selected context that supports the relevance. For this purpose, we designed a three-part activity including preliminary tasks, a practical laboratory phase, and final tasks (see Appendix A). The structure follows the recommendation of Millar's [46] model for a meaningful laboratory activity. The structure ensures that learners orientate to the topic and get inspired. Pre-tasks increase interest toward the laboratory phase. A summarizing final task enables reflecting on what has been learned, so the practical part will not turn out to be separate and unattached [46] (see Figure 3).

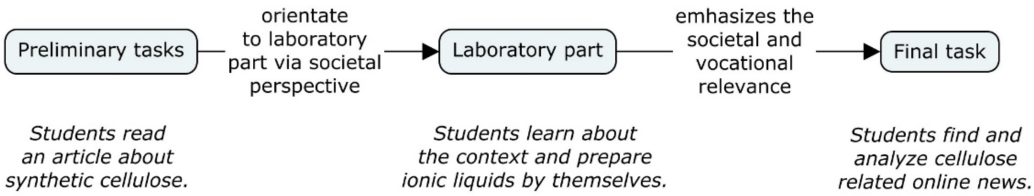

Figure 3. Overview of the developed activity's structure.

Preliminary tasks introduce cellulose as a textile material through an example article. The article highlights the need for synthetic cellulose, which increases the significance of students' work and connects the laboratory part to daily life and society. The tasks also engage learners to use scientific literacy and thus give an image of the nature of chemistry as a science. The work instructions include questions that are related to the article and guide the reading of the article and help focus on essential parts. The article gives extra-situational background information, improving the societal relevance of the context [7,33].

The laboratory part first introduces ionic liquids and cellulose as a material. Afterward, students get to prepare ionic liquids themselves. Cellulose is dissolved into an ionic liquid, and finally, cellulose is precipitated by injecting the solution into water. Reagents are used in small quantities, and therefore it is important to work diligently and concentrate on precise measurements. Syringes and needles are used in weighing, which may be a new experience for students because they are not the most typical laboratory equipment.

The aim of the laboratory phase is to inspire students toward chemistry studies, to illustrate the significance of chemistry in society, and to practice laboratory working skills. Students familiarize themselves with a real application of chemistry that can solve many societal problems [45]. According to research, context-based laboratory activities offer many possibilities for increasing the interest and relevance of science studies. For example, it helps students learn chemical concepts and connects them to scientific inquiry showing how research is done, engages with their studies, and develops problem-solving skills and practical working skills [9,47]. In addition, it supports the development of thinking skills [5]. Thus, context-based laboratory activities can promote students' intrinsic interest in chemistry [33].

For the final task, students must find cellulose-related online news. Students answer questions based on the news, and these questions are related to the tone, viewpoint, and reliability of the selected news article. The aim of this task is to familiarize them with future possibilities of cellulose and ionic liquids and their visibility in the media. The task also helps practice scientific literacy and a critical attitude. Depending on the chosen news articles, they might also increase the viewpoint related to the connection of cellulose with the economy, industry, and professions, strengthening the vocational relevance [33].

The preliminary tasks and final tasks of the activity include reading articles and news. Using news and articles in teaching strengthens the view on the significance of chemistry for the present moment and for society [48] and therefore supports all relevance dimensions [33].

In the designed activity ionic liquids are the scientific context. When chemistry is approached through ionic liquids, it illustrates what kind of chemistry is needed, e.g., in the textile industry. This viewpoint may also broaden the view of the connection between chemistry innovation and society [16]. In the best-case scenario, through context-based teaching on ionic liquids, it is possible to support relevance both in the individual and societal dimensions, and to increase understanding of the meaning of chemistry and its connection to society now and in the future. The context of ionic liquids and cellulose enables versatile and multidimensional work with chemistry, which may also affect vocational relevance by increasing the view on what kinds of things chemistry can be used for.

Ionic liquids and cellulose as a context enable learning about chemistry subject matter such as the interaction of molecules, chemical bonds, and organic chemistry. In this study, the context of ionic liquids has been looked at mainly from the viewpoint of dissolving cellulose, but ionic liquids as a context would also enable other kinds of subject approaches [16].

The ecological, economic, and societal dimensions should be taken into consideration in teaching about sustainable development [49]. In the activity, the ecological viewpoint is introduced alongside materials, such as during studying cotton and solvents. The economic viewpoint is present when it is pondered on how the new methods of using cellulose affect, for example, the Finnish economy. Through the need for cellulose and chemistry's solution-centered viewpoint, the societal view is also considered.

According to Burmeister et al. [49], it is central in teaching about sustainable development that youth are given the ability to develop into responsible and active members of society. It can be said that teaching sustainable development supports the dimension of societal relevance in Stuckey et al.'s [33] relevance model. Additionally, the societal dimension is supported by an illustration of the role of chemistry in daily life and in promoting sustainable development, which may increase students' regard for and understanding the significance of chemistry.

According to example, a context-based laboratory activity based on topical sustainable chemistry that has real-life applications easily found in media can offer many possibilities for supporting the dimensions of relevance. In particular, the activity makes it possible to support the dimension of societal relevance through context and theme. Insights that support the relevance of the activity have been collected in Figure 4. These have been categorized based on the dimension of relevance that they mainly affect. However, the dimensions of relevance are overlapping and interdependent [33], and therefore things that influence the relevance usually affect several dimensions simultaneously, and a direct and unambiguous classification cannot be made.

We do not argue that these matters have a direct effect on a student's relevance; instead, all the above-mentioned viewpoints are possible factors affecting relevance. The effects of relevance can be personal, and things may have very different effects on different students depending on their prior knowledge and their interests. Additionally, the chosen structure and instructional method may have an influence.

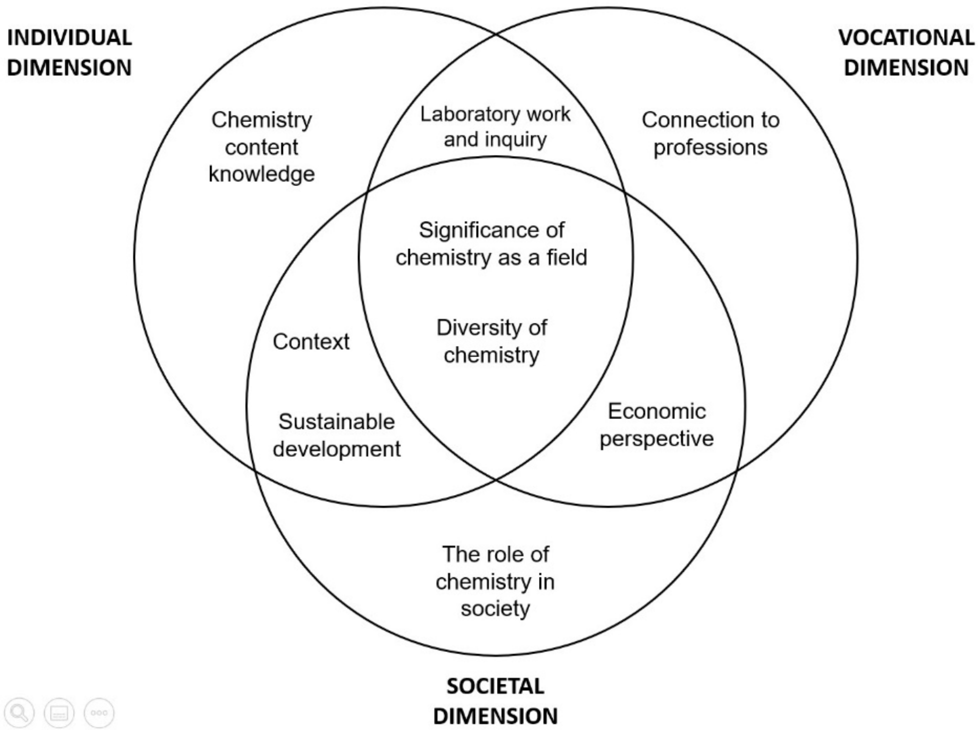

Figure 4. Support for relevance enabled by the design solution (activity), classified according to Stuckey et al.'s [33] dimensions.

5. Empirical Problem Analysis: Future Chemistry Teachers' Perceptions (RQ3)

The design solution is tested and developed in two cycles. The cyclic approach enables iterating towards the objectives set for the design project [26]. As mentioned, the design solution was tested with the end users to address their needs specifically. In this DBR, the final users will be future chemistry teachers and in-service chemistry teachers in general. Therefore, the case study used in the formative evaluation is conducted at the pre-service chemistry education level.

5.1. Methods

The design solution was evaluated as a case study [50]. For increasing the reliability, the triangulation of methods was exploited in data gathering [51]. Data were collected via interviews (n = 3) and student essays (n = 7) (see Appendices B and C). Before the data gathering, all participants were informed about the data processing guidelines and why the research was conducted. For example, all data were anonymized and processed without the risk of recognizing the participants. All participants gave their consent and participated in the study willingly. The research setting design followed the social science ethics guidelines set by the University of Helsinki [52].

The interviews consisted of three future chemistry teachers. Before the interviews, the interviewees had familiarized themselves with the first version of the design solution. The interviewed persons had studied subject teacher studies for 3–5 years, and all of them had much experience in guiding laboratory activities through their work in a non-formal school laboratory operating at the university premises [53]. The interviewees are marked I1, I2, and I3 in the results section. Interviews were conducted as theme interviews by their nature and the questions were classified based on the relevance model [33] (see Appendix B).

The aim of essays was to increase reliability via triangulation. Essays were gathered during a chemistry teacher education course at the University of Helsinki. In the course, students first tested the activity themselves and analyzed the experienced relevance by writing an essay on the topic. Seven students agreed to participate in the study and their essays are included in the data. In the results, the essays are referred to as E1, E2, E3, and so on.

The data were analyzed through a theory-based qualitative content analysis [54] using the Stuckey et al.'s [33] relevance model as the theoretical framework. First, the raw data was simplified to make it easier to process. Then simplified expressions like "Cellulose is interesting because it is familiar" were organized into classes like "Context". Finally, these classes were placed under components and dimensions of the relevance model [33] (see Table 2). After the classification of data, connections were studied by finding regularities and similarities. The results were validated through an interrater collaboration where all results were discussed together by the first author and second author to improve the reliability of the analysis.

Table 2. An example of the classification of data.

Raw Data	Simplified Expression	Class	Components	Dimension
It may interest them, especially because of cellulose, as it's a familiar substance for everyone. (I1)	Cellulose is interesting because it is familiar	Context	Intrinsic Present	Individual relevance

Triangulation is aimed at strengthening the reliability of the case study. When several data collection methods are used, it provides a more comprehensive view of the phenomenon than relying on a single data gathering method [51]. This phase was conducted as qualitative research, where the validity and reliability can be maintained via the following procedures. We aimed for high reliability by recording the interviews, by consistent processes, by accurate word-for-word transcriptions, and by doing logical theory-based classification of data. In addition, direct quotations have been included in the results section for supporting interpretations. Note that the above-described method was used to analyze the RQ3b, the relevance part. Answering the RQ3a, which addressed the practical side of the development, was carried out by analyzing future chemistry teachers' perceptions via inductive content analysis [51].

5.2. Results and Discussion

In this section, we provide answers to the third research question, which had two focuses. First, we address future chemistry teachers' perceptions related to the designed activity's general functionality (RQ3a). Then we report their perceptions of the activity's relevance (RQ3b).

5.2.1. Future Chemistry Teachers' Perceptions of Activity's Functionality (RQ3a)

Perceptions of the functionality were mainly derived from the interview questions 1–4 (see Appendix B). The observations were categorized inductively into the following classes: Significance, Good features, To be improved, and Development suggestions (see a summary in Table 3).

Comments regarding the preliminary tasks were mainly positive. It was mentioned that preliminary tasks, for example, engage well in the topic of the activity and create meaning for the laboratory part. This is especially important for efficient laboratory instruction [46]. The article was experienced as suitable for the topic and the questions were thought to be relevant for the activity. There was some contradiction in the answers regarding the language of the article. One interviewee and a few essay writers felt that the English article was heavy to read, and this made it difficult to understand the topic. On the other hand, two other responses stated that the English in the article was easy to read and that it prepared for further studies, where data are often written in English.

- "Well, I thought it was good and a good length. I first thought it was awfully long, but there were a lot of those pictures in between. So, it was by no means too long. It was a good task." (I1)

- "I think there were good and relevant questions . . . , but I also felt this can be a little hard for high school students. Perhaps a bit difficult words to understand for a that age." (I2)

Background information and questions were included in the work sheet of the laboratory part, and tips for teachers and illustrations were praised in the answers. Two interviewees commented that the pictures were a good addition and that they demonstrated well, for example, the use of two clamps. Additionally, it was mentioned that the picture of a vial was good because many students do not necessarily know what it looks like. However, a small development suggestion was that a caption could be added to the picture of the vial. This was added as requested (see Appendix A).

- "Yeah. The vial and the gap. Should there be a picture showing what a vial is? Or I'm used to it that work instructions explain in detail all not-familiar tools. Especially with the vial because the instructions tell to heat the vial with two clamps. So, it would need a Picture 3. Vial and a cap." (I3)

All interviewees felt that they would be able to complete the activity by following the work sheet. Two interviewees thought that the working instructions were clear, but one paid attention to the text lengths and too few difficult sentences. For example, interviewee 3 commented that the second step of the work instruction included many consecutive units of volume and units of mass, which were difficult to read. As a development suggestion, it was proposed that the sentences could be chopped into smaller parts and for example, the syringe sizes could be written inside parentheses. So the solution texts were elaborated (see Appendix A).

- "Well, for example, in this second step it reads that weigh 1.9 g DNB into a 20-millimeter vial in the fume hood using 0.9 mm needle assisted with two 1 mm syringes. So, I wonder that there were 1.9 and 0.9 etc. i.e., a lot of commas, I would break this section to smaller sentences." (I3)

In two interviews, it was highlighted that the working instruction would need a summary at the beginning or an introduction to the work. The interviewees thought that a piece of text was missing, especially in the laboratory part, where the purpose of the work is explained. Additionally, one interviewee commented that a summary could be added at the beginning, where the parts of the activity are explained. This was added as suggested (see Appendix A).

- "There was some motivation section somewhere up, but there could also be a short summary that explains all the parts that the work will be including." (I2)

The learning tasks related to the laboratory phase were experienced as good. One interviewee suggested that a task related to ionic liquids could be added. In addition, two interviewees pondered on work safety. They commented that one needs to be careful when using needles and that this could be added into the work safety box and written in a more explicit way.

- "Well, that's what I wrote to me about that occupational safety. You have to be pretty careful when there are needles and chemicals in the fume hood." (I2)

In a couple of answers, the final tasks were thought to be such that summarize the topic and give additional information. It is important to summarize the laboratory part so that observations will be understood and linked to the theory [46]. It was also mentioned that the tasks were successful in connecting the societal and economical viewpoints with the activity. These perspectives give an understanding of how chemistry interacts with society teaching about the nature of chemistry as science [13]. One interviewee noted that the final task was very flexible and that it gives the instructor room to support learners individually during work. One interviewee pondered on how to source criticism is considered in the work if students are not familiar with it. On the other hand, in an essay answer, it was noted that the task supports critical literacy. Learning about source criticism is an important skill that should be taught in school [48]. One interviewee reflected on how the task seems to be an engaging task rather than a summarizing task.

- "Well, final task used ICT tools which was good. Then it summarized the work and connected it well to society and industry. In addition, student would have an active role in it. But I was wondering how to teach source criticism. If students search information about cellulose, how do they know what information is reliable?" (I2)

In addition to the above-mentioned observations, the interviewees noticed some spelling mistakes. All in all, the activity was experienced as functional and clear. Some answers highlighted that the preliminary tasks and theory are an essential part of the entity. One development suggestion was that storytelling could be included in the laboratory part for motivation. Additionally, the entity could be made clearer by including a previously mentioned summary or an introduction to the beginning of the activity. All suggestions related to the practical side of the activity were implemented in design solution 2 (see Appendix A).

Table 3. Summary of the future chemistry teacher's perceptions of the activity's functionalities.

	Significance	Good Features	To Be Improved	Development Suggestions
Preliminary tasks	Engages into the activity, decreases the time needed to spend in a lab, creates meaning for the activity, integrates laboratory part with theory.	Suitable length, relevant questions, essentially connected to the work.	The article in English is quite heavy to read. Action: Elaborated (see Appendix A).	It would be good to go over the tasks together, good that tasks are done before coming to the lab. Action: Added to teacher tips.
Laboratory task	-	Good and illustrative pictures, clear instructions, good background for the work, good tasks.	Too many things in the steps of the work instruction, it's not mentioned what the work is about. Action: Elaborated (see Appendix A).	A motivation for the work could be added, highlighting work safety, steps in the work instruction could be differentiated, a caption should be added to one of the pictures. Action: Elaborated (see Appendix A).
Final tasks	Integrated the topic into society and industry, adds meaning, gives additional information.	A good task: integrates ICT well, students have an active role, flexible, gives room for maneuvers.	Mostly engages on the topic, how to take source criticism into account. Action: Elaborated (see Appendix A).	A task related to ionic liquids was added (see Appendix A).
Entity	-	Useful tips for teachers.	Action: Spelling mistakes were corrected (see Appendix A)	An introduction in the beginning, there could be more storytelling, making wordforms clearer. Action: Elaborated (see Appendix A).

5.2.2. Future Chemistry Teachers' Perceptions of Relevance (RQ3b)

Individual Relevance

The data for future chemistry teachers' perceptions of individual relevance were gathered via interview questions 6 and 7 (see Appendix B) and essays. The participants were asked if the context is interesting for upper secondary school students, and can the activity be used for teaching chemistry topics in formal education. In the essays, they were asked to reflect on how the activity supports different relevance dimensions [33]. Altogether, eight different main categories were identified through the analysis (see a summary from Table 4). The categories are bolded in the text.

The context (1) class includes all observations addressing ionic liquids directly or indirectly, for example when ionic liquids, cellulose, clothing, and materials were mentioned. The contexts were evaluated as increasing interest in a current topic, a new viewpoint, and familiar things.

- "Also, at this point, responsibility, consuming, climate and the future are current topics, which may for their part cause intrinsic and extrinsic motivation in students, towards chemistry studies." (E4)
- "It may interest them, especially because of cellulose, as it's a familiar substance for everyone." (I1)
- Yes, this must be a new topic for them. Because ionic liquids are not gone over in upper secondary school. So, this could also increase interest." (I1)
- "I think that the aim of preliminary tasks is to especially create intrinsic motivation through societally important things, and at the same time to create interest towards research objects on an individual level." (E6)

Some answers stated that laboratory work (2) as a learning environment generally increases interest. This claim is supported by many studies [55]. In addition, it is important that the topic is connected to a daily life (3) context for students [7,47]. The ionic liquids as a context were found to be new and interesting. Few respondents felt that a new context would interest students who are already interested in chemistry. On the other hand, it was found that contexts that were familiar and linked to daily life such as clothing could arouse interest also for students that were not interested in chemistry. In our analysis, a context that is interesting for students supports individual intrinsic relevance in the present moment [7,33].

Working skills (4) that occurred in answers included laboratory work skills, group work skills, and ICT skills. Other working methods (5) include information retrieval and reading scientific papers, which are mentioned to be present in the preliminary and final tasks. Additionally, Hofstein et al. [55] mention that laboratory work enables understanding of chemistry concepts, learning to learn, development of problem-solving skills and thinking skills as well as an understanding of the nature of science. It can be thought that practicing all working skills and methods increases the skills and chemistry content (6) knowledge that students need in the future. It was also felt that laboratory work and the context influence the feeling of efficacy and motivation.

- "As a student is working, their feeling of efficacy and influence on the individual and why not on the societal level, is present. Idea about the fact that everyone can be chemists is a factor, which creates interest for young students, and through this increases motivation for developing and diversification of one's individual chemistry skills." (E6)

The above-mentioned skills may also affect the student's behavior in the future. The interdisciplinarity (7) nature of the activity may influence future behavior. Interdisciplinarity in teaching may affect a student's notions and views on chemistry as a field.

- "—this could be linked to many subjects and why we need such an innovation, or an invention could be linked into many topics. In a sense, it could be linked to consuming, a human's consumer habits, food production and others, so this activity supports topics that are taught in school—" (I3)

In addition to interdisciplinarity, it was mentioned in the answers that the activity consists of themes from society, industry, and economy. These have been categorized into an upper class labeled as themes (8). Assimilation of these themes is related to aims set by the curriculum, and therefore they are connected to a student's extrinsic relevance in the present moment, for example, through being successful at school [33]. Another factor that possibly affects being successful at school is the chemistry contents of the activity. Concepts such as hydrogen bonds, organic chemistry, and materials, were mentioned. In addition to the above-mentioned contents, Hernani et al. [16] and Mudzakir et al. [42] have evaluated that the context of ionic liquids enables the integration of, for example, viscosity, carbohydrates, vapor pressure, and acid and base reactions, into teaching. However, in two answers it was highlighted that the activity functions more as an applied addition to chemistry teaching rather than as a general part of topics used in teaching.

- "Personally, I felt like the work was meaningful, when one knows that the process in question that one has completed, may act as an ecological solution that addresses the growing need for textiles." (E3)
- "In the work, I learned new things about chemical work and applications of chemistry, which in my case increase my interest towards chemistry." (E4)

Personal interest in the topic was supported via selected working methods, a new topic (ionic liquids), and the significance of the topic from the teacher's viewpoint. Additionally, one interviewee pondered on the fact that one's own interest is increased by the fact that the context is ahead of its time:

- "Well, I think that this is an odd topic, because there is a student work on the topic, but the topic isn't yet as grand in the commercial sense. Usually, student works are made on a topic a little bit later. In a sense, they have been developed after an innovation. That is why I feel that this is perhaps the first student work that is ahead of its time." (I3)

Table 4. Perceptions of the activity's individual relevance.

	Intrinsic	**Extrinsic**
Present	Context (1) Connection to daily life (2) Laboratory work (3)	Chemistry content (6) Working skills (4) Themes (8)
Future	Working skills (4) Chemistry content (6) Other working methods (5)	Working skills (4) Other working methods (5) Interdisciplinarity (7)

Vocational Relevance

The data for future chemistry teachers' perceptions of individual relevance was gathered via interview questions 8 and 9 (see Appendix B) and essays.

The significance of the field of chemistry was highlighted in the activity, and this came up strongly in almost all answers. It was mentioned that the activity brings out the significance of the field rather than giving information on actual professions. Additionally, chemistry's possibilities to influence were thought of as an important view that was present in the activity. One of the answers mentioned that the activity gives an image especially related to future careers:

- "From the vocational perspective, the activity may give new perspectives for students regarding future career possibilities." (E3)

All of these may influence a student's interest in a profession, which may influence career choices and motivation for studying for a career [33]. Knowledge of careers may also influence working towards a meaningful career.

It was mentioned in an answer that the activity gives information on careers in the field of process chemistry. According to a few answers, the activity highlights the versatility of the field and its possibilities to influence, which was thought to increase understanding and consciousness regarding careers in the field of chemistry.

- "Students get to physically experience, see and test how many problems can be solved on the level of chemistry in the future. For example, the lack of materials." (E4)

- "A practical example of the future of chemical industries supports experienced relevance: if artificial cellulose can address the growth of demand for textiles, what kinds of other global challenges could be solved with chemistry." (E3)

Some answers included a view on the fact that the activity broadens the image of how a chemical innovation can also affect other careers, such as the clothing industry and trade sector, by producing new commercial materials. Views on the field of chemistry and its significance and relationship with other fields can have a significant effect on students' attitudes and motivation toward studying a field [33]. Even if a student is not directly interested in a profession in the field of chemistry, understanding the significance of chemistry may motivate them towards studying chemistry, from the viewpoint of having a career in another field [33,34]. In addition, working skills and working methods were thought to increase the knowledge and skills necessary in careers.

- "Laboratory work shows what kinds of information and skills e.g., a chemist, pharmacist or even a doctor needs in their work." (E2)

Working skills like laboratory skills, research skills, and information retrieval were especially mentioned. Additionally, understanding the chemistry contents of the activity is important. According to the answers, it is mentioned that the field of chemistry is a very significant field that influences society and the economy. According to the answers, this comes up also in the context of the activity and in the tasks. It was mentioned that in particular the final task offers information on the future and on professions. This supports the activity's extrinsic future relevance by preparing students for professions that are important for society.

It was certainly more difficult to find vocational relevance in the activity. Factors related to societal and individual relevance were found much more often, and they were discussed in more detail, especially in the essay answers.

Societal Relevance

The activity's possibilities related to societal relevance were studied with interview questions 10 and 11 (see Appendix B) as well as with the essay answers. The majority of answers were closely related to the significance of the field of chemistry, and chemistry's possibilities to influence.

Several answers highlighted that the activity has high societal relevance. Respondents experienced that the societal view was especially present in the preliminary and final tasks. Most of the observations related to societal relevance are connected to the future dimension. In addition, many respondents noted that activity acts as an example of how chemistry works in solving societal problems via new innovations.

- "—in my opinion this reveals specific kinds of innovative solutions that are needed more than ever in the current world." (I3)
- "It discusses about synthetic cellulose and how chemistry can help in solving the problem." (I1)
- "A practical example of the future of chemical industries supports experienced relevance: if artificial cellulose can address the growth of demand for textiles, what kinds of other global challenges could be solved with chemistry." (E3)

Several essays pointed out that the societal significance comes up in the activity's connections to the economy and industry. In particular, the final task of news retrieval may present how new methods of using cellulose will influence Finland's industry and economy.

- "News offer a possibility to observe future needs of cellulose fibers as well as their significance economically." (E6)

Some respondents paid attention to the activity's themes of food production and the clothing industry and pondered on the societal significance of this. Understanding the significance of the field and influencing possibilities can support societal relevance intrinsically by increasing knowledge of chemistry's possibilities for solving societal issues.

This may also increase interest in societal matters and influence in general, which would strengthen the extrinsic relevance. For example, learning how to be a responsible citizen and developing sustainable lifestyles [49].

All interviewees agreed that the activity might influence students' appreciation of the field of chemistry if learners understand its societal significance. Appreciation towards the chemistry may have an effect on a student's values and actions, which in turn has an effect on society and working as an active citizen [49]. This would support extrinsic societal relevance.

Lastly, many respondents highlighted that relevance perspectives depend on the teachers and instructors. A teacher can affect the experienced relevance by highlighting some dimensions more than others.

- "—In the way in which students think about it and its meaning, I think that the instructor has the responsibility of it. How the instructor instructs and what kinds of examples are introduced during work." (I3)

6. Conclusions

The main result of this DBR is the context-based laboratory activity based on sustainable chemistry research on ionic liquids. The objective of the designed activity is to support the relevance of chemistry learning through a context-based approach. Therefore, the design was grounded in theoretical frameworks of context-based learning [7,43] and the relevance model [33]. The design process included two cycles and the design solution was iterated via the results of a qualitative case study conducted with future chemistry teachers (see Section 5). According to the case study results, the design solution was clarified by adding captions for pictures and including an explicit description of the activity at the beginning of the activity.

The other main result of the research is that the ionic-liquids context offers great possibilities for supporting relevance and sustainable chemistry education. According to future chemistry teachers, an interesting new context for laboratory learning can increase interest in chemistry studies and the designed learning tasks supported all relevance dimensions.

The insights retrieved from the case study encourage us to conduct further studies with the context. In the future, it would be important to broaden the perspective and study the relevance of ionic liquids as the context for laboratory work with high-school students. In addition, it would be important to explore in-service teachers' perceptions too. Teachers are the stakeholders that decide what kind of learning materials and contexts will be used in schools. Do chemistry teachers experience ionic liquids as a relevant context for promoting chemistry's sustainable nature of science to students?

Author Contributions: J.P.: Conceptualization; data curation; methodology; project administration; supervision; visualization; writing—review and editing. V.K.: conceptualization; formal analysis; investigation; methodology; project administration; resources; visualization; writing—original draft preparation. M.A.: conceptualization; methodology; writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: Open access funding provided by University of Helsinki.

Informed Consent Statement: All respondents gave their informed consent before participating to the study.

Data Availability Statement: The data used in this study are available on request from the corresponding author. The data have been anonymized but are not publicly available because of the privacy issues related to the qualitative nature of it.

Acknowledgments: We are grateful to Ilkka Kilpeläinen and his research group for great collaboration and LUMA lab, ChemistryLab Gadolin.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Description of the Designed Activity

The developed activity can be downloaded from Zenodo as a PDF file: https://doi.org/10.5281/zenodo.6417566.

Appendix B. Interview Questions

Functionality of the activity (RQ3a)	1. What do you think of the functionality and significance of the preliminary tasks? 2. Are the instructions of the work instruction clear? 3. What do you think of the functionality and significance of the final tasks? 4. How would you develop the activity?
Individual relevance (RQ3b)	5. How interesting do you find the context of the activity? 6. How interesting do you find the context from the viewpoint of upper secondary school students? 7. Does the activity support topics taught in school?
Vocational relevance (RQ3b)	8. Do you think that the activity includes skills required in professions? 9. Do you think that the activity could influence students' career choices?
Societal relevance (RQ3b)	10. Do you think that the societal significance of chemistry comes up in the activity? 11. Do you think that the activity could influence a student's appreciation of the field of chemistry?

Appendix C. Essay Assignment

Testing phase

1. Do the preliminary task.
2. Test the practical activity in laboratory.
3. Do the final tasks.

Reflection phase

After testing phase think the relevance of the activity from different aspects. Write an essay in which you discuss about:

- How does the activity support the relevance of chemistry studies from the view of Stuckey et al.'s (2013) relevance models dimensions.
- What kind of pedagogical possibilities activity's parts (preliminary task, laboratory phase and final tasks) have? For example, you can reflect your own experiences and perceptions to the curriculum.

References

1. Marks, R.; Eilks, I. Promoting Scientific Literacy Using a Sociocritical and Problem-Oriented Approach to Chemistry Teaching: Concept, Examples, Experiences. *Int. J. Environ. Sci. Educ.* **2009**, *4*, 231–245.
2. Juntunen, M.; Aksela, M. Education for Sustainable Development in Chemistry—Challenges, Possibilities and Pedagogical Models in Finland and Elsewhere. *Chem. Educ. Res. Pract.* **2014**, *15*, 488–500. [CrossRef]
3. Vesterinen, V.-M.; Tolppanen, S.; Aksela, M. Toward Citizenship Science Education: What Students Do to Make the World a Better Place? *Int. J. Sci. Educ.* **2016**, *38*, 30–50. [CrossRef]
4. Herranen, J.; Yavuzkaya, M.; Sjöström, J. Embedding Chemistry Education into Environmental and Sustainability Education: Development of a Didaktik Model Based on an Eco-Reflexive Approach. *Sustainability* **2021**, *13*, 1746. [CrossRef]
5. Rocard, M.; Csermely, P.; Jorde, D.; Lenzen, D.; Walberg-Henriksson, H.; Hemmo, V. *Science Education Now: A Renewed Pedagogy for the Future of Europe*; Office for Official Publications of the European Communities: Luxembourg, 2007; ISBN 978-92-79-05659-8.
6. Sjøberg, S.; Schreiner, C. *The ROSE Project: An Overview and Key Findings*; University of Oslo: Oslo, Sweden, 2010; pp. 1–31.

7. Gilbert, J. On the Nature of "Context" in Chemical Education. *Int. J. Sci. Educ.* **2006**, *28*, 957–976. [CrossRef]
8. Aksela, M. Education for Sustainable Development in Chemistry Teacher Education. *LUMAT-B Int. J. Math Sci. Technol. Educ.* **2016**, *1*, 1–8.
9. Eilks, I.; Hofstein, A. (Eds.) *Relevant Chemistry Education: From Theory to Practice*; Sense Publishers: Rotterdam, The Netherlands, 2015; ISBN 978-94-6300-175-5.
10. Stuckey, M.; Eilks, I. Increasing Student Motivation and the Perception of Chemistry's Relevance in the Classroom by Learning about Tattooing from a Chemical and Societal View. *Chem. Educ. Res. Pract.* **2014**, *15*, 156–167. [CrossRef]
11. Blonder, R.; Mamlok-Naaman, R. Teaching Chemistry through Contemporary Research versus Using a Historical Approach. *Chem. Teach. Int.* **2019**, *2*, 20180011. [CrossRef]
12. McComas, W.F.; Clough, M.P. Nature of Science in Science Instruction: Meaning, Advocacy, Rationales, and Recommendations. In *Nature of Science in Science Instruction: Rationales and Strategies*; McComas, W., Ed.; Science: Philosophy, History and Education; Springer International Publishing: Cham, Switzerland, 2020; pp. 3–22, ISBN 978-3-030-57239-6.
13. Vesterinen, V.-M.; Aksela, M.; Sundberg, M.R. Nature of Chemistry in the National Frame Curricula for Upper Secondary Education in Finland, Norway and Sweden. *Nord. Stud. Sci. Educ.* **2009**, *5*, 200–212. [CrossRef]
14. Nouri, N.; Saberi, M.; McComas, W.F.; Mohammadi, M. Proposed Teacher Competencies to Support Effective Nature of Science Instruction: A Meta-Synthesis of the Literature. *J. Sci. Teach. Educ.* **2021**, *32*, 601–624. [CrossRef]
15. Parviainen, A.; Wahlström, R.; Liimatainen, U.; Liitiä, T.; Rovio, S.; Helminen, J.K.J.; Hyväkkö, U.; King, A.W.T.; Suurnäkki, A.; Kilpeläinen, I. Sustainability of Cellulose Dissolution and Regeneration in 1,5-Diazabicyclo[4.3.0]Non-5-Enium Acetate: A Batch Simulation of the IONCELL-F Process. *RSC Adv.* **2015**, *5*, 69728–69737. [CrossRef]
16. Hernani; Mudzakir, A.; Sumarna, O. Ionic Liquids as a Basis Context for Developing High School Chemistry Teaching Materials. *J. Phys. Conf. Ser.* **2017**, *812*, 012085. [CrossRef]
17. Mahaffy, P.G.; Ho, F.M.; Haack, J.A.; Brush, E.J. Can Chemistry Be a Central Science without Systems Thinking? *J. Chem. Educ.* **2019**, *96*, 2679–2681. [CrossRef]
18. Hurst, G.A.; Slootweg, J.C.; Balu, A.M.; Climent-Bellido, M.S.; Gomera, A.; Gomez, P.; Luque, R.; Mammino, L.; Spanevello, R.A.; Saito, K.; et al. International Perspectives on Green and Sustainable Chemistry Education via Systems Thinking. *J. Chem. Educ.* **2019**, *96*, 2794–2804. [CrossRef]
19. Eaton, A.C.; Delaney, S.; Schultz, M. Situating Sustainable Development within Secondary Chemistry Education via Systems Thinking: A Depth Study Approach. *J. Chem. Educ.* **2019**, *96*, 2968–2974. [CrossRef]
20. Aubrecht, K.B.; Bourgeois, M.; Brush, E.J.; MacKellar, J.; Wissinger, J.E. Integrating Green Chemistry in the Curriculum: Building Student Skills in Systems Thinking, Safety, and Sustainability. *J. Chem. Educ.* **2019**, *96*, 2872–2880. [CrossRef]
21. Ginzburg, A.L.; Check, C.E.; Hovekamp, D.P.; Sillin, A.N.; Brett, J.; Eshelman, H.; Hutchison, J.E. Experiential Learning To Promote Systems Thinking in Chemistry: Evaluating and Designing Sustainable Products in a Polymer Immersion Lab. *J. Chem. Educ.* **2019**, *96*, 2863–2871. [CrossRef]
22. Blatti, J.L.; Garcia, J.; Cave, D.; Monge, F.; Cuccinello, A.; Portillo, J.; Juarez, B.; Chan, E.; Schwebel, F. Systems Thinking in Science Education and Outreach toward a Sustainable Future. *J. Chem. Educ.* **2019**, *96*, 2852–2862. [CrossRef]
23. Michalopoulou, E.; Shallcross, D.E.; Atkins, E.; Tierney, A.; Norman, N.C.; Preist, C.; O'Doherty, S.; Saunders, R.; Birkett, A.; Willmore, C.; et al. The End of Simple Problems: Repositioning Chemistry in Higher Education and Society Using a Systems Thinking Approach and the United Nations' Sustainable Development Goals as a Framework. *J. Chem. Educ.* **2019**, *96*, 2825–2835. [CrossRef]
24. Zuin, G.V.; Eilks, I.; Elschami, M.; Kümmerer, K. Education in Green Chemistry and in Sustainable Chemistry: Perspectives towards Sustainability. *Green Chem.* **2021**, *23*, 1594–1608. [CrossRef]
25. Aksela, M. Towards Student-Centred Solutions and Pedagogical Innovations in Science Education through Co-Design Approach within Design-Based Research. *LUMAT Int. J. Math Sci. Technol. Educ.* **2019**, *7*, 113–139. [CrossRef]
26. Edelson, D.C. Design Research: What We Learn When We Engage in Design. *J. Learn. Sci.* **2002**, *11*, 105–121. [CrossRef]
27. Anderson, T.; Shattuck, J. Design-Based Research A Decade of Progress in Education Research? *Educ. Res.* **2012**, *41*, 16–25. [CrossRef]
28. Juuti, K.; Lavonen, J. Design-Based Research in Science Education: One Step Towards Methodology. *Nord. Stud. Sci. Educ.* **2006**, *2*, 54–68. [CrossRef]
29. The Design-Based Research Collective Design-Based Research: An Emerging Paradigm for Educational Inquiry. *Educ. Res.* **2003**, *32*, 5–8. [CrossRef]
30. Barab, S.; Squire, K. Design-Based Research: Putting a Stake in the Ground. *J. Learn. Sci.* **2004**, *13*, 1–14. [CrossRef]
31. Dede, C. If Design-Based Research Is the Answer, What Is the Question? A Commentary on Collins, Joseph, and Bielaczyc; DiSessa and Cobb; and Fishman, Marx, Blumenthal, Krajcik, and Soloway in the JLS Special Issue on Design-Based Research. *J. Learn. Sci.* **2004**, *13*, 105–114. [CrossRef]
32. Pernaa, J.; Aksela, M. Model-Based Design Research: A Practical Method for Educational Innovations. *Adv. Bus.-Relat. Sci. Res. J.* **2013**, *4*, 71–83.
33. Stuckey, M.; Hofstein, A.; Mamlok-Naaman, R.; Eilks, I. The Meaning of 'Relevance' in Science Education and Its Implications for the Science Curriculum. *Stud. Sci. Educ.* **2013**, *49*, 1–34. [CrossRef]

34. Eilks, I.; Rauch, F.; Ralle, B.; Hofstein, A. How to Allocate the Chemistry Curriculum Between Science and Society. In *Teaching Chemistry—A Studybook: A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers*; Eilks, I., Hofstein, A., Eds.; SensePublishers: Rotterdam, The Netherlands, 2013; pp. 1–36, ISBN 978-94-6209-140-5.
35. Ventura, S.P.M.; Silva, F.A.; Quental, M.V.; Mondal, D.; Freire, M.G.; Coutinho, J.A.P. Ionic-Liquid-Mediated Extraction and Separation Processes for Bioactive Compounds: Past, Present, and Future Trends. *Chem. Rev.* **2017**, *117*, 6984–7052. [CrossRef]
36. Gomes, J.M.; Silva, S.S.; Reis, R.L. Biocompatible Ionic Liquids: Fundamental Behaviours and Applications. *Chem. Soc. Rev.* **2019**, *48*, 4317–4335. [CrossRef] [PubMed]
37. Egorova, K.S.; Gordeev, E.G.; Ananikov, V.P. Biological Activity of Ionic Liquids and Their Application in Pharmaceutics and Medicine. *Chem. Rev.* **2017**, *117*, 7132–7189. [CrossRef] [PubMed]
38. Hummel, M.; Michud, A.; Tanttu, M.; Asaadi, S.; Ma, Y.; Hauru, L.K.J.; Parviainen, A.; King, A.W.T.; Kilpeläinen, I.; Sixta, H. Ionic Liquids for the Production of Man-Made Cellulosic Fibers: Opportunities and Challenges. In *Cellulose Chemistry and Properties: Fibers, Nanocelluloses and Advanced Materials*; Rojas, O.J., Ed.; Advances in Polymer Science; Springer International Publishing: Cham, Switzerland, 2015; Volume 271, pp. 133–168, ISBN 978-3-319-26013-6.
39. Anastas, P.; Eghbali, N. Green Chemistry: Principles and Practice. *Chem. Soc. Rev.* **2010**, *39*, 301–312. [CrossRef] [PubMed]
40. Cho, C.-W.; Pham, T.P.T.; Zhao, Y.; Stolte, S.; Yun, Y.-S. Review of the Toxic Effects of Ionic Liquids. *Sci. Total Environ.* **2021**, *786*, 147309. [CrossRef] [PubMed]
41. Amde, M.; Liu, J.-F.; Pang, L. Environmental Application, Fate, Effects, and Concerns of Ionic Liquids: A Review. *Environ. Sci. Technol.* **2015**, *49*, 12611–12627. [CrossRef]
42. Mudzakir, A.; Hernani; Widhiyanti, T.; Sudrajat, D.P. Contribution from Philosophy of Chemistry to Chemistry Education: In a Case of Ionic Liquids as Technochemistry. *AIP Conf. Proc.* **2017**, *1868*, 030012. [CrossRef]
43. Gilbert, J.; Bulte, A.; Pilot, A. Concept Development and Transfer in Context-Based Science Education. *Int. J. Sci. Educ.* **2011**, *33*, 817–837. [CrossRef]
44. Schwartz, A.T. Contextualized Chemistry Education: The American Experience. *Int. J. Sci. Educ.* **2006**, *28*, 977–998. [CrossRef]
45. de Jong, O. Making Chemistry Meaningful. Conditions for Successful Context-Based Teaching. *Educ. Quím.* **2006**, *17*, 215–221. [CrossRef]
46. Millar, R. The Role of Practical Work in the Teaching and Learning of Science. In *America's Lab Report*; National Academy of Sciences: Washington, DC, USA, 2004.
47. Herranen, J.; Kousa, P.; Fooladi, E.; Aksela, M. Inquiry as a Context-Based Practice—A Case Study of Pre-Service Teachers' Beliefs and Implementation of Inquiry in Context-Based Science Teaching. *Int. J. Sci. Educ.* **2019**, *41*, 1977–1998. [CrossRef]
48. Jarman, R.; McClune, B. *Developing Scientific Literacy: Using News Media in the Classroom*; McGraw-Hill/Open University Press: Maidenhead, UK, 2007; ISBN 9786611129408.
49. Burmeister, M.; Rauch, F.; Eilks, I. Education for Sustainable Development (ESD) and Chemistry Education. *Chem. Educ. Res. Pract.* **2012**, *13*, 59–68. [CrossRef]
50. Cohen, L.; Manion, L.; Morrison, K. *Research Methods in Education*, 6th ed.; Routledge: London, UK; New York, NY, USA, 2007; ISBN 978-0-415-37410-1.
51. Tuomi, J.; Sarajärvi, A. *Laadullinen Tutkimus Ja Sisällönanalyysi*; 8 painos; Tammi: Helsinki, Finland, 2009.
52. University of Helsinki Ethical Review in the Humanities and Social and Behavioural Sciences. Available online: https://www.helsinki.fi/en/research/services-researchers/ethical-review-research/humanities-social-sciences-and-behavioural-sciences (accessed on 10 December 2021).
53. Aksela, M. ChemistryLab Gadolin as a Relevant Learning Environment for Lifelong Learning. In Proceedings of the ESERA 2017 Conference, Dublin, Ireland, 21–25 August 2017.
54. Krippendorff, K. *Content Analysis: An Introduction to Its Methodology*, 2nd ed.; Sage: Thousand Oaks, CA, USA, 2004; ISBN 978-0-7619-1544-7.
55. Hofstein, A.; Kipnis, M.; Abrahams, I. How to Learn in and from the Chemistry Laboratory. In *Teaching Chemistry—A Studybook: A Practical Guide and Textbook for Student Teachers, Teacher Trainees and Teachers*; Eilks, I., Hofstein, A., Eds.; SensePublishers: Rotterdam, The Netherlands, 2013; pp. 153–182, ISBN 978-94-6209-140-5.