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Multidisciplinary Digital Publishing Institute
2021-02-06

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.

http://hdl.handle.net/10138/348944

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Article

Embedding Chemistry Education into Environmental and Sustainability Education: Development of a Didaktik Model Based on an Eco-Reflexive Approach

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Abstract: The aim of this theoretical paper is to develop and present a didaktik model that embeds chemistry education into Environmental and Sustainability Education (ESE) using an eco-reflexive approach. A didaktik model is a tool to help educators make decisions and reflect on why, what, how, and/or when to teach. The model presented here is a revised version of the Jegstad and Sinnes model from 2015. It was systematically developed based on a critical analysis of the previous ESD (Education for Sustainable Development)-based model. This process is part of what is called didactic modeling. The revised model consists of the following six categories: (i) socio-philosophical framing; (ii) sustainable schooling and living; (iii) critical views on chemistry's distinctiveness and methodological character; (iv) powerful chemical content knowledge; (v) critical views of chemistry in society; and (vi) eco-reflexivity through environmental and sustainability education. As in the model by Jegstad and Sinnes, the eco-reflexive didaktik model seeks to support chemistry educators in their sustainability-oriented educational planning and analysis, but from a more critical perspective. Based on an eco-reflexive *Bildung* approach, one additional category—socio-philosophical framing—was added to the revised model. This is because the previous model does not take sufficient account of worldview perspectives, cultural values, and educational philosophy. The eco-reflexive didaktik model is illustrated with boxes, and it is suggested that all categories in these boxes should be considered in holistic and eco-reflexive chemistry education. The purpose of such education is to develop students' *ChemoKnowings*.

Keywords: didaktik model; didactic modeling; eco-reflexivity; *Bildung*; sustainability education; environmental education; chemistry education

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Citation: 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. https://doi.org/10.3390/su13041746

Academic Editor: Catherine Housecroft

Received: 22 December 2020
Accepted: 2 February 2021
Published: 6 February 2021

1. Introduction

Understanding and applying chemistry, among other disciplines, is essential for all citizens, because chemistry is an important part of the world, society, and life. Sustainability as well as education are multidisciplinary fields, and how chemistry relates to sustainability issues depends on how we conceptualize sustainability as well as chemistry [1]. We understand our society as a risk society and sustainability issues as wicked problems with significant implications for science education [2–4]. Chemical actions (e.g., production and transport) have effects that are ecological, social, economic, political, and ethical [5]. It is therefore necessary to socially and critically contextualize science/chemistry in science/chemistry education [6].

Previous research on linking chemistry and sustainability education has focused mainly on combining chemistry education and Education for Sustainable Development (ESD) [7–9]. Due to critical discussions on, e.g., "development" in the term "sustainable development" and "for" in the term "education for sustainable development" [10,11], we argue that by integrating sustainability issues into chemistry education in a critical sense, ESD would better be replaced with "Environmental and Sustainability Education (ESE)". ESE is in line with the development of the research field from Environmental Education (EE) to ESD and further to ESE (e.g., [12–15]). Sund et al. described the difference as: "ESE teaching focuses on students' abilities to embrace and develop a 'democratic action-competence', whereas EE is more product-oriented and oriented towards learning specific facts and attitudes" [12] (p. 86).

We argue that a more critical approach is needed while embedding chemistry education into environmental and sustainability education in relation to the development of the research field, as described above. Therefore, the aim of this theoretical paper is to develop and present a didaktik model that embeds chemistry education into environmental and sustainability education (ESE) using an eco-reflexive approach. The didaktik model is a revised model developed based on a critical analysis of an ESD-based model by Jegstad and Sinnes from 2015 [7]. Chemistry teacher education programs could explicitly incorporate sustainability issues into their programs [16], and therefore the revised model could be used in future pre- and in-service teacher education programs. Our research question is:

- What would be included in a revised didaktik model from the perspective of Environmental and Sustainability Education (ESE), when framed by a *Bildung*-oriented eco-reflexive approach?

Didaktik models are tools for designing, analyzing, reflecting, and developing teaching, including its content [17,18]. They guide our attention and actions in teaching design, curriculum design, and learning assessment [17]. In this paper, we present a theoretical didaktik model. We suggest this model to be empirically tested and further developed with teachers in forthcoming studies.

The approach used in this article is eco-reflexivity, following the European *Bildung*-oriented *Didaktik* tradition. Eco-reflexivity can be understood as a critical and relational approach that is essential in today's risk society [19]. It requires an understanding of life and societal interactions as well as individual and collective responsibility for socio-ecojustice and global sustainability [19].

Bildung is the name of for a 750-year-old philosophical-spiritual tradition in Continental Europe [20]. The use of the term in educational settings began 250 years ago, meaning, for instance, self-formation. It spread from German-speaking countries to the Nordic countries. The two main elements of *Bildung* are: "autonomous self-formation and reflective and responsible action in (and interaction with) society" [21] (p. 273). Similarly, Rucker argued that *Bildung* can "be understood as a process in which an individual deals self-actively with the world and thereby develops a multi-dimensioned ability to self-determination under the claim of morality" [22] (p. 51). Since WWII, the socio-political dimension (emancipation) of the concept has been further emphasized [23]. *Bildung* can also been explained in the following way: "As an educational concept, *Bildung* incorporates culture, aesthetics, self-cultivation, political awareness and engagement" [24] (p. 3 ahead of print).

The Jegstad and Sinnes model revised in this paper consists of five categories: chemical content knowledge, chemistry in context, distinctiveness and methodological character of chemistry, ESD competences, and lived ESD [7] (see Figure 1 for our illustration of their model).

Jegstad and Sinnes also carried out empirical work on their model. In 2018, they analyzed Norwegian teacher education as a case study based on the model [25]. The case study showed that ESD can be implemented through the strengths of teacher educators and realizing ESD in the educators' existing practices. However, it was pointed out that more meta-reflection is needed to make sustainability more explicit for the teachers. To further develop sustainability-oriented chemistry education, we argue that the model needs to be developed theoretically.

Sustainability education should be holistic [8,19] and avoid silo thinking. Similarly, we also avoid a simplistic view of chemistry education and rather take a holistic view as a point of departure. In practice, this would mean including more philosophical, ethical, and socio-political perspectives into chemistry teaching, with a focus on problematization, understanding uncertainties, and balancing the benefits and risks of chemistry [19]. Thus, in addition to scientific concepts and models, both scientific processes—NOS (Nature of Science)—and societal contexts—STSE (Science–Technology–Society–Environment)—should be emphasized in a socio-critical and *Bildung*-oriented science/chemistry education [26]. In addition to these three domains—concepts, NOS, and STSE—Hodson argued for socio-political actions/activism as a fourth domain [27].

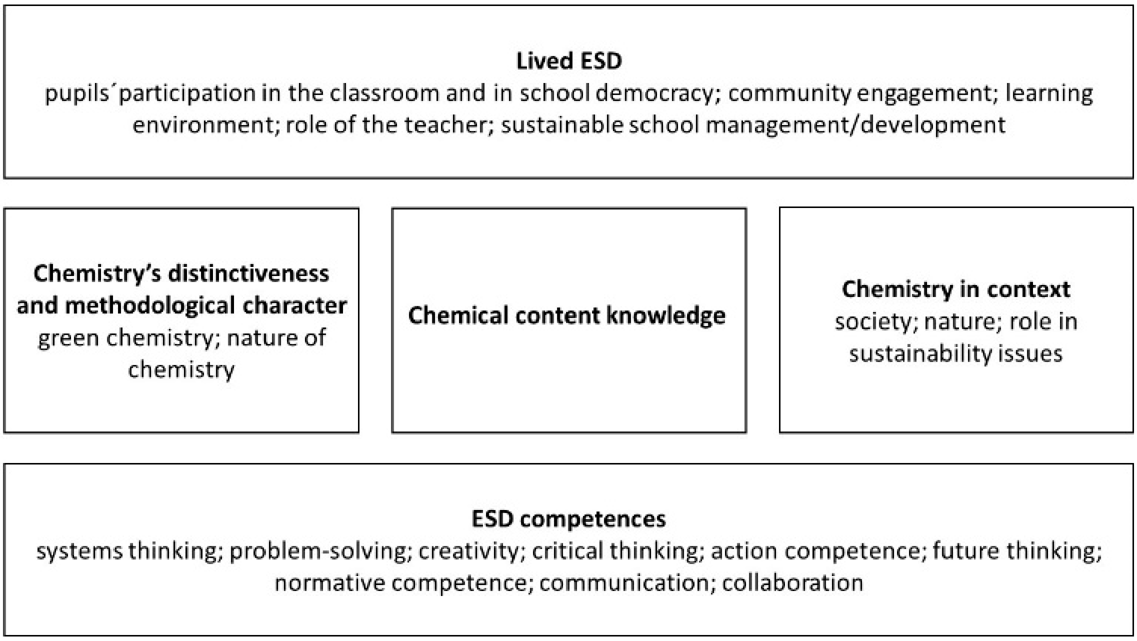

Figure 1. Content from the ESD model in relation to chemistry education [7].

Chemistry education has previously been discussed in relation to ESD [7–9], but not to a larger extent in relation to the ESE-field. This article contributes to the second of these two arenas. The developed didaktik model frames chemistry education through a socio-philosophical perspective. The purpose is to emphasize critical notions and the need to evaluate chemical knowledge in more detail, to describe teachers' and students' roles and views, and to emphasize eco-reflexivity. Special attention is paid to what is called *the pluralistic teaching tradition*. In contrast to the fact-based tradition, which focuses on correct scientific factual knowledge, or the normative tradition, which focuses on changing people's lifestyles in a particular way, the pluralistic tradition emphasizes the uncertainty of knowledge; environmental issues are viewed as moral and political problems [12]. According to the pluralistic tradition, it is important in education that the teacher focuses on "getting students to use their knowledge in action, not solely a belief that learning facts and norms is enough to make the change for a better future" [12] (p. 85).

2. Didactic Modeling

2.1. Critical Analysis of the Previous Model

As with all models, the Jegstad and Sinnes model [7] has its advantages and disadvantages. Their model has succeeded in visualizing how sustainability can be understood as a natural and practical part of chemistry teaching. The model is an elliptic model with chemical content knowledge in the center. Chemical content knowledge is placed at the center of the model because it is linked to the curriculum and is also needed for students to address socio-scientific issues. However, the model has a *within-discipline focus* and is based on the idea that the teacher begins pedagogical planning with chemical content knowledge. Jegstad and Sinnes argued that not all chemistry topics have a link to ESD, and other ellipses can be addressed in those situations. We argue that the weaknesses of the model are in its ESD focus and the way chemistry as a discipline is presented in relation to sustainability.

Firstly, the frames of sustainability-oriented chemistry are not visible in the original model. It must be asked what the foundations are when chemistry and sustainability are intertwined. Practical decisions in didaktik are made with certain values, ethics, and norms in mind [28], regardless of whether the teacher is aware of them. Furthermore, sustainability perspectives also play a role in setting goals for chemistry education [5].

Secondly, in the model, chemistry content knowledge is at the center because, according to the authors, teachers begin to plan their teaching based on it. We agree that content knowledge is important, but we highlight the importance of questioning the choice of chemistry content knowledge chosen for teaching. Not all chemistry knowledge aligns with sustainability. In the Jegstad and Sinnes model, this is addressed by stating that ESD can also be carried out by concentrating on other aspects of the model, if the content taught has no connection to ESD. In chemistry teaching, teachers are required to select the most important content for a limited time. We argue that chemistry content knowledge in the curriculum should be chosen related to so-called *wicked problems*, i.e., problems that are not easy to solve or even define [2]. According to the Jegstad and Sinnes model, the starting point is the curriculum, and teachers teach based on the curriculum. However, in future curriculum planning, the chosen chemical content knowledge could be critically reflected so that it is also relevant to sustainability issues.

Therefore, thirdly, a more critical view of how chemistry contributes to sustainability is needed. For example, *what* content is chosen, *why* is it chosen, and *how* it is taught or learned (the so-called didaktik questions in italic). In addition, the different approaches to sustainability and sustainable development are concepts that need to be taken into account. Especially, the environment, society, and economy cannot be seen as separate views, but as multi-layered [29], as different aspects that are interdependent.

Fourthly, teachers' and students' role in sustainability education should be specified. In Jegstad and Sinnes model, it is important to educate responsible citizens. While we agree with this goal, we also think that opportunities for student participation could be seen more openly. We could ask what space we give students in the classroom. Teachers and their educational planning are seen as central in the original model, and the whole model is built around this premise. However, the teachers' planning process could be more specified. Teachers always have didaktik questions to consider. While the original model seems practical, it is also narrow in how it presents the teachers' educational planning in this context.

Fifthly, while the considerations set for ESD competences are important, ideas about competencies need to be problematized (e.g., [30,31]). Furthermore, ESD as a concept has been under debate because it involves several perspectives [10], as discussed in the previous section.

2.2. Systematic Development of the Revised Model

Together, the three authors systematically developed the revised model presented in this article. We performed one step—a theoretical one—of what in the literature is called *didactic modeling* (e.g., [18,32,33]). It is a multifaceted concept that can be understood in different ways and includes both theoretical and practical steps. The aim of our didactic modeling was to create a clear model, which would serve as a didaktik model for (chemistry) educators (also those teaching younger students). It includes new, critical aspects that we think are—and which we argue are needed—in a model embedding chemistry education with sustainability issues based on an eco-reflexive *Bildung* approach.

The development process was carried out in five phases (see Figure 2). In the first phase, the authors collaboratively decided how the development would be carried out and decided that the development process could include both individual and collective phases. In addition, it was decided that, for the development of the model, the contents of the model would be transferred from spheres to boxes. In the second phase, the authors individually created separate versions of the model by critically analyzing the old model and including aspects into the model based on the latest literature on the topic. In the third phase, the authors met and discussed their different views. In the fourth phase, the authors individually created their versions of the model by including aspects of the other authors' preliminary model drafts. In the fifth phase, the final model was collaboratively negotiated and finalized by discussing on the various aspects.

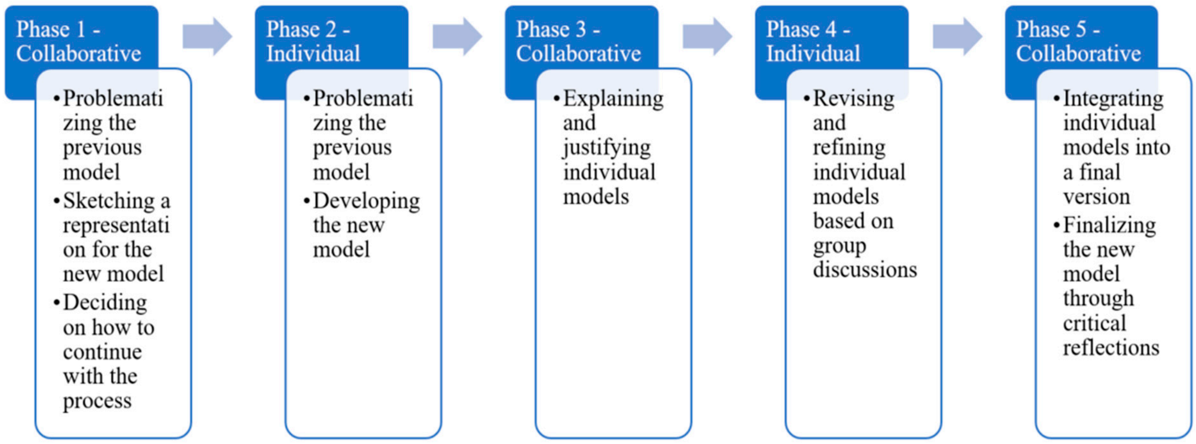

Figure 2. Illustration of the modeling process in five phases.

3. Justification of the Revised Didaktik Model

3.1. Didaktik Model for Eco-Reflexive Chemistry Education

The new didaktik model for eco-reflexive chemistry education (see Figure 3) has six categories: (i) socio-philosophical framing; (ii) sustainable schooling and living; (iii) critical views on chemistry's distinctiveness and methodological character; (iv) powerful chemical content knowledge; (v) critical views on chemistry in society; and (vi) eco-reflexivity through environmental and sustainability education. Compared to the Jegstad and Sinnes model [7], a new category (socio-philosophical framing) has been added. Furthermore, the initial five categories were critically reformulated. The six categories of the new didaktik model and its contents are systematically justified, explained, and argued for in this section.

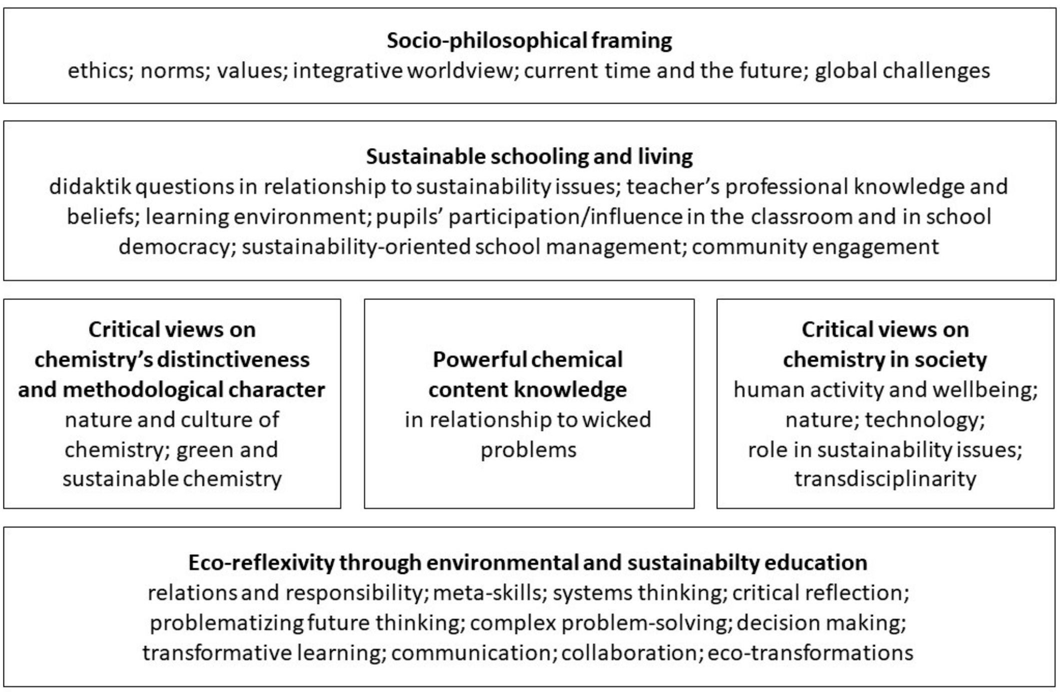

Figure 3. Didaktik model for eco-reflexive chemistry education.

3.2. The Model Categories

(1) Socio-philosophical framing

One identified aspect to be developed in the model by Jegstad and Sinnes [7] was a socio-philosophical framing. We argue that teachers' decision-making is framed by a socio-philosophical framework. This is the reason this category is on top of the developed model. For instance, the socio-philosophical views influence the didaktik choices teachers make [34]. As an example, what a teacher constitutes as powerful chemistry knowledge (see further below) depends, e.g., on her/his values and views on global challenges. This effects the knowledge that the teacher considers relevant to address global challenges. It specifically regards the didaktik question *why*. However, the teacher may be aware of those aspects or not. Besides the teacher, learning material, etc. mirror these aspects, such as values and norms.

Values, including freedom and equality, direct our goals and provide standards for assessing behavior [35]. The connection between what we think and feel (e.g., emotions, attitudes, values, interests, and motivation) and what we do (behavior and actions) has been studied in different contexts, and values appear to be good predictors of pro-environmental behavior [36]. However, the relationship among knowledge, values, and action is complex. Therefore, in addition to knowledge of environmental issues, education needs to open up space for a focus on values, social norms, and emotions [37]. In accordance with Bencze and Carter [38], we support ideas and values such as holism, critical realism, egalitarianism, and altruism in science education (see also [32,39]).

Teaching should be framed with democratic values. In addition, education always needs to expose students to well-informed alternative views and thinking. This gives them the possibility to question mainstream discourses. In line with such thoughts, Alexander stated: "Pedagogy worthy of the designation 'critical' must not only initiate into particular ethical viewpoints but also offer exposure to alternative perspectives" [40] (p. 914). Similarly, but focusing more on content issues and the European didaktik tradition, Hopmann argued that didaktik and *Bildung* require normativeness, "they challenge the teacher to be aware of the unavoidable normativeness in every dealing with whatever subject matter" [28] (p. 117).

In accordance with Hedlund-de Witt [41], we believe that worldviews are essential for transformation into sustainable societies. In particular, we recognize the *integrative worldview perspective* suggested by her and her colleagues [42]. The perspective is about emphasizing global systems and transformation. Furthermore, such a view emphasizes wisdom, wholeness, unity with nature, and world peace. Values impregnated knowledge comes though bringing together different perspectives, integrating objectivity with subjectivity, science with spirituality, etc. [43]

The temporal perspective, current time, and the future are also included in the model, because understanding sustainability issues is challenging and teachers need reflection tools to think about the future [10]. It must also be emphasized that sustainability challenges are global. These challenges include, for example, air pollution, climate change, and biodiversity loss, all of which are intertwined [44]. The interconnection of challenges is suggested to be analyzed and an attempt is made to address them system-based, instead of looking at each challenge separately [44]. The United Nations has set sustainable development goals (SDG) to address the challenges and to provide the necessary goods within planetary boundaries [45]. Planetary boundaries is a term for safe operating spaces on Earth, such as climate change, biosphere integrity, and biochemical flows [46].

(2) Sustainable schooling and living

At the heart of the reflection and development of teaching is *Didaktik*. Didaktik questions, mainly why, what, and how [17,32], are essential to ask if we aim to embed chemistry education into ESE. Our view of didaktik models is based on the idea of *Bildung* [17,28], according to which learning is an open and continuous process framed by for instance critical-democratic values and relevant knowledge [23,26]. Learners are considered active and democratic citizens [47].

In recent decades, ideas have emerged for less anthropocentric versions of *Bildung* that emphasize both relationships and responsibilities—including relationships with global ecosystems [34,48]. It can be labeled as eco-reflexive or posthuman *Bildung*. According to Biesta, "the role of the individual in the process of Bildung, [. . .] has to be understood as a reflexive process, that is, a process where the individual establishes both a relationship and a critical stance towards the existing culture and society" [49] (p. 817). In another article, he wrote that *Bildung* is about "human subjectivity that is not selfish or self-centered but always understood as being in responsible relation with other human beings and, by extension, with the natural world more generally" [50] (p. 739).

Several factors influence what a student learns, also in terms of environment and sustainability. One of these factors is professional knowledge and beliefs of the teacher [51]. Teachers combine aspects of their sustainability knowledge, when they translate this knowledge for the students [52]. Therefore, teaching based on didaktik models is not a straightforward process.

Students' participation in the classroom has been highlighted as important in providing opportunities for student-centered approaches [8]. For transformative sustainability education, students could be given more opportunities to make decisions concerning their learning, to drive the learning process [53]. Student participation can also be student-driven, so that the students actively contribute to the learning in their learning community, for instance in their classroom [53]. That kind of learning can be seen as a complex social activity, in which students develop their agency [54]. In order for students to develop critical science agency, they need to have both conceptual understanding and understanding of their own actions [55].

Supporting students' participation in sustainability aims to enhance students' *action-competence*. By this we, and other scholars, mean readiness to act responsibly on the basis of *Bildung*-ideas rather than on 21st century skills (e.g., [31,56]). Action-competence promotes critical thinking (in a *Bildung*-sense) so that students learn to deal with power relations and conflicting interests, to be empathic and appreciate different perspectives, and to think about alternative actions and opportunities (e.g., [47,57]). Students who have developed action-competence have learned to take action in their own lives, such as to make decisions individually as well as collectively [58]. Action-competence has traditionally been studied in the context of the environment [59]. What is pro-environmental behavior then? The cognitive point of view includes knowledge about environmental problems (often related to the natural sciences), knowledge about the causes and consequences of the problems, knowledge how to influence and change conditions, and knowledge and skills to visualize and develop possible solutions to problems [59]. Action-competence is also connected to self-efficacy beliefs [60], beliefs about one's own actions and what the actions require [61]. It has been emphasized that citizens "need relevant action-oriented knowledge and skills" [62] (p. 299). Recently, Sass et al. elaborated on a generic definition of action-competence and suggested that an action-competent person is:

> *Someone, who is committed and passionate about solving a societal issue, has the relevant knowledge about the issue at stake as well as about the democratic processes involved, takes a critical but positive stance toward different ways for solving it, and has confidence in their own skills and capacities for changing the conditions for the better.* [62] (p. 303).

With regard to chemistry, action-competence mainly concerns relevant chemical knowledge together with more general democratic capabilities. We suggest "ChemoKnowings" as a concept that includes relevant theoretical and practical knowledge in and about chemistry as well as about the nature and culture of chemistry (see further below). Such *knowings* are crucial for action-competence [63]. However, chemistry is only one of several important knowledge areas and we agree with Sass et al. when they wrote: "knowledge from different fields should not exist in a fragmented fashion, but needs to be understood as an interconnected whole" [62] (p. 299) (see also, e.g., [12,19]).

(3) *Critical views on chemistry's distinctiveness and methodological character*

The discourse of chemistry as a discipline is important to reflect on [64]. Practitioners of chemistry engage in some core disciplinary practices, such as, analysis, synthesis, and transformation of substances [65]. Through a review of the existing literature, Mahaffy et al. identified two lines of thinking about chemistry as a discipline [66]. Firstly, the discipline serves as a bridge between physical sciences, life sciences, and applied sciences. The second line of thinking is based on the uniqueness of chemistry. Due to the role of chemistry in our everyday life and society, and its relationship with the material nature, chemistry is claimed to be a central science. Chemistry is a creative science because the theories and practices targeting analysis, synthesis, and transformation of substances have impacts on society. Chemical theories and practices have the potential of both causing serious problems and improving quality of life [64,66].

One component of chemistry as a science is the knowledge of chemistry, conceptualized by Johnstone in his triangle, including the macroscopic, submicroscopic, and symbolic levels of chemistry. Several authors have extended Johnstone's triangle to other dimensions (see, e.g., [17]). In the context of sustainability, the role of chemistry has often been reduced to discussion on the environmental effects of chemistry and typically green chemistry [5,19,66].

It has been argued that green and sustainable chemistry are not the same because green chemistry tends to focus on ecological aspects, such as waste reduction, while sustainable chemistry also takes the other dimensions of sustainability into consideration [67]. However, it is often subjective what is considered to be best for sustainability. The wickedness of sustainability issues comes again into discussion here. We might not achieve consensus on the measures needed for a sustainable future, for example, on how to produce energy. The unexpected impacts of biofuels are an example of a controversial policy issue [44].

In addition, chemistry teaching is a complex task, and teachers may prefer to use teaching and learning methods that are tangible. Teaching sustainability in the chemistry class, using green chemistry as an example, may be simpler or easier to implement than other models that incorporate sustainability and chemistry teaching [8]. Chemistry teaching models have also been concluded to successfully incorporate real-world issues into chemistry [66]. However, the question arises: How complex can the context be for students to be able to learn from it?

(4) *Powerful chemical content knowledge*

Young emphasized that every citizen must have so-called *powerful knowledge* [68]. Powerful knowledge is relevant knowledge developed within disciplinary contexts. In other words, it refers to discipline-grounded knowledge important for all. Young contended that "Powerful knowledge opens doors: it must be available to all children [...] It transcends and liberates children from their daily experience." [68] (p. 118). However, at the same time, powerful knowledge differs from disciplinary core knowledge in that it is socio-politically embedded (e.g., [69]).

Knowledge of chemistry is essential in dealing with sustainability challenges. However, not all chemical knowledge necessarily contributes to handling sustainability challenges. Especially knowledge connected to wicked problems is important. However, the ill-defined and multifaceted nature of wicked problems means that we do not know what knowledge may be useful in the future. While we may not know what a sustainable future looks like [10], we can envision a desired future and plan a pathway towards it, using collaborative as well as systems thinking approaches [70].

At least one question remains: Who defines the most relevant content to be taught? This question is important in chemistry education in general, but not least in the context of the environment and sustainability. Knowledge that is believed to be most important, such as a contextual big idea as greenhouse gases affecting climate change, could be prioritized in teaching [71]. In addition, concepts that students have misconceptions about, such as the confusion between greenhouse effect and global warming, are important for understanding the climate as a system and the role of human actions (anthropogenic greenhouse effect). Chemical content knowledge is also important in many other societal issues related to environment, health, food, energy, and/or material resources.

It is stated above that the so-called *ChemoKnowings* are crucial for action-competence. Recently, Bladh—in relation to school geography—discussed so-called GeoKnowings [72]. It is about having descriptive world knowledge, relational understanding of people and places in the world, and "disposition to think about alternative social, economic and environmental futures", or, in other words, having "geographical knowings" [72] (p. 211). Similar to GeoKnowings we have here introduced the term *ChemoKnowings*. It is about "the application of the perspectives of powerful [. . . chemical] knowledge and capabilities as specific [. . . chemical] knowings" [72] (p. 217). From an eco-reflexive *Bildung*-perspective, such *ChemoKnowings* are framed by a socio-eco-critical awareness. They are examples of "powerful knowings" [63].

From a *Bildung* point of view, discussions about the connection between content and student can be raised based on Klafki's idea of "double unlocking" [23,56]. Double unlocking refers to unlocking both the knowledge and the student. During teaching and learning, students can be provided with examples that they can relate to, and also students can participate in discussions about the content and how to study it.

(5) Critical views on chemistry in society

Chemistry is part of our society. How it relates to environmental and sustainability issues depends, for example, on how we understand the term. Both sustainable development and sustainability have many meanings [11], which also affect how teaching of them can be discussed.

The components of sustainable development—ecological, societal, and economical—are sometimes addressed separately. However, they are multi-layered [29], in addition to sustainability challenges themselves being multi-layered [44]. Sustainability issues cannot be addressed by analyzing the components separately, due to planetary boundaries and the wickedness of the problems [29]. The three components are constantly interacting, for example, as materials and energy flows [29]. Instead of continuous growth, human well-being can be achieved through non-material goods that help create good life and life satisfaction [73].

The societal transformation towards sustainability requires changes at the societal level, importantly at the organizational level [74]. For organizational change to take place, learning should be not only social but also higher-order, reflective, and system-wide [74]. Related to this discussion is the question of good life: What constitutes a good life (now and in the future), and what are its requirements? [73] Our answer to this question influences our view of the need for societal transformation and how extensive they need to be.

In science teaching, societal aspects have been taken into consideration using teaching models about, for instance, socio-scientific issues (SSI) (e.g., [6,75]). Its benefits include, for instance, learning of and applying scientific content knowledge in societal contexts, improving the thinking skills of moral and ethical aspects, increasing students' motivation to learn chemistry, and improved understanding of the importance of science for everyday life and society [9].

Furthermore, it has been suggested that equity and social justice should be better integrated in chemistry education [76]. Crossing planetary boundaries is a threat to humanity and the entire ecosystem [46]. Environmental pollution is the leading cause of mortality and morbidity in low- and middle-income countries [77]. A justice-centered focus in the curriculum requires the consideration of identity, bias, inclusivity, systems thinking, community-engaged participatory research, and pedagogy for social justice [76].

(6) Eco-reflexivity through environmental and sustainability education

Major sustainability challenges demand a societal approach and cannot be addressed fully in silos. Transdisciplinary collaboration should be seen as an opportunity, rather than a problem [74]. Especially given that sustainability issues are wicked, there is need for interdisciplinary collaboration [12]. Socially and culturally situated communities of practice and learning focuses on constructing interactive understanding [74].

Our society can be characterized as a risk society, because the consequences of techno-scientific artifacts and decisions are complex and unpredictable. A risk society needs participation in collective decision-making processes and individuals who are able to navigate in and transform this complex world [3]. Considering the role of science education, and chemistry education in particular, scientific literacy, environmentalization, and integration of ecological, economic, and socio-cultural perspectives seem crucial in a world characterized by climate change, chemicalization, and anthropocentrism. Chemists need to be aware of the socio-environmental impacts of their profession. This requires a critical reflection of chemical practices [5]. Reconceptualization of chemistry education is therefore essential so that we can connect with the world with critical glasses in relation to research and our daily practices.

Critical thinking can be considered a meta-skill [78]. Meta-skills also refer to creativity, self-efficacy, and resiliency. Self-efficacy comes into question, for example, in challenging situations [61]. However, resiliency is important because it helps a person to bounce-back in challenging situations [79], such as those connected to sustainability [80]. In making a plan for sustainability in our society, resiliency will be needed to overcome the inevitable challenges ahead.

Connections between creativity and sustainability have been identified as important in future research efforts [81]. Creativity has in many cases been defined through novelty and value [82]. New and useful products and services concern sustainability both from the side of the producer as well as the consumer [81]. There has been discussion on whether creativity comes from the person itself or from outside, and whether we prioritize ideas or actions [82]. Nonetheless, creativity is a skill needed in a changing world to handle global challenges, and it can be developed through education [82].

The eco-reflective approach includes an understanding of interconnectedness and holistic thinking. One way to obtain a holistic view of chemistry instead of fragmented pieces of knowledge is to adopt a *systems thinking approach*. It allows us to see the system components of chemistry, the integration of chemistry with other disciplines and with the Earth and societal systems. The relationship between chemistry and the global challenges we face can be analyzed with systems thinking perspectives [66]. Chemical systems thinking includes a mechanistic-reasoning approach, context-based focus, and decision-making processes [83]. Systems thinking in chemistry education has a context-based focus and decision-making processes are emphasized, especially global challenges, to prepare citizens and professionals for a complex and uncertain future. This is achieved by acting responsibly and understanding the complex relationships between system components and the holistic view on chemistry [83].

Transformative learning [80], including futures thinking, negotiation, and self-initiated action [84], is at the heart of environmental and sustainability education (ESE). Thinking about the future is an essential part of it, as we are trying to affect what the future will look like. There are opportunities for sustainable or unsustainable patterns of behavior. Visions of probable, possible, and desirable futures are influenced by our identity and background [13]. Supporting students' futures thinking should therefore also be included in chemistry teachers' toolbox:

> *Envisioning sustainable futures as an educational process that actively engages people, young and old, both generationally and intergenerationally, offers a way into the future and helps us move beyond fear and despair in humanity's attempt to become more caring, responsive, responsible with the whole Earth in mind.* [13] (p. 25).

Systems thinking and transformative learning have much in common with recent versions of *Bildung* [20,26]. They are related to, for example, less anthropo-centered versions of *Bildung*, such as post-human *Bildung* [48] and eco-reflexive *Bildung* [19,34].

From a *Bildung* perspective, it has been argued that the chemistry discipline and chemistry education need to be open to reflectivity and debate [85]. To achieve this, three kinds of knowledge are crucial: (1) ontological knowledge, which is chemical knowledge about substances, processes, and so forth, i.e., content knowledge; (2) epistemological knowledge, which is basically understanding of chemical activities (see also [65]) and understanding of the nature and culture of chemistry (see also [64]); and (3) ethical knowledge, which allows considering chemistry in a social context and considering ethical aspects based on this relationship. In fact, these three domains are closely related to the three smaller boxes in Figure 3. They are also related to the above-mentioned three domains of science education: concepts, NOS, and STSE. *Bildung*-oriented chemistry education embraces all three domains of knowledge and reflectivity on chemical activities (e.g., [5,19,86]).

4. Summary and Concluding Remarks

Considering the crucial role of teachers towards sustainability through new curricular perspectives, didaktik models in general support teachers in their didaktik choices. They support in-service teachers and student teachers by providing different perspectives on local curriculum work and instruction [18]. Therefore, the revised didaktik model can be embedded in both pre-service and in-service teacher education programs.

In this article, we theoretically develop, argue for, and present a revised model for ESE-embedded chemistry education. The model was systematically developed jointly by the three authors based on a model for ESD in chemistry education by Jegstad and Sinnes from 2015 [7]. In the revised model, the five categories of the old model were critically reframed, and a new category (socio-philosophical framing) was added. The revised model is based on an eco-reflexive *Bildung* approach. The new didaktik model consists of the following six categories: (i) socio-philosophical framing; (ii) sustainable schooling and living; (iii) critical views on chemistry's distinctiveness and methodological character; (iv) powerful chemical content knowledge; (v) critical views on chemistry in society; and (vi) eco-reflexivity through environmental and sustainability education.

Through the acceleration of scientific knowledge and various curricular reforms, chemistry curriculum has been criticized for having fact overload, which has led to the accumulation of isolated facts in chemistry classes [87]. In addition, a curricular overload challenges teachers in different curricular attempts. The didaktik model presented here proposes (chemistry) educators a reflective tool, a lens, and a professional language to design, analyze, critically reflect, and develop their courses in relation to environmental and sustainability perspectives. It can also be used in teacher education to give attention to the possibility of using sustainability issues as a context for chemistry education. Doing so, student teachers could develop the skills to integrate different contents of chemistry into sustainability, regardless of which content is included in the curriculum.

The revised model, which has critically developed six categories, challenges also the accumulation of isolated facts without relevance and proposes a holistic approach to chemistry education embedded in, for instance, sustainability awareness, integrative worldview perspectives, and pluralism. Through the inclusion of socio-philosophical framing and critical perspectives on the chemistry discipline, and its relationship with the society, the model provides a tool to address the didaktik questions, especially the *why* and *what* questions. In the center of the model, we place powerful chemical knowledge related to what we call *ChemoKnowings*. From an eco-reflexive *Bildung*-perspective, they are framed by a socio-eco-critical awareness.

The revised didaktik model could be further developed and tested, especially empirically, with teachers and students from different backgrounds and ages. To test the functionality of the model, one could evaluate, for example, its rationale for teaching [18,88]. Testing the model in teachers' practices can empirically demonstrate its potential, usefulness, and limitations [18]. Because teachers are in the position of translating new ideas into practices in their teaching [89], they play a crucial role in the practical steps of didactic modeling.

Author Contributions: Conceptualization, J.H., M.Y. and J.S.; Methodology, J.H., M.Y. and J.S.; Writing—Original Draft Preparation, J.H., M.Y. and J.S.; Writing—Review & Editing, J.H., M.Y. and J.S.; Visualization, J.H., M.Y. and J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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