World Journal of Chemical Education, 2021, Vol. 9, No. 4, 121-129
Available online at http://pubs.sciepub.com/wjce/9/4/4
Published by Science and Education Publishing
DOI:10.12691/wjce-9-4-4

Surveys on the Energy Concept - implications on Curricular Adaptions in Teaching (Light) Energy in the Science Classroom

Rebecca Grandrath*, Matthias Teeuwen, Claudia Bohrmann-Linde

Department of Chemistry Education, University of Wuppertal, Gaußstr. 20, 42119 Wuppertal, Germany
*Corresponding author: grandrath@uni-wuppertal.de

Received October 11, 2021; Revised November 12, 2021; Accepted November 28, 2021

Abstract Various questionnaire-based studies were carried out to get an impression of the (pre-)concepts and understanding of the scientific term “energy” in different age groups. In addition to primary school pupils, secondary school pupils and pre-service teachers, the impressions of in-service teachers were also obtained using similar questionnaires. In this article, the results of the studies are brought together in order to identify a need for action at school teaching the scientific energy concept.

Keywords: *energy, pre-concepts, misconceptions, energy conversion, forms of energy, learning progression*

Cite This Article: Rebecca Grandrath, Matthias Teeuwen, and Claudia Bohrmann-Linde, “Surveys on the Energy Concept - implications on Curricular Adaptions in Teaching (Light) Energy in the Science Classroom.” *World Journal of Chemical Education*, vol. 9, no. 4 (2021): 121-129. doi: 10.12691/wjce-9-4-4.

1. Introduction

The term “energy” is used in many ways, with different meanings depending on the context: In everyday language, advertising and the media, the term energy has often been associated with something esoteric, mystic and impalpable – a kind of power. This use of the term and this understanding also goes back to historical or biblical traditions for generations [1].

It contrasts with the scientific understanding, needed to reveal invisible processes [2]: Here, a comprehensive concept is linked: Energy could be described as work stored in a system. As energy cannot be gained or lost, it is transformed from one energy form to another. Single forms can be defined and quantitatively measured. For example, thermal energy can be listed in the unit *cal*, whereby one calorie is equivalent to the amount of energy required to increase the temperature of one g water from 14.5-15.5 °C [1]. Today the internationally accepted unit is joule (J), with one joule being equal to 0.24 cal [3].

Taken in a whole, ***energy*** is a concept that is central for developing a deeper understanding of the natural sciences [4]. Hence, the concept is structurally anchored as a recurring basic concept in the teaching of the natural science chemistry in Germany [4]. The four key ideas of energy to be taught (and understood) are forms (1.), transfer and transformation (2.), dissipation (3.) and conservation of energy (4.) [6]. Basic features of the energy concept can already be part of lessons in primary school. From this point on, the development of an increasingly complex understanding of the concept of energy takes place along the educational biography, a learning progression aimed at a conceptual growth begins [4,5]. Empirically validated descriptions of successive in-depth concepts are understood as learning progression [6]. The cognitively reasonable levels depending on age are proposed in the literature: A current approach assumes that the learning progression of energy is a two-aspect framework, adopting the key ideas of energy and the conceptual development levels (Figure 1). Basically, the conceptual development can be divided into four levels as shown in Table 1.

Table 1. The four conceptual development levels [6]

Level	Level description
Fact level	Students describe and interpret daily life phenomena using everyday experience and piece knowledge, which is unconnected to each other
Mapping level	Students can generate a concept by mapping its abstract feature to observable physical quantities
Relation level	Students can articulate relationships between several concepts or specific mechanisms
Systematic level	Students can coordinate more than one concept in multivariate systems in a variety of contexts

This framework is illustrated as a hierarchic model for the learning progression in Figure 1.

In order to enable a sustainable and efficient learning progression, both variables should be considered and addressed. This model is nevertheless a simplification, as it has become empirically clear that learning growth is not linear and very complex [6].

When students are introduced to the scientific concept of energy at school, they usually already have pre-concepts from their everyday lives [6]. These pre-concept are not necessarily wrong [1], but influence the speed and straightness of developing of a scientific concept [6].

Not least through everyday language, that often doesn´t match with today´s scientific concepts, pupils develop concepts by themselves and deviate from the planned learning progression. With regard to the concept of energy, we often find linguistic expressions that point at the misconceptions of creation and destruction or materiality of energy. Therefore, according to the use in media such as TV or online newspapers about future energy supply, young people often formulate that solar cells e.g. would "*create*" energy [1].

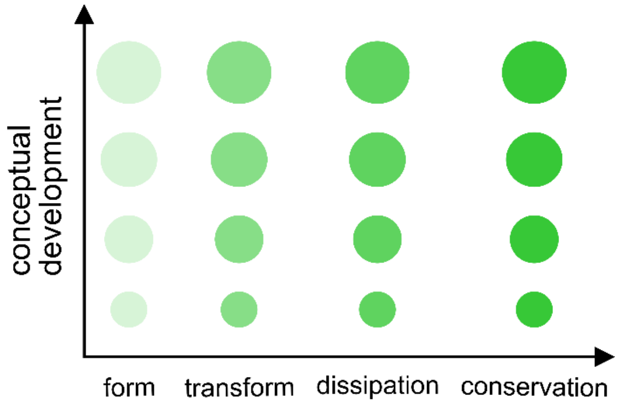

Figure 1. Hierarchic model for the learning progression of energy [6]

In addition, other alternative conceptions of energy are described in detail by Yao, Guo et al. [6]: "energy as

- something that is mainly associated with human beings
- something stored in certain objects such as batteries
- a dormant ingredient that needs a trigger to be released
- an obvious activity
- a (by)product of a particular situation
- a very general kind of fuel
- a fluid that can be 'put in', 'transported', or 'conducted'."

One global challenge of our time is to complete the energy transition. The 2030 agenda for sustainable development sets the aim to ensure access to sustainable energy for everyone by the year 2030 [7]. The closer it gets to 2030, the more urgent it becomes to implement the energy transition. Therefore, it is of elementary importance that pupils both understand the scientific concept of energy and recognise the significance and convertibility of different forms of energy into each other.

In this context, ***light energy*** is becoming increasingly important, especially since thousands of times more energy is radiated to earth from the sun each year than is stored on this planet in fossil fuels [8]. Therefore, this article will not only give a general impression of the energy concept of different age groups, but will always refer to light energy in particular. From the questionnaire-based studies carried out in Germany, concepts of the participating pupils, students and teachers can be gathered. Since (chemical) education should be a bridge between people´s alternative concepts and scientific concepts [1], valuable ideas emerge which aspects need to be picked up and to be intensified in school lessons.

2. Materials and Methods

The questionnaires were generated with the intention of gathering information about the (pre-)concepts, understanding and potential misconceptions of the scientific energy term in the cohort of students of different ages and pre-service teachers plus in-service teachers´ impressions of the issue. The questionnaires are a mixture of closed and open questions (Table 2). The younger the cohort, the more closed question formats were chosen.

Table 2. Overview of the structure of the questionnaires

	P	S1	S2	S3	T
Demoscopic characterisation	X	X	X	X	X
Content questions					
1. Please briefly define the scientific concept of energy. *		X	X	X	X
2. Cross which statement applies to the scientific concept of energy.	X	X	X	X	X
3. Name forms of energy you know. *	X	X	X	X	
4. Cross which forms of energy you know from chemistry lessons.		X	X		
5. If we have filled up with petrol and the car is fine, we can drive long distances. Where does the energy come from?	X	X	X	X	
6. Solar cells are on the roofs of many houses. What are they used for?	X	X	X		
7. What do you think is conceivable for the future energy supply?	X	X*	X*	X	
8. Mark which energy converters you consider to be of growing importance in the future energy supply.				X	
9. In what contexts are you confronted with the term *energy* in everyday life? *					X
10. In which (content-related) contexts do you talk about energy within your lessons? *					X
11. Which (mis)perceptions about energy are you familiar with from your teaching? *					X
12. Do you differentiate the concept or expression of energy depending on your respective subject and if so, how? *					X
13. What opportunities and problems/risks do you see in the fact that the concept of energy is used differently in the individual scientific subjects? *					X
X question contained in the questionnaire					
* open questions are marked with an asterisk					

The questionnaires were distributed in three different ways: We cooperated with an association of German Engineers (VDI), and performed educational programs for children in the age range of six to eleven years. Before the start of the particular program print questionnaires were distributed and completed by the children (P). Moreover, pre-service teachers (S3) also filled out print questionnaires as part of a lecture. As an element of his bachelor´s thesis our student Matthias Teeuwen created digital questionnaires at the platform "SoSci Survey" and distributed them to secondary school students in grades five to ten (S1), in grades eleven to thirteen (S2) plus all teachers (T) with at least one subject from the natural sciences working at these schools. Participation was voluntary and did not take place in classroom groups.

To sum up five different cohorts were questioned, each without prior intervention. The results were summarised, as shown in the following part.

3. Results

The following is an attempt to present the results of the individual cohorts as clearly as possible and to highlight concise findings.

3.1. Characterisation of the Cohorts

Together, there were 146 participants who took part in the questionnaire-based studies. The age distribution and number of participants in the respective cohorts are summarised in the table below (Table 3).

Table 3. Age distribution and number of participants

	P	S1	S2	S3	T	Σ
Age	6-11	10-14	14-22	19-39	30-60	6-60
f	20	28	43	42	13	146
%	14	19	29	29	9	100

With the exception of one comprehensive school pupil, all S2 attended a grammar school. At the time of the survey, all pre-service teachers (S3) questioned were in the Bachelor's degree programme for primary school teaching. Prospective elementary school teachers were selected for the survey because, on the one hand, the topic of energy is prominent in the curriculum of the school type and thus also in teacher training and, on the other hand, the course of study includes a comparatively large number of people. They were all interviewed at the same time before the topic of *energy* was taken up in the chemistry module. The participating in-service teachers (T) work at different types of schools, as shown in Table 4.

Table 4. Teachers´ scope of work

type of school	f	%
primary school	5	39
secondary education (grades 5-10)	1	8
secondary education (grades 11-13)	6	46
comprehensive school	1	8

In Germany teachers usually teach at least two different subjects. The subjects taught by the questioned cohort are shown in Figure 2. The number in parentheses corresponds to the absolute number. It becomes clear that these teachers not only work at different types of schools, but also teach different subjects belonging to various departments.

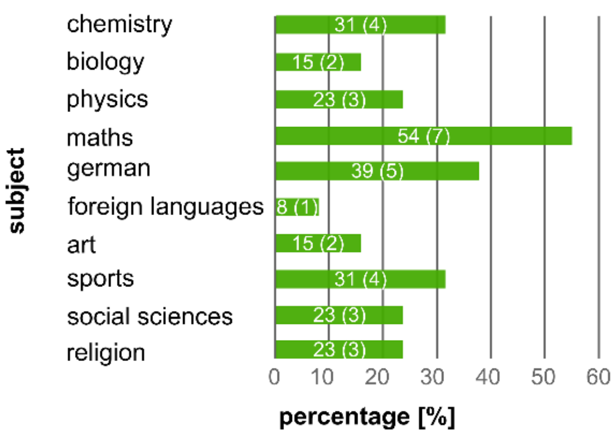

Figure 2. Subjects taught by the questioned teachers.

3.2. Results of Content Questions

3.2.1. Definitions of the Energy Term

With the exception of group P, all groups were asked for a short definition of the scientific concept of energy. Not all respondents complied with this request. For better clarity, not all individual contributions but summaries based on concise terms or ideas are presented (Table 5). Furthermore, trends are named and outstanding contributions are cited. In group S1, all respondents attempted a definition - even if it was through a single word. It was noticeable here that the abstract concept of energy was rarely described, but rather the visible effects of individual forms of energy such as "*motion*" (kinetic energy) were mentioned more frequently. Energy was set equal to electricity by the majority. In this group, everyday language interpretations of terms were also quoted, for example by the "*energy drink*" or "*motivation*". The misconception of energy being created and in reverse annihilated became clear in isolated cases. In addition, there were also answers that indicate that it is not only the concept of energy itself that is subject to misconceptions. For example, one pupil wrote: "Energy is electrons giving off their charge." Another one formulated: "Energy is a force that can be negatively or positively charged." Also, the electricity theory or electrochemistry seems to be afflicted with misconceptions here.

Table 5. Mentioned terms or concepts

	S1 (%)	S2 (%)	S3 (%)	T (%)
battery	11	-	-	-
creation	16	2	7	8
electricity	37	16	7	-
energy conversion	5	9	7	8
Energy drinks	5	-	-	-
forms of energy	11	19	5	8
fuel (materiality)	5	-	7	-
impulse	-	9	15	8
motion	21	16	5	-
motivation	5	-	-	8
not destructible	-	-	12	-
physical quantity	-	7	2	23
power	-	12	7	15
supply	-	-	-	8
work	-	9	7	8
no indication	-	14	17	62

"*Energy* is hard to define", a student of group S2 summarised. Even in this group the majority set energy equal with electricity. Energy was often associated or set equal to with the motion of particles, molecules or bodies. Typical statements were "Motion is energy" and "Motion produces energy". In contrast, one person presented a very differentiated definition of the scientific energy term: "Various forms of stored work which can be transformed and never get lost."

The participants in the group S3 seldom set energy and electricity or motion equal, but gave indications of the misconception of destruction and materiality of energy. In contrast, as answers to the question there was often the detached statement that energy cannot be destroyed.

Since teachers have a special role to play in teaching the scientific concept of energy, their statements seemed particularly interesting. There was an astonishingly great number of abstentions in the teachers' group T. Under 40%, i.e. only 5 out of 13 respondents, attempted to define energy. For example, one approach was: “Energy can be contained in a system in various forms, e.g., kinetic energy, chemical energy or electrical energy. Different forms of energy can be converted into each other.” Two of the in-service teachers, in addition to the scientific concept of energy, point to its use in everyday language, e.g.: “On the one hand, an open term for what drives people, on the other hand, a physical quantity that has something to do with reactions.” Overall, the term was described in abstract ways rather than precisely defined: For example, the statement was made that it was a physical quantity without subsequently characterising it. Forms of energy taken up in class will be discussed in section 3.3.2.

Looking at the misconceptions of destructibility and materiality of energy, the trend becomes clear that these are least represented in the group S2 and increase again among the surveyed pre-service teachers S3 and in-service teachers T.

It should be noted here that the sample was significantly lower due to the abstentions and that only descriptive statements are possible overall. Neither the causes of the abstentions nor the concepts hidden behind the respective formulations adopted are clearly known. It cannot be ruled out that the indicators for misconceptions are only linguistic imprecision - but this must also be avoided in order to strengthen the understanding of the scientific concept of energy among the whole population.

All respondents filled in the closed question on the definition of the energy term. Looking at the results (Table 6), the misconception of materiality seems to decrease along the educational biography (item 1). Nevertheless, a quarter of the teachers surveyed chose the statement that energy was an invisible substance. With regard to agreement on the scientifically correct definition and the property of being non-destructible, a positive trend was shown along the educational biography (item 3 and 5).

Table 6. Agreements in the context of the scientific energy concept

Item	P (%)	S1 (%)	S2 (%)	S3 (%)	T (%)
1. Energy is an invisible substance.	60	68	35	30	25
2. Energy allows you to move.	55	68	72	30	63
3. Energy is work stored in a system.	10	21	44	73	75
4. Energy can be bought at the power plant.	-	36	7	-	25
5. Energy is not consumed.	-	7	40	-	63
6. None of them.	5	7	7	5	39

A precise classification of the respective cohorts into the hierarchic model of learning progression regarding the scientific energy concept (Figure 1) cannot be made due to the data situation. Despite all the limitations in the interpretation of the data, it can be stated that even in the groups studied, that have an affinity with natural science, misconceptions on the concept of energy seem to be represented. This seems particularly alarming for pre-service teachers (S3) and in-service teachers (T), as both groups are responsible for teaching the concept of energy to further generations of pupils.

3.2.2. Familiar Forms of Energy

With the exception of teachers, all cohorts were asked which forms of energy they knew about (Table 1, question 3). The terms mentioned in each case were clustered and stored in a word cloud. The more often the term was mentioned, the larger it is shown. Inappropriate terms were not sorted out, so that energy carriers and energy converters, *sugar* and *fuel cell* for example, can also be found (Figure 3).

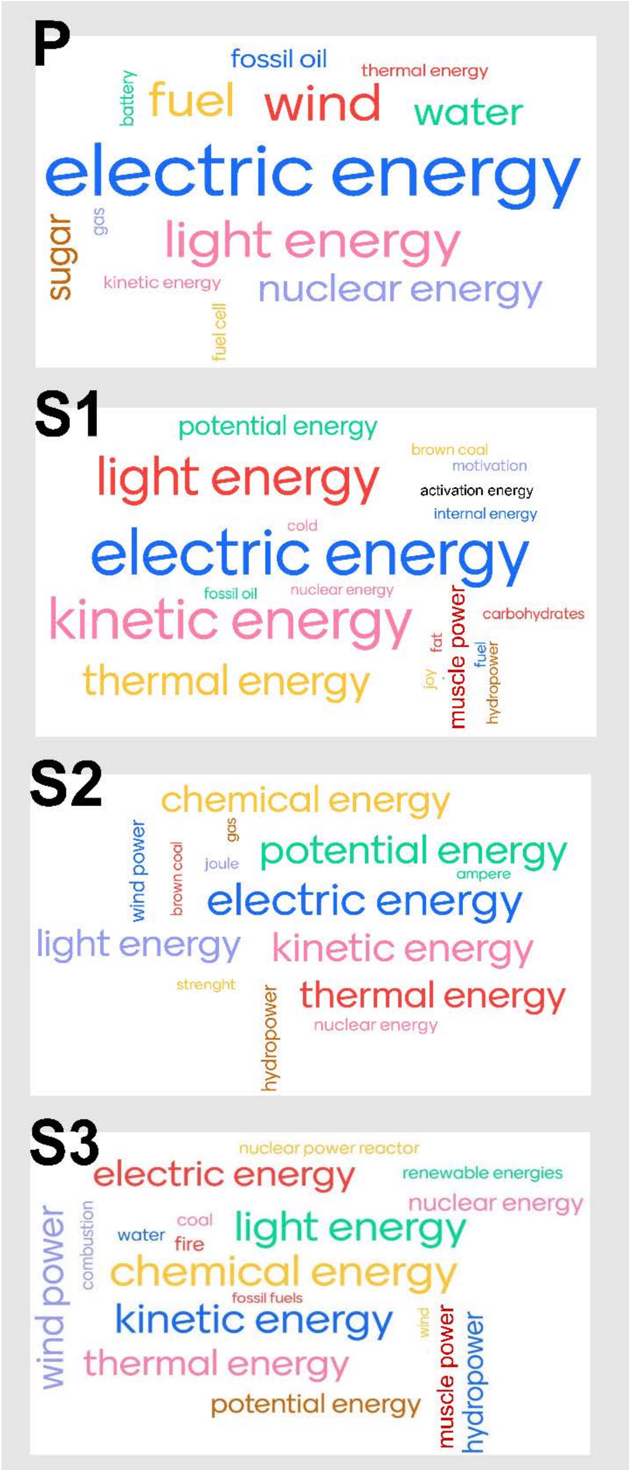

Figure 3. Terms mentioned as form of energy

First of all, it is noticeable, that forms of energy were mixed up with energy carriers, energy converters and other aspects in every cohort. The more advanced the educational biography, the more different terms were written down – even though they do not always correspond to the question: While *electric energy* is the most frequently mentioned term in the group of primary school pupils (P) and secondary school pupils in the age between ten and fourteen years (S1), other forms of energy are also mentioned with about equal frequency in the higher educated groups (S2, S3). For example, the term *chemical energy* is found for the first time in cohort S2 and occupies almost the same position as *electric energy*. The term *chemical energy* is also revisited in the group S3.

It remains unclear at this point which terms have been assimilated to their energy concept by the students in different age groups by their everyday life experiences or have been introduced in the school context on purpose. Looking at the trends in the terms mentioned along the educational biography, it seems that terms that are more familiar from everyday life are initially listed in the context of energy by younger students, before this pool of terms is increasingly supplemented by scientific forms of energy. Here it is remarkable that existing terms are supplemented by others, but not replaced. *Electric energy*, *light energy*, *nuclear energy* and *kinetic energy* seem to be the forms of energy, that children are already familiar with from their everyday lives. As the children from cohort P have been taking part in a longer program hosted by the VDI one can assume that their knowledge in this field is broader than that of other primary school children.

The concept of energy is used in various scientific subjects at school. At this point, in the questionnaire the cohorts S1 and S2 were explicitly asked which forms of energy they know from chemistry lessons (Table 2, question 4).

In this closed question, answer options were deliberately given that are not related to the scientific energy concept, for example muscle power. The results are shown in Table 7. The numbers in parentheses indicate the percentage corrected for the abstentions. Some respondents actually chose inaccurate terms. For example, in the cohort S2 about 30 % named *muscle power* as a form of energy known from chemistry lessons. Compared to this, light energy was chosen alarmingly seldom. It is also surprising that not all S2 learners marked *electric energy*, as they must have dealt with electrochemistry and applications in batteries and accumulators in previous chemistry lessons.

Table 7. Forms of energy known from chemistry lessons

	S1 (f)	S1 (%)	S2 (f)	S2 (%)
chemical energy	16	57 (62)	34	79 (81)
electric energy	22	79 (85)	35	81 (83)
fire energy	7	25 (27)	6	14
ground energy	5	18 (19)	2	5
kinetic energy	20	71 (77)	30	70 (71)
light energy	15	54 (58)	23	54 (55)
muscle power	11	39 (42)	12	28 (29)
thermal energy	21	75 (81)	35	81 (83)

3.2.3. Ideas about Future Energy Supply

All students were questioned about their ideas about future energy supply. Primary school pupils (P) and pre-service teachers (S3) were interviewed using a closed question, the others (S1, S2) using an open question (Table 2, question 7). The response to the closed question (Table 8) makes very clear, that the majority of P and even S3 assumes that the energy supply will change in the future. Providing energy by wind power and solar panels seemed to be the most likely scenario to both cohorts. Also, in both groups using biological fuel cells to convert chemical energy out of waste into electric energy seemed more plausible than using methane or hydrogen as energy storage, which is surprising as the latter topic is more prominent in everyday media.

Table 8. Ideas about future energy supply (P, S3)

	P (f)	P (%)	S3 (f)	S3 (%)
It remains the way it is.	**3**	**15**	**4**	**10**
With the help of biological fuel cells, energy can be recovered from waste.	**8**	**40**	**24**	**57**
Energy will increasingly be provided by wind power and solar panels.	**13**	**65**	**36**	**86**
Energy will increasingly be stored in the form of hydrogen or methane.	**4**	**20**	**3**	**7**
None of it.	**3**	**15**	**0**	**0**

The cohorts S1 and S2 have expressed their ideas about future energy supply in their own words. Complete sentences were not always formed, sometimes only keywords were added. Clustering the terms and summing up the frequencies of them being mentioned therefore seemed to be a legitimate evaluation method (Table 9). Both S1 and S2 essentially attribute the future energy supply with solar cells, wind power and hydropower – whereas solar cells were mentioned most often.

Table 9. Ideas about future energy supply (S1, S2)

	S1 (f)	S1 (%)	S2 (f)	S2 (%)
biogas	-	-	1	2
bioreactor	1	4	-	-
electromobility	-	-	1	2
geothermal energy	-	-	2	5
hydrogen storage	-	-	3	7
hydropower	2	7	13	30
nuclear power	-	-	6	14
renewable energies	-	-	14	33
solar cells	12	43	26	60
wind power	9	32	23	53

In the written responses, solar power was often set equal to green power. The keywords *renewable energies*, *solar cells*, *hydropower* and *wind power* were labelled as eco-friendly. Unfortunately fuel cells weren't designated as possibility for future energy supply by the pupils, although fuel cells are taught in both age groups´ chemistry lessons in Germany.

Additionally, the S3 cohort was requested to mark, which energy converters they consider would be of growing importance in the future energy supply (Table 10).

Table 10. Energy converters of growing importance (S3)

	S3 (f)	S3 (%)
petrol engines	0	0
electric motors	29	69
solar cells	37	88
fuel cells	25	60
batteries	4	10
none of them	0	0

Providing energy by solar cells was the most mentioned scenario of future energy supply in all cohorts.

Finally, it remains unclear whether the decisions were made on the basis of a deeper scientific concept or the presence of individual energy converters in the media - especially since light energy was mentioned quite rarely as a form of energy in the previous question (Figure 3).

3.3. Additional Teachers' Impressions

3.3.1. The Energy Term in Everyday Contexts

Eight of the thirteen teachers described the everyday contexts in which they are confronted with the term "*energy*" (Table 2, question 9). The answers were given in keywords so that they could easily be merged into the word cloud in Figure 4.

Figure 4. Energy term in everyday contexts

The term was most prominent in the area of nutrition and sports, followed by energy supply. According to the teachers, the scientific understanding of the energy term was not present in everyday life. This is in line with data from various literature [1,5,9] and once again illustrates the influences on the students' understanding of the scientific energy concept.

3.3.2. The Energy Term in School Lessons

Seven of the thirteen teachers answered the question, in which contexts they talk about energy during their lessons (Table 2, question 10). The answers were also given in keywords, but a subject-specificity of the aspects mentioned became evident. In six out of seven cases, a scientific reference was made, while one answer had a social dimension through the terms "distributive justice" and "responsibility". Activation energy, aspects of electrochemistry, photosynthesis and metabolism in general were named as points of contact for the energy concept in science teaching in particular. According to the teachers interviewed, in general studies at primary schools the teaching of electricity, nutrition and sport is related to energy. These topics coincide with the everyday contexts in which the term energy is used. It remains unclear how sensitively this young target group is introduced to the scientific concept of energy or whether misconceptions are reinforced in the lessons.

3.3.3. Familiar Misconceptions

Six of the teachers stated that and which misconceptions regarding the scientific energy concept they were aware of from the lessons (Table 2, question 11). Three of them named the misconception of creation and destruction of energy. The idea that energy is the same as electricity was also mentioned. The statement that nuclear power is the cheapest and most environmentally friendly electricity was also referred to. Finally, the student conception was listed, that energy would only come out of the socket and would be produced there.

In addition to the frequently described misconceptions of creation, destruction and materiality of energy, there were prominent references as well as an equation with electricity. These misconceptions should be actively included in the lessons by the teachers in order to enable the students to undergo a conceptual change regarding the scientific energy concept.

3.3.4. "energy" in Different Subjects: Opportunities and Problems

Finally, the teachers were asked for their assessment, which opportunities and problems may occur because of using the term "energy" differently in the individual (scientific) subjects (Table 2, question 13). Only three teachers addressed this question. Of these, one contribution describes energy as having no relevance for primary school children. The remaining two answers represent the opportunity of building a crosslinked concept of energy in which natural sciences are seen as a unit. It was seen as a danger that separated structures, might be established. Furthermore, one teacher saw a problem in the fact that confusion or incorrect use of the terms can occur if some colleagues do not pay attention to their precise use.

4. Conclusion and Resulting Impulses

We are well aware of the small numbers of participants in the surveys. This restriction was decided on for organizational reasons. Additionally, the surveys were carried out in the proximity of our university, in order to further involve students, teacher trainees and teachers in cooperation without having them to travel long distances.

Even if the sample was small, impulses can be derived from the surveys: according to the hierarchic learning progression presented in Figure 1 throughout the educational biography increasingly complex fragments of key ideas of the scientific energy concepts are brought together successfully into complete definitions. Younger students often set energy equal with an observable phenomenon or a specific form (idea 1) of energy, whereas older students also took up the aspect of transformation (idea 2) as well as conservation (idea 4). Similar trends were also seen in the results of the closed question (Table 6). Agreement with misconceptions decreased, the selection of scientifically correct statements increased. In fact, however, misconceptions were observable in all age groups on the basis of the written answers. It is not known whether these persist due to influences from everyday life or possibly also due to miscommunication in class. Significantly, statements made by the teachers, who all voluntarily participated in this survey, also showed incorrect concepts of the scientific concept of energy. It can be expected that they also pass these on to their students.

In the course of the educational biography, increasingly diverse and scientifically correct forms of energy are named. Again, however, not all students gave correct answers, but energy converters or energy carriers were also categorised as energy forms in this cohort (Figure 3).

Surprisingly few students in all age groups are familiar with light energy as an energy form from chemistry lessons. Especially since the interviewed learners of all age groups predominantly attribute an enormous importance to solar cells in the future energy supply (Table 8, Table 9, Table 10), this context seems to be a suitable starting point for addressing energy conversions with the inclusion of light energy in schools.

Conscious that newly acquired concepts can be easily affected when lessons are over [1] and even in-service teachers are not infallible at teaching the energy concept (section 3.3.5), it seems appropriate to teach the concept along the educational biography in an progressively complex and constantly repetitive way, explicitly pointing out the differences between the meaning of the word energy in everyday life as well as in the natural sciences. This attachment to the learners´ everyday life and linguistically sensitive handling of the energy concept can possibly give a larger number of pupils the opportunity to change their concept in the long run.

The importance of the increasing use of light energy in the course of the desired energy turnaround seems undisputed. Therefore, the following outlines how light energy and its conversion can be addressed along the educational biography. A brief overview is given in Table 11 that is based on Table 1 and Figure 1.

Table 11. Curricular links to light energy along an educational biography

	curricular link	level	key idea
P	Different energy forms and conversions, including light (energy)	Fact	Form, transform
S1	Future-proof power supply, light energy in the energy transition	Fact, mapping	Form, transform, dissipation
S2	Spectrum and light absorption, energy level model for light absorption (and emission)	Fact, mapping, relation	Form, transform, dissipation, conservation

For example, the curriculum for primary school (P) science lessons in North Rhine-Westphalia provides for dealing with resources and energy in the field of "Technology and the world of work". Teachers are free to design the content of the focus; only the learning target at the end of primary school is fixed. Learners should collect and document different forms of energy and their convertibility by giving examples [10]. The importance of light energy can be illustrated to the pupils using solar cells as an example from technology and photosynthesis as an example from nature. In both cases, light energy is converted into a form of energy that can be either stored, transported or transformed into other forms. Already at this point in the educational biography, it is important to explicitly name the transformation in order to prevent the misconception of destruction. In this way, pupils may reach the basic fact level in the development of the energy concept.

The descriptive level of phenomena is then increasingly replaced by abstract considerations in grades five to ten (S1). In addition to energy transfer, the energy dissipation in chemical reactions is considered. Abstract quantities such as chemical energy are understood with the help of energy diagrams, so that energy becomes quantifiable [11]. Even if not explicitly named, solar cells and thus light energy should be addressed in the field of “future-proof power supply”. As is also evident from the survey presented, these energy converters are familiar to the pupils from everyday life. Using the example of solar cells, the meaning of efficiency can be problematised and an energy balance can be considered in a simplified way. This is another possibility to prevent or handle the misconception of energy being destroyed.

Towards the end of the school period in grades eleven to thirteen (S2), the aspects regarding the scientific energy concept are taken up and expanded in terms of complexity. The curriculum contains the energy level model for light absorption. For the first time, there is also an explicit link to solar cells [12]. Since chemical energy was quantified in grades five to ten, the energy content of light at different wavelengths can now be discussed. By introducing semiconductors, the working principle of solar cells can be explored in detail. It might be a good idea to make solar cells accessible experimentally, for example via lowcost solar cells based on titanium dioxide [13,14]. In this way, all the components used and the abstract concept “energy” can be experienced in practical application.

What has been pointed out here for light energy and solar cells could also be applied to other forms of energy: Aspects of the energy concept must be taken up repeatedly along the educational biography and interwoven in an increasingly complex way, which is possible as there are matching links to the (chemistry) curriculum.

In order to support teachers in their daily work, other actors in the education system can also create and provide teaching opportunities.

So far, we have developed and carried out several times the learning unit *E^3- **E**xperience **E**nergy **E**xperimentally* which addresses secondary school students in grades eleven to thirteen. It focuses on the transformation of different energy forms using school experiments. At the beginning of the unit, the students express their pre-conceptions about different everyday language terms from the context of energy.

In the laboratory, the students carry out one classic and one innovative school experiment on analogue energy conversions at each of three stations (Figure 5) [15]. The innovative experiments can be related to the field of sustainable energy supply. In this unit, the transformation of light energy is elucidated at station 1and 3 by the solar cells (based on titanium dioxide) [13,14] and experiments on (artificial) photosynthesis [16].

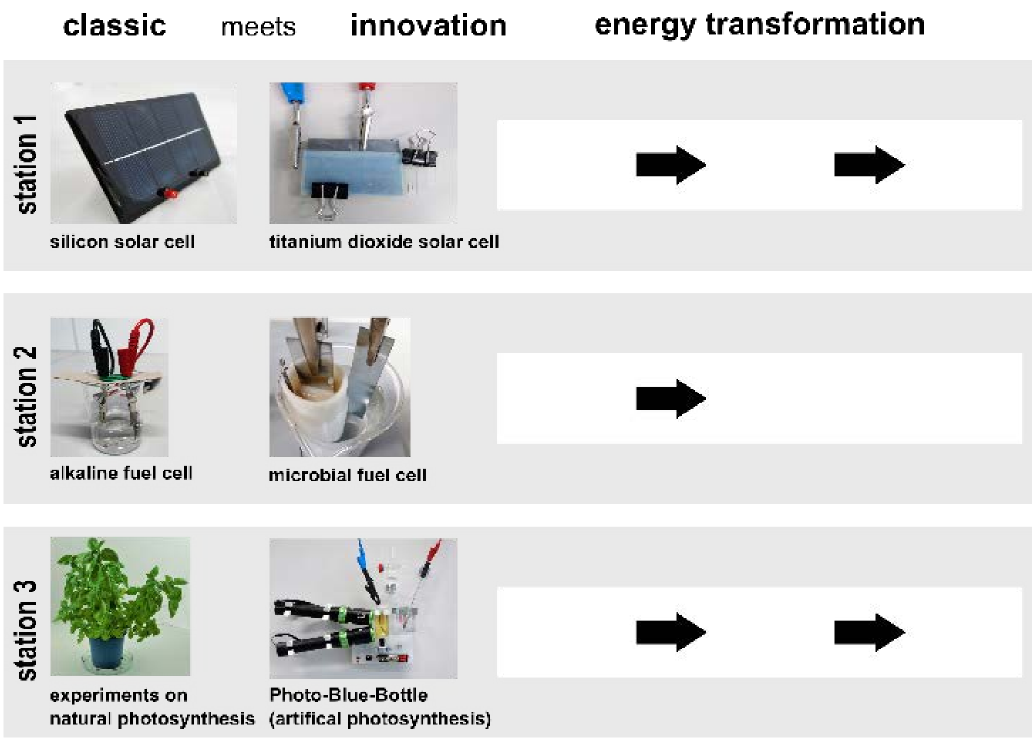

Figure 5. Overview of the learning unit E^3

During the time spent in the laboratory, the lecturers actively confront the existing concepts before the everyday terms from the field of energy are finally problematised in plenary in comparison with a scientific understanding. For example, the term "energy consumption" is used to refer to the conservation of energy in the scientific understanding. In this way we try to contribute to the conceptual change and growth of the students.

The effectiveness could not yet be empirically verified due to the pandemic situation. However, the first, immediate impressions of the lecturers were positive.

In addition to the continuation of the didactic exploration at university, cooperation between university and practitioners from schools should be further developed. It would also be desirable to provide (regular) further training for teachers so that they are continuously coached to teach the scientific concept of energy in a language-sensitive way and with regard to the integration of promising energy converters.

5. Outlook

In order to update the impressions gained, the questionnaires for recording the scientific energy concept are handed out at suitable events so that the sample size is constantly growing. Based on these impressions - the (pre)-concepts - experimental learning units are created for different target groups. For example, the programme *E^3- **E**xperience **e**nergy **e**xperimentally* was updated and promptly offered in a semi-digital version, where students were sent materials to experiment with in advance and conduct them simultaneously in a video conference together with lecturers.

References

[1] Barke, H.-D., Hazari, A., Yitbari, S. (2009). Misconceptions in Chemistry. Addressing Perceptions in Chemical Education. Springer, Berlin, Heidelberg.

[2] Kubsch, M., Nordine, J., Fortus, D., Krajcik, J., Neumann, K. (2020). Supporting Students in Using Energy Ideas to Interpret Phenomena: The Role of an Energy Representation. International Journal of Science and Mathematics Education, 1635-1654.

[3] Pelte, D. (2010). Die Zukunft unserer Energieversorgung. Eine Analyse aus mathematisch-naturwissenschaftlicher Sicht, 1. Aufl. Vieweg+Teubner, Wiesbaden.

[4] Neumann, K., Viering, T., Boone, W. J., Fischer, H. E. (2013). Towards a learning progression of energy. J. Res. Sci. Teach. 50/2, 162-188.

[5] Schmidkunz, H., Parchmann, I. (2011). Basiskonzept Energie. Naturwissenschaften im Unterricht Chemie 22/121, 2-7.

[6] Yao, J.-X., Guo, Y.-Y., Neumann, K. (2017). Refining a learning progression of energy. International Journal of Science Education 39/17, 2361-2381.

[7] Transforming our world: the agenda 2030 for sustainable development, A/RES/70/1, 2015.

[8] Tausch, M. (2019). Chemie mit Licht. Innovative Didaktik für Studium und Unterricht, 1. Aufl. Springer Berlin Heidelberg; Imprint: Springer Spektrum, Berlin, Heidelberg.

[9] Wagner, T., Flint, A. (2018). Energie für Chemie oder Chemie für Energie? CHEMKON 25/3, 98-103.

[10] Guidelines and curricula for primary schools in NRW (2008). https://www.schulentwicklung.nrw.de/lehrplaene/upload/klp_gs/LP_GS_2008.pdf (letzter Zugriff am 3.8.2021).

[11] Curriculum for the Grammar School - Secondary Education (grade 5-10) in North Rhine-Westphalia. Chemistry (2008). https://www.schulentwicklung.nrw.de/lehrplaene/lehrplan/150/gym8_chemie.pdf (letzter Zugriff am 3.8.2021).

[12] Curriculum for the Grammar School /Comprehensive School - Secondary Education (grade 10 - 13) in North Rhine-Westphalia. Chemistry (2014). https://www.schulentwicklung.nrw.de/lehrplaene/lehrplan/151/KLP_GOSt_Chemie.pdf (letzter Zugriff am 3.8.2021).

[13] Zeller, D., Bohrmann-Linde, C. (2017). Solarzellen ohne Silicium für den Chemieunterricht. Nachr. Chem. 65/12, 1236-1239.

[14] Bohrmann-Linde, C., Zeller, D. (2018). Photosensitizers for Photogalvanic Cells in the Chemistry Classroom. WJCE 6/1, 36-42.

[15] Grandrath, R., Zeller, D., Kremer, R., Venzlaff, J., Tausch, M. W., Bohrmann-Linde, C. (2019). E hoch drei - Energieumwandlung experimentell erleben. Naturwissenschaften im Unterricht Chemie 30/4, 29-33.

[16] Brunnert, R., Yurdanur, Y., W. Tausch, M. (2019). Towards Artificial Photosynthesis in Science Education. WJCE 7/2, 33-39.