

A teaching unit on electric vehicles to foster students' decision-making competencies

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Abstract. According to the national education standards set by the standing Conference of Education Ministers in Germany in 2004, one of the central aims of science education in schools is to develop the competency of responsible decision-making. However, appropriate didactic and methodical concepts remain rare. Against this background, a targeted teaching unit for secondary schools including all teaching resources (worksheets, sample solutions, handouts, etc.) has been developed and evaluated. We have chosen electric vehicles as a contemporary context, since there seems to be no consensus in the public debate on this topic yet. Therefore, good arguments abound and can easily be found either for or against the new technology. As an introduction to the unit, students are asked to make a choice for one of two controversial, opposing articles presented to them. They are also asked to estimate how confident they are about their choice on a Likert scale. During the following lessons, students explore the topic not only through physical and technical principles, but also consider aspects outside the technical sphere. At the end students are asked to write their own composition in form of a newspaper article on the subject. The way they base their decisions on their arguments is analysed and assessed. This paper reports on the structure and the materials of the teaching unit as well as classroom experiences.

1. Introduction

In his speech given at the National Academy of Science and Engineering in October 2016, the German Federal President Joachim Gauck pointed out how complex decision-making regarding modern technologies can be. He said that in our democratic communities, modern technologies could not be forced upon people. We, the citizens, are to make the decisions. Therefore, we should realize what is technically feasible and what is economically reasonable. We should discuss what is desirable, but also what is ethically defensible for the individual citizen and for the whole of society as well as for future generations. He concluded that quite often he was not sure we were doing this with the necessary consistency.

Wide ranging political discussions on modern technology are common these days, but the public at large often remains disengaged and adoption becomes a personal choice. Do I benefit financially from installing solar panels on my home? Do I lay internet cables throughout my flat or do I use a wireless LAN connection? Do I buy a conventional or an induction stove top? Mobile, smartphone, tablet, or laptop – which of these items do I really need and which do I forgo? Joachim Gauck stressed informed decision-making, taking into account not only what is feasible but also what is ethically justifiable for the individual and society, as one of the core competencies of responsible citizens today.



The same sentiment is found in the concept of scientific literacy. Despite many attempts to clarify the terminology of scientific literacy [1–3], different definitions are still used in the field. In general, it expresses the broad aim of science education to help students meet the challenges of a modern technology oriented society in the 21st century. It often targets scientific knowledge to everyday situations with the purpose of educating future citizens rather than future scientists, a tension outlined by [4].

In the OECD Program for International Student Assessment (PISA) scientific literacy has been the major domain in 2006 and 2015. According to the PISA framework in 2006 scientific literacy included an individual's "willingness to engage in science-related issues, and with the ideas of science, as a constructive, concerned, and reflective citizen" [5]. The framework in 2015 described that "a scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology" [6].

Informed and responsible decision-making as part of the objectives in the scientific literacy concept are also found in German and English education policy. The following part of this paper describes in greater detail the definition and operationalization of these competencies. However, while well-recognized as a political slogan, appropriate didactical and methodical concepts that foster decision-making competencies remain rare. Against this background, a targeted teaching unit for secondary schools including all teaching resources (worksheets, experimental instructions, sample solutions, handouts, etc.) has been developed. We will discuss our choice of electric vehicles as a contemporary context before proceeding to present the course and materials for the proposed teaching unit. In the final section we will share experiences from a classroom implementation in Germany. Resulting from these, a revision of the materials has been made. Finally, they have been translated into English and are now available in both languages for teacher use.

2. Theoretical framework

2.1. Definition of the Competency of Decision-Making

Based on the political aims mentioned above to direct science education to foster public scientific and technical understanding, the concept of decision-making competencies has been focused during recent years. To get a first impression of the level of students' decision-making competencies, Höttecke [7] distinguishes between two superordinate ways of reasoning. In a non-compensatory approach, students draw their conclusions depending on whether an argumentative threshold value is reached without taking other arguments into consideration. In contrast, when using compensatory reasoning, students consider that the negative aspects of one argument could be outweighed by positive aspects of other arguments. Thus, they draw their conclusion by considering the issue from different perspectives. They compile and prioritise arguments for both conflicting options. With a more complex consideration this is regarded a higher level of decision-making.

Furthermore, according to Höttecke [7], argumentation and evaluation have to be considered independently though both part of the decision-making process. While argumentation refers to choosing and arranging ones points such that they will convince others, evaluation is part of the process of decision-making itself; that is taking a stand on a controversial issue. The influence of argumentation on evaluation is twofold: First, to come to one's own decision weighing different arguments against one another is necessary. Second, to stand up for that decision, convincing argumentation is inevitable once again. Thus, argumentation is an important aspect of evaluation and both are taken into account for decision-making.

Therefore we combined one model to rate argumentation levels with another model to rate decision-making competencies. Feierabend *et al* [8] suggest a scheme to rate argumentation on five levels: key-arguments (level 1), intuitive arguments (level 2), reasoned arguments (level 3), reflective arguments (level 4) and constructivist arguments (level 5). Eggert and Bögeholz [9] propose a scheme to rate decision-making competencies. This scheme is based on the concept of scientific literacy [1,5,6] and the models of Koker [10] and Hammann [11] in the field of biology education. It has been tested empirically

in large-scale assessments several times, and has been shown to be appropriate to classify decision-making competency [12]. For our purpose we used an adapted scheme including both the models of Eggert & Bögeholz and Feierabend *et al* [8,9] as shown in Table 1.

Table 1. Adapted scheme combining Feierabend *et al*'s model [8] with Eggert and Bögeholz's model [9] to rate students' decision-making competencies based on the argumentation levels.

Competence Level 1	<ul style="list-style-type: none"> • <i>argumentation predominantly intuitive (levels 1 and 2)</i> • <i>considers criteria from two themes at most</i> • evaluate and decide intuitively • tend to justify this opinion • without a clear strategy of decision-making
Competence Level 2	<ul style="list-style-type: none"> • <i>argumentation predominantly reasoned (level 3)</i> • <i>considers criteria from at least three themes</i> • partially compare options on the basis of these criteria • document their decision-making strategy • non-compensatory
Competence Level 3	<ul style="list-style-type: none"> • <i>argumentation reasoned and reflective (levels 3 and 4)</i> • <i>considers criteria from at least five themes</i> • completely compare options on the basis of these criteria • completely document their decision-making strategy • either compensatory or non-compensatory • reflect on the main normative decisions of the process
Competence Level 4	<ul style="list-style-type: none"> • <i>argumentation reasoned, reflective and constructivist (levels 3 to 5)</i> • <i>considers criteria from at least six themes</i> • compare options on the basis of these criteria • completely document their decision-making strategy • compensatory • reflect on the normative decisions of the process • consider the limitations of their decision-making strategy

2.2. Choosing the Topic of Electric Vehicles

Although decision-making competencies are one of the central aims of science education in schools, didactic valuable concepts and topics can be challenging to find. Höttecke [7] lists seven properties that make a topic suitable for a unit on decision-making competencies. We will now present a translation of these properties. Simultaneously we will discuss to what extent our chosen topic of electric vehicles meets these properties.

- **Definable content:** Although electric vehicles are a highly complex achievement of engineering, elementarisation of the most important components is possible. We singled out the electric motor, the rechargeable battery, energy recovery, and efficiency as the most relevant aspects for the teaching unit.
- **Meaningful content:** The context of electric vehicles is currently relevant in the public debate. Newspaper articles of both, advocates and opponents, can easily be found. Besides, the purchasing behaviour seems in stark contrast to political ambitions.
- **Interesting content:** Being a rather technical topic electric vehicles may not create interest by itself. However, the evaluation of its pros and cons also involves arguments from a social as well as an economic and environmental point of view, such as arguments concerning ecological, lifestyle, financial and social issues. Thus, we are confident the topic is met with interest by the vast majority of girls and boys alike.

- Connected to students' actions: Cars a prominent part of students' everyday life. Students are involved as traffic participants, either non-motorized or motorized as a passenger in their parents' car or in public transportation. Although students at the age of secondary school don't yet drive cars themselves, they will be allowed to start taking driver's license courses in only a few years' time (depending on the exact regulation of each county).
- Connected to the subject matter: The relevant aspects for the teaching unit mentioned above obviously have a foundation in the subject matter of physics. Besides, these are relevant factors that must be considered in the decision-making process.
- Undetermined with regard to conclusion: There currently is no consensus in the public debate on the adoption of electric vehicles as good arguments can be found both in support of the new technology and its deficiencies alike.

Well-balanced with regard to the ratio of subject matter and decision-making: As elementarisation breaks the topic down to the most relevant aspect on which informed decision-making can be based, it is possible to balance the time students spend on the physical concepts of electric vehicles and the time they spend on the process of evaluation and decision-making.

3. The teaching unit

3.1. Description of the Course and the Materials

In a **pre-sectional phase**, two contradictory newspaper articles are presented to the students. They are asked to first retrace and then rank the argumentation of the authors in order to decide about which they find more trustworthy. Afterwards information on the topic is gathered during the following lessons and collected in a "search-brochure", which every student is meant to complete throughout the course. This **elaboration phase** is subdivided into two parts. In the first lessons the *physical aspects* of the topic are conveyed in a carousel activity consisting of four stations: Three experimental stations (*electric motor, rechargeable battery, energy recovery*) and one theoretical station (*efficiency*), which students work through in small groups. In the subsequent lessons *interdisciplinary aspects* such as *social, ecological, lifestyle, and financial issues* are conveyed. For this, every student chooses one of the four domains to become acquainted with as an expert. The experts work through materials on their domain individually. After that, they meet in groups of four experts on different domains to compare notes. In the subsequent **reflective phase**, students have to bring together the collected aspects to write their own article on the topic of electric vehicles. After this overview, the following is a more detailed description of the course and the materials of the unit.

The **initial phase** should be designed to be both introductory of the topic and activating of prior knowledge and beliefs. This will take approximately one lesson. We propose the instructor should search for two articles from current editions of regional or supra-regional newspapers which convey contradictory opinions on the topic. They also serve to stress that attitudes towards the topic are manifold in public disputes. Students are then encouraged to follow the argumentation of the two authors and asked to decide which author they are more likely to agree with. Additionally, we propose to ask the students about how confident they feel in their decision for choosing one presentation over the other on a five-tier scale from "very uncertain" to "very certain". Wrapping up the initial lesson, a discussion with the whole class explores the different viewpoints, strengthens acceptance of opposing viewpoints, and sets the stage for the necessity of further exploration.

The **first part of the elaboration phase** will span approximately three lessons. Here the main focus lies in developing the physical aspects of the topic as well as related concepts from chemistry and engineering. The instruction is designed to build upon prior subject knowledge and help students in synthesizing the various concepts from different disciplines. Key content areas are:

- Physics – energy, alternating and direct currents, electromagnetic induction, motor/generator principle, efficiency, and entropy. Students should be familiar with the first three listed ideas as they are essential in their exploration of the latter ones throughout the materials.

- Chemistry – ions, electrodes, and electrolysis as the chemical principals of batteries which are applied to study of rechargeable lithium-ion batteries. A basic understanding of these principles is essential as they are only presented as a refresher and consequently applied to the exploration of new aspects such as energy storage density.
- Science and Engineering – direct and alternating current engines, polyphase-current engine, power electronics. Students should be able to construct and understand electric circuits and take evaluation measurements on different designs.

Here we apply a student-centred active learning approach wherein which they work through the materials in a carousel activity. In four dedicated, inquiry (problem) based, workstations the topics are explored in small collaborative groups including both experimental and theoretical challenges. Stations pose an initial question to the students which is subsequently investigated by them. This may involve data collection and analysis for experimental stations or can take the form of a thought experiment within a demonstrative explanatory approach in the study of entropy. Differentiated instructional materials allowing for further, more in-depth investigation of the content by stronger students/groups, is available throughout the activities. Lessons should conclude with students reflecting on their newfound knowledge.

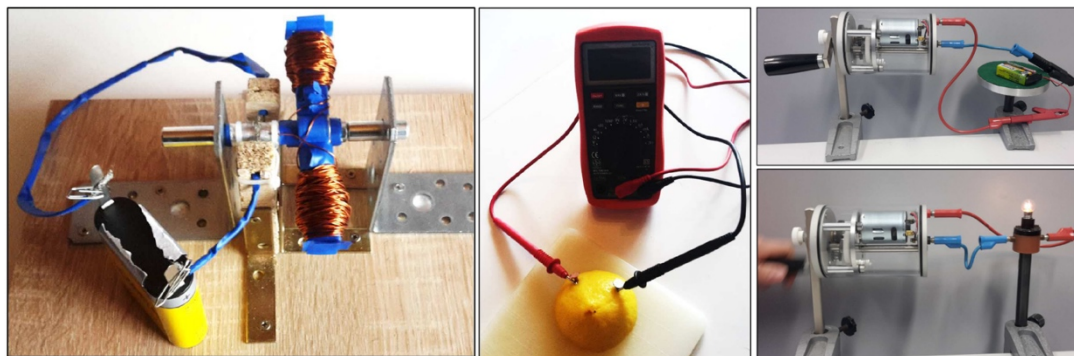


Figure 1. Experimental explorations.

The **second part of the elaboration phase** will span approximately two lessons and will focus on the development of interdisciplinary aspects outside the technical sphere such as ecological, lifestyle, financial, and social issues. In the meaningful discussion of electric vehicles students will have to be able to draw on wide-ranging knowledge throughout the school curriculum:

- Sociology and Politics – political interventions, motivations, and necessities.
- Business and Finance – subsidies, costs for acquisition and maintenance, amortization of costs including utilization, expenses for production and recycling.
- Ecology and Lifestyle – decreased exposure to noise leads to a higher quality of life in urban areas but also to new challenges concerning traffic safety, particulate and carbon dioxide pollution, driving habits, commuting and personal use, duration of the charging process, range of the battery, and sportive manner of driving.
- Infrastructure and Economy – coverage of charging stations, electricity generation from conventional and renewable sources, reorientation of the automobile industry, impulses for scientific innovations, and exhaustion of neodymium and lanthanum.

In contrast to the inquiry approach focusing on experimental evidence in the development of scientific and technical ideas, we employ a jigsaw approach in this section where students have to gather and synthesize large amounts of information. Based on the cooperative Think-Pair-Share learning strategy students begin their explorations in ‘think time’ where they acquire expertise in one of the well-defined and focused topical areas. These individual expert materials are built on an initial presentation of information in the form of a narrative. Students will have to draw from this newly acquired

information when applying the presented line of argumentation to a scenario and explore the implications of their reasoning. Activities are differentiated in their scope and extent of the reading material and the mathematical complexity of the subsequent analysis so they can easily be matched with students' abilities. Additional materials are available through the teacher to assist students struggling with individual items. Subsequently, the experts meet with their peers who have in the meantime acquired a different set of knowledge. This jigsaw approach to pairing up collaborative groups assures that all viewpoints are represented. Members now share and discuss their newly found expertise and the group synthesizes a final broader cohesive understanding of the issues.

A final **reflective phase** dedicates approximately one lesson to conclude the unit. It is designed to bring together the collected aspects by students writing their own article on the topic of electric vehicles. We propose that they are allowed to use their own "search-brochure", which they have been completing throughout the teaching unit as their main resources. This validates their efforts of careful notetaking and promotes a reflective approach to their writing. A closure of the unit can take the form of a classroom discussion. Here students can comment on their experience, apply their insights to novel questions and challenges, and reflect on their initial motivation and ideas.

3.2. Practical Experiences with the Unit

With only slight variation due to the conditions we found at the two participating schools (such as different allocations of the rooms and the lessons in the schedule), this teaching unit has been tested in genuine classroom settings of two ninth grade classes (21 girls, 29 boys in total, approximately fifteen years old). 47 of these 50 students handed in their completed materials for analysis. Unfortunately, only four lessons were made available for the whole unit which was carried out at the beginning of the year 2017. To gain an insight in students' decision-making competencies, an initial analysis of the teaching unit has been conducted, which we will now report.

3.3. Methods of the Analysis

As a starting point we compared students' decision of the first lesson for the pro- or the con-article (alongside with their estimation about how confident they felt in their decision on a five tier scale from "very uncertain" to "very certain") with their overall opinion expressed in their own article (analysis i) during the last lesson.

Next, we examined students' argumentation and decision-making as evident in their own article more closely. In order to work out which arguments prevail, we developed the following coding scheme. The arguments appearing throughout an article can originate from different resources: "A) expert material on ecological issues", "B) expert material on lifestyle issues", "C) expert material on financial issues", "D) expert material on social issues", "E) newspaper articles of the first lesson", "F) stations of the carousel activity on physical aspects", "G) other resources". We went through all the resources (A-F) identifying and enumerating arguments which can be found within (A1-12, B1-16, C1-10, D1-22, E1-18, F1-4). These were consequently assigned to several themes: "physics/engineering/science" (19 arguments), "environment" (17 arguments), "finance" (16 arguments), "lifestyle" (29 arguments), "politics/society/safety" (17 arguments) and "infrastructure/economy" (11 arguments). (Note, resources and themes are not necessarily congruent. For example, in resource "A - expert material on ecological issues" arguments on the theme "environment" can be found, but also arguments on the theme "lifestyle".) Using this rubric we coded students' argumentation with regard to the resource (analysis ii) and the theme (analysis iii) in order to subsequently rate the argument according to Feierabend et al.'s model (2013) from level 1 to level 5. For example: "While driving, electric vehicles are emission-free." (resource: D8, theme: environment, level 3) "And if the electricity to recharge is supplied by a solar power system, that can be emission-free, too." (resource: A6, theme: environment, level 3) In many cases the appropriate coding of the theme of an argument becomes clear only by the way it is presented. The argument "noiseless driving" for example could be used within the theme "lifestyle" regarding positive effects on living conditions, or within the theme "politics/society/safety" regarding dangerous effects on outside traffic participants.

For further analysis, we used the adapted scheme combining Feierabend *et al*'s model [8] with Eggert and Bögeholz's model [9] to rate students' decision-making competencies based on the argumentation levels of their own article (analysis iv).

Additionally, we also asked students about how strongly they agree to the statements on electric vehicles a) "being worthwhile already today", and b) "being the technology of transportation for the future" on a five-tier scale (analysis v).

3.4. Results of the Analysis

Analysis i) Based on the nature of students' decision for either the pro- or the con-article presented to them at the beginning of the teaching unit, we draw conclusions about their decision-making process. These can be regarded as intuitive opinions. 30 students followed the article expressing a positive view, while 14 students followed the alternative article which holds a negative view on the subject. (Three students didn't advance an opinion on that question at all.) Interestingly, only four students expressed some doubts about this position, the vast majority of 30 students being "(very) certain" ($M=3.78$, $SD=0.87$). Considering the very quick decisions alongside their almost absolute conviction, these can be best regarded as mostly non-compensatory. After the teaching unit about two thirds of the students maintained their initial opinion. However, we will next argue that the underlying argumentation and thus their decision-making competencies can now be regarded as compensatory, meaning on a higher level than before.

Analysis ii) When summarizing students' criteria organized by resources, we found that arguments originate from all resources: from expert material A)-D) as well as from the newspaper articles of the first lesson and from the stations of the carousel activity on physical aspects. As the numbers of arguments provided by each resource varies from 4 arguments in the carousel activity to 22 arguments in the expert material on social issues, we weighted the number of used arguments by the number of provided arguments. Such, we obtained the following normalized distribution (rounded to the nearest full number): arguments from "A) expert material on ecological issues": 15%, arguments from "B) expert material on lifestyle issues": 19%, arguments from "C) expert material on financial issues": 16%, arguments from "D) expert material on social issues": 17%, arguments from "E) newspaper articles of the first lesson": 9%, arguments from "F) stations of the carousel activity on physical aspects": 15%, arguments from "G) other resources": 8%.

Concerning ecological, social, lifestyle, and financial aspects, we found that about 30% to 50% of the interdisciplinary arguments, which students brought in, originate from their own expert domain. Therefore at least 50% of interdisciplinary arguments originate from the three remaining expert domains of other students, with a fraction of not less than 12% each. From this result we conclude that the exchange of arguments among students with regard to the four domains was effective.

Analysis iii) In addition, we also considered students' criteria organized by themes and found that they were not evenly distributed. We again weighted the number of used arguments by the number of arguments provided on each theme throughout the teaching unit. This yields the following distribution: arguments on "physics/engineering/science": 18%, arguments on "environment": 6%, arguments on "finance": 20%, arguments on "lifestyle": 29%, arguments on "politics/society/safety": 16% and arguments on "infrastructure/economy": 11%. These results indicate that "lifestyle" and "finance" are predominant themes, both concerning everyday life, as "finance" refers to arguments such as expected acquisition- and maintenance-costs for consumers.

Analysis iv) Rating students' decision-making competencies according to our adapted scheme, we categorized most to be on competence level 2 (25 students). A fair fraction was also categorized on competence level 3 (15 students). Only very few students demonstrated decision-making on competence level 1 (4 students) or on competence level 4 (3 students).

Unfortunately, we cannot carve out the gain in decision-making competencies due to the teaching unit, because we have not assessed students' competencies in this regard at the beginning. Still the seemingly quick and easy decision for one of the two contradictory positions presented in the two

newspaper articles in the beginning of the unit, regarded as non-compensatory, evolved into a compensatory strategy.

Analysis v) When asked about their overall opinion on the topic of electric vehicles, about 50% believe them to be worthwhile already today. 80% believe them to be the means of transportation for the future. In summary, the majority of students seem to hold a positive view, particularly with regard to the potential of the technology.

3.5. Conclusion

We have developed and evaluated a teaching unit for secondary schools around the topic of electric vehicles with the aim of fostering students' decision-making competencies as part of the framework of scientific literacy. We have argued that this context is both a highly relevant and also contentious issue in the public debate. As good arguments can be found either for or against the new technology, it is particularly suitable for our aims.

During the lessons students not only work out the physical and technical principles (electric motor, rechargeable battery, energy recovery, and efficiency), but also consider interdisciplinary aspects such as ecological, social, lifestyle, and financial issues. At the completion of the lessons we analysed students' argumentation and decision-making competencies by combining a model of Feierabend *et al* [8] with a model of Eggert and Bögeholz [9]. Although our initial analysis is based on a rather small number of students, it does serve to give an impression of how the teaching unit might be conceived. We have come to conclude that our approach succeeds in developing students' decision-making from a non-compensatory to a compensatory level in many cases.

All instructional and support materials can be downloaded from our website:



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