1. Introduction

Introductory electricity is one of the core elements of lower secondary physics classrooms all over the world. Students’ understanding of the concepts current, voltage and resistance presents one of the main goals. However, even after instruction, students show typical misconceptions such as ‘electric current is used up’ or ‘voltage is a quantity of the electric current’. Despite years of research on the teaching and learning of electricity (e.g. [1–6]), how physics schoolbooks concerning introductory electricity integrate these findings from educational research has fallen short.

Science teachers and researchers often think of schoolbooks as useful instructional resources that support teachers in planning and carrying out science lessons [7]. However, schoolbooks fulfil a much more important role when it comes to science education: To some extent, textbooks determine student’s general perception of science [8].
Furthermore, it is undeniable that schoolbooks frequently act as a ‘secret curriculum’ and determine what is taught and learned about physics in these classrooms [9, 10]. Banilower et al [11] for example reported that in the USA, more than 85% of middle and high school teachers rely on commercially published schoolbooks when it comes to preparing for and organising science lessons. In recent years, science education researchers have investigated various aspects of textbooks. For example aspects regarding the nature of science [7, 9, 12], misconceptions [13], readability [14], creativity [15] and diversity [16] or gender aspects [17]. However, studies regarding the content structure of physics schoolbooks have not been the focus of research, especially for the topic of introductory electricity.

In this article, we report the analysis of four widely used physics textbooks in Austria. Since introductory electricity is an integral part of the curriculum in year 7, we focused on this level.

2. Theoretical Framework

In this chapter, theoretical concepts relevant for the quality of schoolbooks are discussed: content structure, content structure diagrams and analogies in science education.

2.1. Content structure and content structure diagrams

Although there is a compulsory syllabus in Austria, teachers have a lot of freedom regarding the general structure as well as the sequencing of concepts covered in physics classes. This means that it is the teachers’ responsibility to elementarise concepts, plan the sequencing of these concepts, select adequate models, analogies and scientific methods but also integrate aspects of the nature of science. Additionally, historical, technical and social aspects of the current topic should be considered. All of these aspects can be subsummed under the term ‘content structure’ [18–20].

However, there is no single ‘content structure’ for a specific topic, since it needs to be adapted in order to address students’ needs to allow meaningful construction of knowledge in science classrooms. The model of educational reconstruction [21] offers one guideline to construct meaningful, evidence-based content structures. Following this model, it is necessary to analyse the scientific content structure with respect to its support for learning and inclusion of students’ conceptions about it. As a tool for planning the content structure of lessons, Duit, Häußler and Kircher [18] proposed so called ‘content structure diagrams’. These are flowcharts, in which the lesson content is split up into so-called ‘meaningful units’, which are subsequently linked using arrows. If the content of a meaningful unit is a logical prerequisite for understanding another, they are connected with an arrow. By using content structure diagrams, it is possible to represent the content of a lesson in a clear manner but also to evaluate physics lessons from a quality perspective.

After their introduction, the concept of content structure diagrams was also used in video studies to analyse the content structure of physics lessons in Germany [20]. Thereby, especially the interlinking of concepts during lessons supported students’ gains in content knowledge. Since then, these findings have been replicated in other studies [19], different countries [22] and for different topics [23].

However, this method can easily be adapted to analyse physics textbooks in various categories. Doing so, instead of analysing single physics lessons, sections of textbooks are investigated, which is one focus of this article. Figure 1 shows a small part of a content structure diagram from one of the analysed schoolbooks. The text in the various meaningful units stems from the schoolbooks and was carefully translated into English.

2.2. Analogies

As part of the content structure, analogies play a crucial role when teaching physics, especially introductory electricity [24]. They are powerful tools for teaching abstract concepts [25] and they can be used to explore and develop insights into phenomena which are otherwise intangible [26].

Analogy stems from the ancient greek word ‘ἀναλογία’ and can loosely be translated into ‘according to the ratio’ or ‘relatively’. An analogy entails a comparison between two phenomena, system or principles that share similarities [27, 28]. The goal is to describe unknown and/or abstract concepts with the help of already known concepts. Gentner [29] distinguishes between
the source domain (or base domain) and target domain of an analogy. Objects and relations between the objects in the target domain are compared with those of the source domain, as shown in figure 2. This means that the effective use of analogies in science education presupposes that at least one domain of the analogy needs to be familiar to students [30].

However, despite the potential of analogies, research has revealed learning obstacles for students’ learning processes when analogies are used. For example, students could transfer misconceptions from the source to the target domain of the analogy or the analogy may produce misconceptions itself. For instance, this was shown for ‘flat’ water circuits (e.g. [31–33]). In this analogy, the electric circuit corresponds to pipes, the voltage supply to a pump and the electric current to the waterflow [34]. Furthermore, students could be overwhelmed with the transformation process between the target domain and source domain per se [32, 35, 36].

However, for introductory electricity, some analogies showed to support students’ knowledge construction [1, 30]. Hence, a second focus of this article is the analysis of used analogies in the introductory electricity chapters of common Austrian year 7 schoolbooks.

3. Focus of the study—research questions
We compared the introductory electricity sections of four widely used Austrian physics textbooks for year 7 [37–40]: ‘Big Bang 3 (BB3)’, ‘Physik 3 (P3)’, Physik verstehen 3 (PV3)’ and ‘Prisma Physik 3 (PP3)’. Thereby we focused on four different aspects: Content structure, interlinking of the content structure, definition of the concepts voltage, current and resistance and analogies used. Those aspects are reflected in the research questions:

1. How can the sequence of core concepts of the introductory electricity sections of the analysed physics schoolbooks be described?
2. How interlinked are the introductory electricity sections of these physics schoolbooks?
3. How are the key concepts voltage, current and resistance elementarised in the schoolbooks?
4. Which analogies are used in the introductory electricity sections of the schoolbooks?

To answer the first two research questions, the content structures of the textbooks were analysed using ‘content structure diagrams’ which can be compared to flow-diagrams. The resulting diagrams were subsequently analysed using different criteria, in our case the amount of covered content, interlinking of meaningful units and relative amount of ‘island-units’.

To answer research questions three and four, the definitions of the concepts and the analogies used were analysed using the meaningful units which cover those aspects. After analysing the textbooks separately, a comparative analysis of the four textbooks was conducted.

4. Results

The content structures of the schoolbooks were analysed on a detailed (using meaningful units) and on a general level in order to get a better overview of the underlying sequencing of the concepts. First, results of the analysis of the general content structure are reported. The chapters of all four schoolbooks were double-coded reaching an accordance between $0.91 < \kappa < 0.94$. Figure 3 shows an example for a sequencing structure of the schoolbook ‘Big Bang 3’. The sequencing of the other four schoolbooks can be found in the supplementary materials (stacks.iop.org/PhysEd/54/065023/mmedia).

The analysis of the sequencing of core concepts revealed that all four schoolbooks share some aspects while others are diverse. Three of the four schoolbooks (BB3, P3, PP3) start the electricity chapter with introducing electric charges and forces related to the atomic model in order to explain electric current on a microscopic level. The schoolbook P3 also starts with electric charges and forces but chooses to introduce the atomic model only at a later part of the chapter, after the introduction of the basic quantities voltage, current and resistance.

Concerning the introduction of these basic quantities, three schoolbooks (BB3, P3, PP3) introduce them in the same order as shown in figure 4. Followed by Ohm’s law and series/parallel circuits.

The fourth schoolbook PV3 chooses to introduce voltage first, followed by electric current. Afterwards, batteries and accumulators as well as solar-, thermal- and piezoelectricity are covered, these concepts are not covered in the other schoolbooks. There, only then electric resistance, parallel- and series circuits and Ohm’s law are introduced.

Next, the analysis of the detailed content structure diagrams using meaningful units is described. We double-coded 15% of all schoolbook-sections and found an accordance of $\kappa = 0.74$. These diagrams were further analysed, three different aspects of this analysis are reported in this article. The first aspect analysed concerns the amount of covered content in the different schoolbooks, a summary of the number of analysed pages and meaningful units is shown in table 1.

We operationalised the covered content as the amount of meaningful units and further distinguished between relative and absolute amount of covered content. The absolute amount

![Figure 2. Relationship between the target and source domain of an analogy, after Burde [28].](image-url)
varied between 71 and 99 meaningful units in the introductory electricity chapters of the analysed schoolbooks ($\overline{x} = 84.5$, $sd = 12.4$ units). The relative amount of covered content refers to the amount of meaningful units per page in the schoolbook. Figure 5 shows the relative amount of covered content of the four schoolbooks ($\overline{x} = 4.2$, $sd = 1.3$ units). The error-bars in the figure indicate the standard deviation; the dashed line indicates the mean value of the four schoolbooks.

As shown in figure 5, BB3 shows the largest relative amount of covered content, more than a standard deviation above the mean. In contrast, PP3 covers three meaningful units per page, which is a standard deviation below the mean. This result may also be due to the pages analysed, since in BB3 the introductory electricity chapter covers 16 pages while in PP3 it covers 33 pages. However, when comparing two schoolbooks with the same amount of covered pages (P3 and BB3) there is also a difference of 0.7 for the relative amount of covered content.

Next, we analysed the interlinking of meaningful units of the four schoolbooks. The interlinking of meaningful units is operationalised as the average amount of arrow connections per meaningful unit ($\overline{x} = 1.6$, $sd = 0.3$ units). Figure 6 shows the interlinking of the four analysed schoolbooks. While BB3 and PP3 show a relatively high amount of interlinking with about 1.8, P3 and PV3 shows a value of about 1.3.

The last aspect we analysed concerns the relative amount of ‘island units’ as shown in figure 7 ($\overline{x} = 0.08$, $sd = 0.05$ units). A meaningful unit counts as an island unit, when this unit is not logically linked to any other meaningful units. A comparison between figures 6 and 7 shows that the books with a high interlinking also have a relative low amount of island-units. PV3 shows...
the greatest relative amount of island-units with a value of 0.14.

To answer research question three and four, the elementarisations of the basic quantities voltage, current and resistance in the schoolbooks were analysed. For the flow of electricity, three schoolbooks use an analogy. The range of different analogies can be seen in table 2.

Regarding voltage, also three schoolbooks use an analogy. BB3 uses a height analogy and
Content structure and analogies in introductory electricity chapters of physics schoolbooks

Figure 7. Relative amount of island-units of the four analysed schoolbooks.

Table 2. Analogies used in the four analysed schoolbooks, all concepts that are introduced using a water-related analogy are highlighted in blue.

| Concept                        | ‘Physik 3 (P3)’ | ‘Prisma Physik 3 (PP3)’ | ‘Physik verstehen 3 (PV3)’ | ‘Big Bang 3 (BB3)’ |
|-------------------------------|----------------|-------------------------|----------------------------|-------------------|
| Flow of electricity           | Water flow in a pipe | Comparison with a „flow of students” | — | Water flow in a pipe |
| Electric current              | — | Comparison with airflow and traffic flow | — | — |
| Voltage                       | Comparison with water pressure in a pipe | Comparison with a pump in a closed water circuit | — | Pumped-storage power plant |
| Electric resistance           | Comparison of conductor diameter with pipe diameter | — | — | Pumped-storage power plant |
| Series and parallel circuits  | — | — | — | Pumped-storage power plant |

‘electrical height difference’ synonymous to voltage, comparing it to a pumped-storage power plant. P3 uses the analogy of water pressure in a pipe, voltage is conceptualised as the ‘cause of the flow of an electric current’. PP3 also uses a closed water circuit analogy. However, voltage is elementarised as a measure of ‘how much the electrons are driven’. PV3 does not use any analogies, voltage is defined as ‘the propulsion of the electrons i.e. the reason why electrons can move’.

Furthermore, we analysed the definitions of electrical resistance in the four schoolbooks. All four schoolbooks define it as a quantity of a material to hinder the electrical current or the flow of electrons. In addition, PP3 distinguishes between the electrical resistance (as a phenomenon) and the value of the electrical resistance, which is defined by Ohm’s law in this schoolbook. Although PV3 does not differentiate between these two aspects, it links the definition of electric resistance to Ohm’s law.

5. Conclusion and outlook
Overall, we demonstrated that the concept of ‘content structure diagrams’ can be a meaningful tool to analyse physics schoolbooks.
The analysis shows that the content structures of the four analysed schoolbooks are similar regarding some aspects on a general level. As far as the sequence of concepts is concerned, three schoolbooks first introduce the atomic model of a conductor in order to explain electric current on a microscopic level, while the remaining textbook introduces this atomic model only after the introduction of the concepts voltage, current and resistance.

Another result worth mentioning is the fact that also three schoolbooks show the same sequence of concepts regarding the introduction of the concepts voltage, electric current, resistance and Ohm’s law. Especially interesting is that these aspects are listed in the same order in the Austrian compulsory syllabus. One reason for the sequencing in the schoolbooks could be that although the content listed in the syllabus, which is supposed to be covered in physics classes in year 7, does not prescribe a specific sequence, the authors of the schoolbooks just used this sequencing. Additionally, it is interesting that although the national syllabus does not mention parallel or series circuits, all four schoolbooks cover this aspect.

Furthermore, the analysis shows that the four textbooks greatly differ in the amount of covered content, interlinking of meaningful units and also in the amount of island-units. For example, for the relative amount of covered content, meaning the average amount of meaningful units per page, the values lie between 1.28 und 5.63 meaningful units per page.

Regarding the introduction of the key concepts flow of electricity, electric current, voltage and electric resistance and parallel/series circuits, three of the four schoolbooks use analogies. Although the used analogies use quite different source domains ranging from ‘flow of students’ to ‘airflow’ and ‘traffic flow’, water related analogies dominate. This is especially interesting since the use of certain water-related analogies have proven to be counterproductive in supporting students’ understanding of simple circuits [30]. Additionally, BB3 is the only schoolbook that uses the same analogy for the introduction of more than one of these key concepts.

These findings result in a few desiderata for future physics education research: First, further research is needed that links the content structure of schoolbooks, usage of schoolbooks by teachers in science classrooms and how this relates to students’ learning. While this article aims to compare and analyse the content structure of different schoolbooks, research of this kind would answer the question whether the interlinking of concepts in schoolbooks at least partially translate to the interlinking of concepts in physics lessons. Second, more evidence is needed regarding the sequencing of the basic quantities voltage, current and resistance and whether these aspects influence student learning. For example, Burde and Wilhelm [30] argue that an introduction of voltage before electric current benefits student learning.

Acknowledgments
The authors acknowledge the financial support by the University of Graz.

ORCID iDs
Thomas Schubatzky https://orcid.org/0000-0002-0736-7468
Claudia Haagen-Schützenhöfer https://orcid.org/0000-0002-6245-7888

References
[1] Steinberg M S and Wainwright C L 1993 Using models to teach electricity—the CASTLE project Phys. Teach. 31 353–7
[2] Silva A A and Soares R 2007 Voltage versus current, or the problem of the chicken and the egg Phys. Educ. 42 508–15
[3] Cottle D and Marshall R 2016 Exploring electrical resistance: a novel kinesthetic model helps to resolve some misconceptions Phys. Educ. 51 54004
[4] Leone M 2014 History of physics as a tool to detect the conceptual difficulties experienced by students: the case of simple electric circuits in primary education Sci. Educ. 23 923–53
[5] Kokkonen T and Mäntyli T 2018 Changes in university students’ explanation models of DC circuits Res. Sci. Educ. 48 753–75
[6] Haagen-Schützenhöfer C, Burde J-P, Hopf M, Spatz V and Wilhelm T 2019 Using the electron-gas model in lower secondary schools—a bi-national design-based-research-project Concepts, Strategies and Models to Enhance Physics Teaching and Learning
Content structure and analogies in introductory electricity chapters of physics schoolbooks

- Learning ed E McLoughlin and P van Kampen 1st edn (Cham: Springer) pp 3–12
- Abd-El-Khalick F, Waters M and Le A-P 2008 Representations of nature of science in high school chemistry textbooks over the past four decades J. Res. Sci. Teach. 45 835–55
- Valverde G A, Bianchi L J, Wolfe R G, Schmidt W H and Houang R T 2002 According to the Book: Using TIMSS to Investigate the Translation of Policy into Practice Through the World of Textbooks (Dordrecht: Springer)
- Chiappetta E L and Fillman D A 2007 Analysis of five high school biology textbooks used in the united states for inclusion of the nature of science Int. J. Sci. Educ. 29 1847–68
- Härtig H and Fischer H E 2012 Do physics textbooks promote conceptual understanding? 9th European Science Education Research Association Conf. Science Learning and Citizenship: Proc. of ESERA 2011 ed R Pinto and K Nibert (Lyon) pp 44–50
- Banilower E R, Smith P S, Malzahn K A, Plumley C L, Gordon E M and Hayes M L 2018 Report of the 2018 NSSME+ (Chapel Hill, NC: Horizon Research I)
- Irez S 2009 Nature of science as depicted in Turkish biology textbooks Adv. Physiol. Educ. 33 649–72
- King C J H 2010 An analysis of misconceptions in science textbooks: earth science in England and Wales Int. J. Sci. Educ. 32 565–601
- Skorecova I, Teleki A, Lacsmay B and Zelenicki L 2016 An easy to compare tool for more readable (physics) textbooks Phys. Educ. 51 65009
- Kluger A and Sherman G 2015 Physics textbooks: do they promote or inhibit students’ creative thinking Phys. Educ. 50 305–9
- Ceglie R and Olivaes V 2012 Representation of diversity in science textbooks The New Politics of the Textbook: Critical Analysis in the Core Content Areas (Constructing Knowledge vol 2) ed H Hickman and B J Portillo (Rotterdam: Sense) pp 49–68
- Elgar A G 2004 Science textbooks for lower secondary schools in Brunei: issues of gender equity Int. J. Sci. Educ. 26 875–94
- Duit R, Häußler P and Kircher E 1981 Planung und analyse von schachstturen für den physikunterricht Unterricht Phys. 4 35–58
- Brückmann M 2009 Sachstrukturen im Physikunterricht: Ergebnisse einer Videostudie (Studien zum Physik- und Chemie lernen Bd. 94) (Berlin: Logos-Verl.)
- Müller C and Duit R 2004 Die unterrichtliche Sachstruktur als Indikator für Lernerfolg—Analyse von Sachstrukturdiagrammen und ihr Bezug zu Leistungsergebnissen im Physikunterricht Z. Didaktik Naturwissenschaften 10 147–61
- Duit R, Groppengießer H, Kattmann U, Komorek M and Parchmann I 2012 The model of educational reconstruction—a framework for improving teaching and learning science Science Education Research and Practice in Europe. Retrospective and Prospective (Rotterdam: Sense) pp 13–37
- Viiri J and Helaakoski J 2014 Content and content structure of physics lessons and student’s learning gains: comparing Finland, Germany and Switzerland Quality of Instruction in Physics: Comparing Finland, Switzerland and Germany ed H E Fischer et al 1st edn (Muenster: Waxmann Verlag GmbH) pp 99–110
- Liepert S and Borowski A 2018 Testing the consensus model: relationships among physics teachers’ professional knowledge, interconnectedness of content structure and student achievement Int. J. Sci. Educ. 37 1–21
- Chiu M-H and Lin J-W 2005 Promoting fourth graders’ conceptual change of their understanding of electric current via multiple analogies J. Res. Sci. Teach. 42 429–64
- Duit R 1991 On the role of analogies and metaphors in learning science Scien. Educ. 75 649–72
- Brown S and Salter S 2010 Analogies in science and science teaching Adv. Physiol. Educ. 34 167–9
- Coll R K, France B and Taylor I 2005 The role of models/and analogies in science education: implications from research Int. J. Sci. Educ. 27 183–98
- Burde J-P 2018 Konzeption und Evaluation eines Unterrichtskonzepts zu einfachen Stromkreisen auf Basis des Elektronengausmodelles (Berlin: Logos Verlag)
- Gentner D 1983 Structure-mapping: A theoretical framework for analogy Cogn. Sci. 7 155–70
- Burde J-P and Wilhelm T 2017 Concept and empirical evaluation of a new curriculum to teach electricity with a focus on voltage 2017 Physics Education Research Conf. pp 68–71
- Schwedes H 1985 The importance of water circuits in teaching electric circuits Aspects of Understanding Electricity—Proc. of an Int. Workshop. IPN-Arbeitsberichte ed R Duit et al (Kiel: Schmidt & Klaunig) pp 319–30
- Temney Y J and Gentner D 1985 What makes analogies accessible: experiments on the water-flow analogy for electricity Aspects of Understanding Electricity—Proc. of an Int. Workshop. IPN-Arbeitsberichte ed R Duit et al (Kiel: Schmidt & Klaunig)
T Schubatzky et al

[33] Bullock B 1979 The use of models to teach elementary physics Phys. Educ. 14 312–7
[34] Dupin J J and Johnsua S 1989 Analogies and ‘modeling analogies’ in teaching: some examples in basic electricity Sci. Ed. 73 207–24
[35] Gentner D and Kurtz K J 2006 Relations, objects, and the composition of analogies Cogn. Sci. 30 609–42
[36] Gentner D 1989 The mechanisms of analogical learning Similarity and Analogical Reasoning ed S Vosniadou and A Ortony (Cambridge: Cambridge University Press) pp 199–244
[37] Barmeier M et al 2008 Prisma Physik vol 3 1st edn (Wien: ÖBV)
[38] Gollenz F, Breyer G, Tentschert H-H and Reichel E 2012 Physik vol 3, 1st edn (Wien: ÖBV)
[39] Apolin M 2017 Big Bang 3: (Physik) 1st edn (Wien: ÖBV)
[40] Kaufmann E, Zöchling A, Grois G and Masin C 2013 Physik Verstehen vol 3, 1st edn (Wien: ÖBV)

Thomas Schubatzky is a trained high school teacher for physics and mathematics. Currently, he is working on his PhD in physics education at the University of Graz, Austria. He is involved in the development and implementation of a curriculum on introductory electricity. Additionally, he is interested in the use of innovative software and online data repositories in climate physics education.

Claudia Haagen-Schützenhöfer is a professor at the Institute of Physics at the University of Graz, where she is the department’s Chair for Physics. Education and deputy director of the institute. She has eight years of experience as a high school teacher. In 2016 she completed her habilitation in physics education and gained the venia docendi for didactics of physics at the University of Vienna.