education sciences

MDPI

Article

Group Work during Inquiry-Based Learning in Biology Teacher Education: A Praxeological Perspective on the Task of (Collaborative) Protocol Generation

Petra Olschewski [1,*], Petra Herzmann [2] and Kirsten Schlüter [1]

[1] Institute of Biology Education, University of Cologne, 50931 Cologne, Germany; kirsten.schlueter@uni-koeln.de
[2] Department of Educational and Social Sciences, University of Cologne, 50823 Cologne, Germany; petra.herzmann@uni-koeln.de
* Correspondence: polschew@uni-koeln.de

Abstract: Writing protocols is a central activity in the natural sciences, but is also a part of science education. In the context of inquiry-based learning, keeping records is considered beneficial for the comprehension of scientific reasoning and the associated problem-solving process. Previous studies have focused particularly on the evaluation of learner-generated protocols and their potential for learning. The process of protocol writing, especially in the context of inquiry-based group work, as it is usually implemented in practice, has hardly been researched so far. In this video-based study, we use the documentary method, a reconstructive analysis method, in order to investigate how student groups implement joint protocol generation in an experimental inquiry-based setting and which action-guiding orientations emerge in the process. In all groups, action-guiding orientations to "task completion" and using the "protocol as means to provide structure and security" were found. Moreover, we have found differing orientations which can be titled "protocol as a flagship" and "protocol used in a pragmatic manner". Overall, the protocol seems more to serve as a guide and an assurance in the experimentation process rather than as a tool for improving scientific thinking and problem solving.

Keywords: biology teacher education; inquiry-based learning; experimental protocols; documentary method; group work

Citation: Olschewski, P.; Herzmann, P.; Schlüter, K. Group Work during Inquiry-Based Learning in Biology Teacher Education: A Praxeological Perspective on the Task of (Collaborative) Protocol Generation. *Educ. Sci.* **2023**, *13*, 401. https://doi.org/10.3390/educsci13040401

Academic Editor: Lisa Bendixen

Received: 28 February 2023
Revised: 11 April 2023
Accepted: 13 April 2023
Published: 15 April 2023

1. Introduction

Experimental protocol generation is part of scientific work in the laboratory and therefore should also be taught to students in science education [1,2]. Thus, it is a part of experimental settings in general, including inquiry-based learning settings [3,4]. Writing protocols during inquiry-based learning may promote scientific thinking and enhance the scientific problem-solving process [5,6].

Previous studies have focused especially on the evaluation of learner-generated protocols [7,8], the effectiveness of different instructional approaches regarding keeping records [9], and the learning benefits of writing protocols [6,10]. What has been less studied so far are the processes occurring during learners' protocol generation. These processes involve peer interaction, since inquiry-based learning, and therefore also protocol generation, are usually carried out in groups [11,12]. Apart from cognitive aspects, negotiation processes between learners must also be taken into account when investigating group work [13,14]. Analysing (group) processes during protocol generation is important since it provides insights into how students implement and construct protocol writing with each other. We use the documentary method as an analysis method to gain deep-level insights that go beyond the content level [15]. Our aim is to reconstruct the students' "action-guiding orientations" concerning protocol writing. That is, we reconstruct what

understanding of keeping records shows up in their actions at an implicit level [15,16]. This can extend the previous output-related findings on protocol evaluation and learning benefits by shedding more light on the processes leading up to it.

In the following, a general overview is given on the topic of protocol writing in science education, since there are only a few studies in this field. Thereby, we address three areas of keeping records: general aspects, conceptual approaches and empirical studies. This overview reveals that there are hardly any process-related studies on protocol generation. The present study takes a closer look at this research gap.

1.1. General Aspects of Protocol Writing

In the natural sciences, the experimental protocol is typically a text type which is part of laboratory activities and used to report the experiment in a short and precise way [1,17]. The methodological procedure being part of the protocol shall be presented in such a way that it can be understood and replicated by others [18,19].

Additionally, in science education, writing protocols is an important task during the activity of experimenting [2,7]. The experimental protocol is characterised by a certain structure which is based on the experimental procedure [3,8]. The sequence of the individual steps during experimentation is reported in a linear way, but it is still important to make the interrelationships between the steps clear [1]. Furthermore, the protocol is characterised by the use of educational and technical language as well as (especially in German) passive constructions [3,7,8]. The use of educational and technical language is necessary for the requirement of a precise representation and for writing down non-linguistic events such as test arrangements and observations [3]. During protocol writing, different language actions such as describing, explaining and arguing are used [7,19].

Additionally, in the context of inquiry-based learning and scientific activities, learners are expected to write experimental protocols [3,4,19]. Inquiry-based learning is used as a learning method that shall improve the learners' scientific reasoning by letting them go through the entire research process themselves [20]. Usually, inquiry-based learning is carried out in groups based on the research reality in science, and also because collaborative group work may support learning [11,21]. Accordingly, protocol preparation can also be performed jointly in this instructional approach. In general, the structure of the protocol should correspond to the phases of the inquiry circle, namely setting up a research question, generating hypotheses, noting down test procedures and observations, and analysing and interpreting data [3]. Protocol preparation is considered beneficial for promoting scientific reasoning and the associated problem-solving process, as well as learning in general [5,6].

1.2. Conceptual Approaches of Protocol Writing

In pedagogical contexts, protocols have an additional function beside reporting, as they can also act as a learning tool [6,17,22]. This is taken into account in the so-called "writing to learn" (WTL) approach, which is used in order to engage students in scientific methods and to train their scientific reasoning [4]. The WTL approach can be distinguished from the "learning to write" (LTW) approach [4,10]. While the LTW approach focuses on providing students with skills to write better texts in science and is a rare part of the inquiry process [10], within the WTL approach, writing is seen as a knowledge-generating action during experimentation [10,22]. Keys [22] refers to the knowledge-transforming model by Bereiter and Scardamalia [23]. In this model, writing (protocols) is not just characterised by the retrieval and sharing of the writer's existing knowledge, but rather seen as a reflective action. Furthermore, the model involves interaction between the *content problem space*, which deals with facts and data, and the *discourse problem space,* referring to the phrasing of the text. For example, when drafting text, the writer can be led to reflect upon and develop new ideas. This means the writer makes a "return trip" from the discourse problem space back to the content problem space [22].

Learners show deficits and motivation problems with regard to writing protocols, although protocol writing is supposed to have an important and beneficial role during

experimentation and in the context of inquiry-based learning [10,12,24]. Furthermore, learners seem to understand lab reports rather as pedagogical tools than as part of scientific activity [25]. There are different kinds of approaches to integrate lab reports into the process of scientific activity to counteract this problem [2]. The science writing heuristic (SWH) is an example of an approach that is used to improve the learners' scientific reasoning, metacognition, negotiating and writing when producing experimental protocols [6,22]. Within this approach, the link to the nature of science and the role of inquiry is emphasised, and the learners are trained to think in depth about scientific concepts and the importance of evidence in relation to claims [2]. Another example is the argumentative-driven inquiry (ADI) instructional model, which is student-centred and writing-intensive [10]. The idea is to create authentic writing tasks that shall lead the learners to experience writing protocols rather as "doing science" and not "doing school" [10]. The integration of peer interaction and co-working is part of these approaches and is seen as beneficial from the perspective of constructivism [12].

There is a strong need for future teachers to learn these competencies during their university studies, as they will go on to train pupils in writing protocols [8].

1.3. Empirical Studies of Protocol Writing

In the following, we will present different empirical studies investigating the topic of protocol writing in science education. The studies relate to different subjects in the field of natural sciences and investigate different study groups (school and university students). The following studies are presented according to their focus of investigation. Those referring to process-related aspects on protocol writing that are most closely related to our own research are located at the end of this section.

There are studies whose main focus is on the analysis of written protocols to determine special features or challenges, but also to improve the writing skills through the development of certain tools. Müllner et al. [3] carried out content analyses of tenth graders' lab reports in biology lessons with regard to the separate steps of the experiment and the use of language. They found that many of the protocols lacked a hypothesis. In contrast, nearly all of the students included procedure as part of the protocol. The authors assume that pupils believe that this is the crucial part of writing a protocol, which acts as a representative of the whole experiment. Still, they found that procedure is not written as precisely as needed due to a deficit in pupils' vocabulary. Additionally, often a discussion of results is missing, and pupils use a personal style of writing by, e.g., presenting biased evaluations of the experiment.

Brede [7] investigated the lab reports of eighth graders, also taking into account first and second language speakers, in biology lessons with focus on observation and data evaluation as part of the protocol. The author points out that for the observation section, precise language is needed for describing all relevant processes, while for data evaluation, explaining is central. The pupils' protocols not only varied in linguistic features, but also in content features, which led the author to the assumption that writing protocols is not only a linguistic challenge for the learners, but one that also contains difficulties on the content level. In particular, writing down the data evaluation is challenging for pupils, since it requires explanations that are related to certain specialist concepts they need to know. Merely by using observation, data evaluation is not possible. A gap in knowledge of technical terms is less of a problem than a lack of knowledge of biological concepts, as paraphrases can be used instead.

In the context of university, Bayrak [8] investigated and developed a tool for promoting protocol writing with chemistry teacher students by using a design-based research approach. The research aimed firstly to reduce the numbers of mistakes when students write protocols, and secondly to professionalise students so they can guide pupils when writing lab reports in the future. Different criteria for evaluating protocols were established and used in order to determine the students' capability of writing protocols. The most common mistakes made by students were missing content, imprecise word use and incorrect structure. Bachelor's

students made more mistakes of a technical or content nature than Master's students did, while Master's students showed more grammar and formality mistakes. In addition to the written protocols, students' dialogues on joint protocol revision were also analysed to gain an insight into students' ideas. These results were then used to enhance the tool for promoting writing skills.

Deiner et al. [9] showed in their study that a scaffold for teaching how to write protocols improved the writing skills of chemistry teacher students. This scaffolding was characterised by breaking the laboratory report into different sections that are then processed separately through the use of certain questions.

In the context of writing to learn and the knowledge-transforming model by Bereiter and Scardamalia [23], Keys [22] investigated the thinking processes of eighth graders during lab report writing within a laboratory activity referring to the topic of erosion. The science writing heuristic (SWH), as an instructional approach for promoting scientific thinking, was used to guide the pupils. The aim of the study was to investigate scientific thinking processes with regard to the content and discourse space. By analysing written reports and think-aloud protocols, the author found that some pupils wrote down information from their memory directly into the report without reflecting it within the content or discourse space. Most of the pupils showed thinking patterns that were characterised by starting to write but then interrupted this process to make a return trip to the content space, and showing scientific problem solving by e.g., generating hypotheses to be able to continue writing. A few students showed rhetorical planning before starting to write, namely taking into account content and discourse space aspects in advance instead of making return trips in between.

Sampson et al. [10] studied how science learning and writing skills changed by using the argument-driven inquiry (ADI) instructional model. In their intervention, they focused on middle and high school students in different science courses (chemistry, biology, physics and life sciences) and measured both their writing skills and their understanding of science content using two different assessment tools over the period of one school year. They showed that learning within the ADI approach improved the pupils' writing skills and their understanding of core scientific ideas. They also found that the more often pupils took part in those special activities, the better their writing developed.

There are studies investigating the question of what teachers see as relevant criteria for lab report writing. In a pilot study, Holschemacher and Bolte [26] asked chemistry teachers this by using an online questionnaire about their ideas of protocol writing in school. The results show that for them the aspects of "writing down observations", "interpretation of observations", "distinguishing between observation and interpretation", "interpretation of data" and "using correct technical terms" are very important. Despite their ascribed high importance, the teachers assessed the role of these aspects in practice and students' competencies in these respects as rather low.

Hoehn and Lewandowski [2] developed a framework of goals for writing in physics lab courses which is based on a literature review and interviews with four instructors teaching advanced lab classes for physics majors. Their framework consists of fifteen goals (e.g., argumentation, reflection, content mastery, using texts for grading) divided into five broader overlapping categories. The categories they identified are "communication", "writing as professionalisation", "writing to learn", "course logistics" and "social emotional goals". "Communication" is about sharing what the students know and what they have done. In "writing as professionalisation", the focus is on writing as a scientist's skill, which is in line with certain norms, while on the other hand, "writing to learn" focuses on writing as a process in which knowledge is acquired. The category "course logistics" is about how the class functions, e.g., that a method of grading students is necessary, which is often based on a written product. Lastly, "social emotional goals" include those goals that relate to the emotional and experiential world of the learners, for example, the development of the learner's own science identity. Looking separately at the fifteen goals, one of them is "nature of science (NOS)", to which a special role is attributed by the authors. This is because

NOS beliefs are seen as elementary in the context of lab classes, and this goal addresses nearly all of the five categories (except for course logistics). Therefore, the development of a sophisticated view about NOS is crucial in their framework, and an important goal in the context of lab writing. Moreover, students are also aware of the multitude of functions a protocol can have [27].

In a study of Haagen-Schützenhöfer [18], the aim of the author was to strengthen the aspect of NOS during lab work and writing in physics lessons. Within an instructional approach focusing on the replication of experiments, pupils should use their written lab reports to reflect upon this aspect. Subsequent reflective group discussions and questionnaires showed that this approach was helpful in creating awareness of NOS-specific aspects during lab work and lab writing.

Hill et al. [28] also investigated protocol writing, with a focus on students' scientific reasoning taking place during such activities. They analysed teaching assistants' comments on lab reports that were written in an introductory biology course at university. In this way, they could show that the teaching assistants' main attention was on the style and form of the protocols instead of students' scientific reasoning. The authors discuss that grading check lists often focus on genre-specific conventions of writing (e.g., use of passive constructions or past tense), and therefore, teachers' and students' main attention is also paid to these aspects. Thus, they call for a change in course design, stressing the importance of scientific reasoning and students' ideas.

A further type of investigation refers to the process of protocol writing. While the study of Engl [5] is placed in the context of science education, that of Heinzel et al. [29] does not refer to scientific protocol writing, but shall be mentioned here because their methodological approach and key interest are close to those of our study.

Engl [5] studied protocol writing of groups of sixth graders in science classes. In her analysis, protocols ("research books"), videos and interviews were included. In this way, she could investigate how experimenting and protocolling was processed within the groups. The results show that co-working was more present during experimentation than during writing, which could have been caused by the fact that one single test setting was installed but each pupil had their own research book. She also found hints that some pupils used the protocol rather as a reminder for themselves (writing down only a few things), while others tried to write a complete protocol.

Heinzel et al. [29] investigated protocol writing in a non-scientific but university context, namely analysing collaborative protocol writing during casuistic (case-based) learning settings of prospective elementary school teachers. Therefore, it is important to mention that in this study, no experimental protocols were written, but progress reports that record the joint work and discussions of the groups were. The task of writing a protocol was assigned to one member of the group beforehand. By using a reconstructive analysis method, the so-called documentary method, the authors could show that students framed the task as rather stressful, and as an imposed necessity which serves to control performance. They compare this with Breidenstein's [30] "pupil's job", which shows that pupils fulfil the requirements placed on them in the classroom, but in a mode that is focused on the performance product, which shall be reached in a manner as time-efficient as possible and with minimum effort. In this general frame, the authors reconstructed the different ways that students dealt with the problem of writing protocols. One approach refers to different ways students assign the task of writing minutes; this was either through using a game called "nose goes", in which the last person that touches his or her own nose becomes the one to take over the task, or the person who has a notebook with him or her agrees to write. Another approach is one that the authors call "gift exchange", in which one person offers to write the protocol but in reward expects the others to supply the content. In a third approach, the person who writes the protocol asks the others not to talk too much in order to reach a reduction of text that needs to be produced.

1.4. Research Objective

Previous studies on protocol writing focus especially on evaluations of learners' protocols, the learning potential of protocols, and the testing of different instructional approaches. A research gap exists in the area of process-related research. Therefore, the research interest of our study is to analyse the process of generating experimental protocols in collaborative, inquiry-based settings in science education. Our research objective is closely related to that one of Heinzel et al. [29], who investigated collaborative protocol writing in a non-scientific educational setting. However, the setting and type of protocol are different in our study.

Through the use of video data of students' group work, we wanted to gain detailed insight into the processes of collaborative protocol generation. By using the documentary method for data analysis, it is possible to access patterns of student actions that are not directly observable on a visual level. Thus, we refer to the following questions: How do students integrate protocol writing into the experimental process? How do they construct the protocol, and what meaning do they ascribe to the protocol? Moreover, our focus also includes social interactions within the group in the analysis.

2. Materials and Methods

2.1. Study Design

The work processes of four student groups were recorded on video. The following task was assigned to the student groups: "*What happens to potatoes in salt solutions? Investigate this question by conducting an experiment. Write down the important aspects during the experiment so that you have a meaningful protocol as a group*". Each group was composed randomly and consisted of three students. The participants were Bachelor's students at the end of the second semester, and had previously attended a lecture on the basic principles in biology and completed a laboratory course on inquiry-based learning, in which writing protocols was also taught. The survey was conducted outside of the compulsory seminars, and students could choose freely to participate. Therefore, an evaluation-free context was given. The given inquiry-based task required the student groups to conduct an experiment to answer the research question. They had one hour to do this, and could choose from a pool of experimental material which was provided to them. The task can be classified as a guided form of inquiry-based learning, since no subject-specific instructions for action were given to the students [31]. Still, a research question was predetermined and had to be investigated. Besides conducting an experiment, a second requirement was imposed, as the students had to write a protocol. For this purpose, they were provided with blank sheets, but not with a structured protocol sheet. The structure, scope and content of the protocol were therefore not predetermined and could be freely chosen by the students.

2.2. Data Basis and Analysis Method

The video data were transcribed and the relevant sequences referring to protocol generation were selected.

For data analysis, the documentary method was used, which is a reconstructive analysis method [15]. Originating from the context of group discussions' analyses in social sciences [16], the documentary method is now also increasingly used in educational research and gradually in (science) education, too [32–34]. The documentary method makes findings accessible on both an explicit and implicit level, and this is achieved through two separate analysis steps: formative and reflective interpretation [15,33]. In the formative interpretation, explicit meanings within verbal and nonverbal actions are analysed; thereby, the question of *what* is being said and practiced is answered [33]. With the second step, the reflective interpretation, the question of *how* verbal and non-verbal acts are processed is central, and gives insight into the students' key orientations guiding their actions [33,35]. In addition to the action-guiding orientations, the analysis of the interaction structure is also a component of the reflective interpretation, and it provides insight into whether shared orientations exist in the group [33,36]. If there are shared orientations in the group, we speak of inclusive modes of interaction, while diverging orientations refer to an exclusive

mode of interaction [33,36]. By using comparisons between the groups, during the analysis, it becomes increasingly apparent what the similarities between the groups are, and which specific characteristics appear in the way they deal with the task of generating protocols while conducting an experiment [33]. Analyses across all student groups were presented in different interpretation groups and validated communicatively. Thus, the central sequences were revalidated several times by different groups of people either working in the field of biology education or being experts in the documentary method. During this process, the raw material (video data) was looked at collaboratively, and the formative and reflective interpretations were examined and validated with regard to the reconstructed action-guiding orientations. By analysing different sequences across all student groups together, and by presenting the same sequences in different interpretation groups, it was possible to ensure that the central reconstruction results were valid. Due to the large number of relevant sequences, it is not possible to validate all of the material together. However, since it can be assumed that the action-guiding orientations repeatedly appear in a homologous way in the material [33], this is not necessary.

3. Results

Table 1 provides an overview of the reconstructed action-guiding orientations regarding protocol writing and their allocation to the respective student groups. In the following, those action-guiding orientations which are reconstructed in *all* student groups are represented first (Section 3.1). They can be called "basic orientations". After that, the *contrasting* orientations are presented (Sections 3.2 and 3.3). Questions as to what the students construct the protocol as, and what function and what relevance it has for them are addressed. In doing so, both process-related aspects as well as social negotiation processes within the groups are taken into account. Transcript excerpts of the individual groups are included to illustrate the results.

Table 1. Overview of the reconstructed action-guiding orientations for protocol writing in an inquiry-based setting. Distinction between basic orientations (referring to all groups analysed) and contrasting orientations (referring to some of the groups).

Basic orientations	• Task completion • Protocol as means to provide structure and security	
Contrasting orientations	• Using the protocol as a flagship	• Using the protocol in a pragmatic manner
Student groups	B, C	A, D

3.1. Basic Orientations: Task Completion and Using the Protocol as Means to Provide Structure and Security

What applies to all groups in terms of protocol writing is an orientation towards *task completion*. Already at the beginning of the group works, keeping records is framed as a necessary requirement and is also implemented in the course of all group works. In all groups, the task of protocol writing and the role of the protocol taker is determined quickly without long negotiations. As an example, please see the following sequence from Group A:

Ida: *Mhm, for the dependent and independent variable (turns pages). Okay, we have inquiry-based learning here, let's set up our hypotheses (arranges sheets). Who wants to write (has pen in hand and sheet in front of her)? #00:01:27-5#*

Jan: *Not me. #00:01:27-9#*

Laura: *Oops, (laughs slightly) you go ahead. #00:01:28-2#*

Ida: *You had a nice handwriting. #00:01:29-5#*

Laura: *No. #00:01:30-8#*

Ida: *Okay (writing).*

Ida makes a proposition (introduces a new topic) and asks the other group members "*who wants to write?*". While making this proposition, she already holds the pen in her hand and is ready to start writing. Therefore, this question could be classified as rhetorical, since her holding the pen expresses a willingness to take responsibility for writing. Both Jan and Laura elaborate on her question by refusing to take over the task. Afterwards, Ida makes a comment about Laura's nice handwriting, but then quickly overtakes the task of writing. It seems that protocol writing is no popular task; however, the group still comes to a conclusion quickly, and Ida takes on the task. This pattern is similar in all the other groups, although the role of the protocol taker is not always stable. None of the groups spent much time discussing it, but all of them start on task completion quickly.

Additionally, ensuring that (external) requirements are met points to this orientation of task completion. In all groups, for example, the necessity of using technical terms or standardised expressions is emphasised. However, frequent formulations such as "*we must*" or "*is that enough?*" also express such an orientation towards task completion and performance.

Beside task completion, there is another orientation which can be found in all groups and which deals with the function that the protocol has for the groups themselves. In all groups, the protocol generation is an action that *provides structure and security* to the group members in a setting that is rather open and insecure to them. There is a shared understanding of the general protocol structure and content, which also guides them through the experimentation process. In the beginning of their group work (Group B), Nora and Kathi refer to the given task, considering what might happen to potatoes in saline solutions based on the initial question in the assignment, while Jens refers to the protocol and introduces what they need in any case:

Nora: *Yes, what happens there (looks at the protocol sheet with the task)? #00:01:10-1#*

Kathi: *Potato, starch, salt. #00:01:13-6#*

Nora: *So, when you cook them, they're in salt water. Not? #00:01:16-8#*

Jens: *Mhm #00:01:16-9#*

Kathi: *Mhm #00:01:21-5#*

Nora: *Wow, I think we all here cook quite a lot of potatoes, I realise. #00:01:29-5#*

Jens: *So; we need the four things in any case; why am I actually writing? I probably have the ugliest handwriting of us. So, we need hypothesis, counterhypothesis, dependent, independent variable (writes). #00:01:42-3#*

Nora: *Mhm #00:01:44-2#*

Jens: *So (clicks out ballpoint pen). #00:01:46-4#*

While Nora and Kathi are freely associating concerning this rather open question ("*What happens to potatoes in saline solutions?*"), Jens provides a structure by proposing what they "*need in any case*", and writing down certain components into the protocol, namely "*hypothesis, counterhypothesis, dependent and independent variable*". There is no negotiation, but all group members seem to share an understanding of which aspects should occur within the protocol, and it is not questioned by the other group members. This also becomes apparent in the following sequence from Group C:

Katja: *So, I don't know what in evaluation we. Should we then write our hypothesis has been confirmed? #00:43:51-0#*

Anke: *Well, it is also #00:43:52-7#*

Vera: *Yes, #00:43:53-5#*

Anke: *So, that's not the explanation yet, is it? Because we actually always had that directly then with the observation, and afterwards already comes the explanation or why that is so. Because the hypothesis, it does not explain it directly. #00:44:13-7#*

Katja: *Yes but we can still say? #00:44:15-5#*

Anke: *Yes yes despite. #00:44:15-8#*

Katja: *First of all, the hypothesis, the hypothesis has been confirmed because #00:44:18-5#.*

Anke: *Yes #00:44:19-4# (...)*

Katja: *The concentration, yes the position of the potato influences? So the concentration of the solutions influences the position of the potato #00:44:35-0#*

Anke: *Mhm, #00:44:35-4#*

Katja: *So that it then swims on the surface of the water. #00:44:37-1#.*

Anke: *Exactly. #00:44:38-3#*

Katja: *And then we can name that with the plasmolysis then, I would say. #00:44:41-7#*

Anke: *Mhm #00:44:42-6#*

Katja: *As an explanation. #00:44:45-7#*

Anke: *Yes, then let's do it that way; well, the hypothesis? has been confirmed. #00:44:59-2#*

The group talks about the aspect of (*data) evaluation* as the component of the protocol coming up next, which is shared by all group members. Still, there are negotiations over what should be included. First, Katja makes the proposition whether they shall write in their evaluation that they can confirm their hypothesis. However, she also mentions that she is not sure about it. While Vera is validating Katja, Anja mentions that they should also give an explanation, and that the confirmation of the hypothesis is not enough at this point. She refers to her experiences in the past ("*because we actually always had that*") and a certain structure of the protocol ("*after the observation follows an explanation*"). Both the confirmation of the hypothesis and the explanation are then included under "data evaluation".

This shared understanding about the components of a protocol in general makes it possible for the groups to move forward with their group work and to have something similar to a framework, in which certain specific aspects can then be discussed.

While *task completion* and the use of the *protocol as means to provide structure and security* are patterns that can be found in all groups, it should be noted that there are also differences between the groups in the way they construct the protocol. In the following sections, these differences are illustrated.

3.2. Orientation "The Protocol as a Flagship"

In two groups, an orientation that we call *using the protocol as a flagship* can be reconstructed. This overall orientation contains further action-guiding orientations, namely *completeness and form* and *clarity*. In the statement of Jens (Group B), it becomes apparent what an orientation to *completeness and form* means:

Jens: *(. . .) So, let's look over here again. We have a hypothesis. A counterhypothesis. We have dependent, independent have interference variants; we have procedure? Um yes. We can um write it down in full form. We shall, we shall make a protocol. That means we can, must write it out (. . .) #00:28:24-8#*

After starting with the experimental work, Jens comes back to the protocol and suggests having another look at it. He goes through what it already contains and what should follow next ("*we have procedure?*"). He uses expressions such as "*write it down in full form*", "*make a protocol*" and "*write it out*". This points out a view of a protocol as the flagship of the group and as proof of the quality of their work. "*To make a protocol*" also stands for something resembling a craft. They are the producers of something that has relevance and needs to be created with care. Writing the protocol does not happen as a side task, but takes

up a large part of their time, and requires full concentration. The use of the modal verbs changes during his statement from "*can*" to "*shall*" and finally "*must*". By the increasing urgency expressed in his use of modal verbs, Jens also constructs a situation in which there is pressure to perform.

The relevance of the protocol for these groups is also visible, since a "protocol check" takes place. Thereby, these groups review their writing in order to improve and complete it at the end of the group work sessions. This can be shown in the following sequence from Group B:

Jens: *So. Let's go through everything we have again? (rustling paper) If we forgot anything. So we started. We have a hypothesis, we have a counterhypothesis. We wrote down dependent, independent variable too mixed up but we corrected that (takes a breath). We have an interference variable. #00:54:26-5#*

Nora: *However, maybe we should write it down. #00:54:28-2#*

Jens: *That #00:54:28-2#*

Nora: *That um that the hypothesis is not confirmed. We have not written that down at all. #00:54:34-3#*

Jens: *That's right, we still have to write that down in the conclusion. In addition. #00:54:36-4#*

Nora: *Mhm #00:54:36-9#*

Jens: *That is why we'll just go through it again. Very good. Uh we had the #00:54:40-5#*

Jens proposes to check that they "*have all*" by referring to the written protocol in order to make sure that they did not "*forget*" anything. This shows that there seems to be an orientation to completeness. They make sure that nothing is missing within the protocol, which becomes clear through statements such as "*additionally*" or "*we still have to write this down*". Additionally, the correction of the protocol is an aspect that relates to an orientation to meeting external requirements.

A strong focus on the wording is also reflected in statements such as "*that sounds better/incorrect*", "*how shall I write this?*", "*just phrase it nicely*", which are used in these groups. This expresses a strong focus on the phrasing rather than the content.

The groups are oriented to *clarity* when writing the protocol. This means that uncertainties or unresolved issues are left aside, and instead, an almost ideal course is expressed within the protocol. Group C talks about possible explanations of their observations at the end of their group work:

Katja: *And for this reason? one could say, the potato swims above and the uhm water particles from the potato, flow into the hypertonic solution. #00:46:57-2#*

Anke: *Or diffuse? #00:46:58-4#*

Katja: *That would be the explanation of #00:47:00-8#*

Anke: *Do not diffuse. Or, because you said flow. However, this well, I know the or nope nope nope. #00:47:06-2#*

Katja: *Nope diffusing is actually the mixing. Or not; or? Or am I mistaken? I don't know. #00:47:12-5#*

Anke: *However, flowing; I just don't know how to say it. What to use for it. That's why I just thought about this, then both I think. #00:47:21-3#*

Katja: *I don't know #00:47:23-0#*

Anke: *Uuh, or particles; the uh particles move, into the solution? (laughs slightly) Oh, I don't know. Mm. #00:47:40-2#*

Vera: *You can just. #00:47:40-7#*

Anke: *I'm sorry if I've caused any confusion now. #00:47:42-9#*

Vera: *No, all good um. #00:47:44-0#*

Katja starts with an explanation referring to water particles flowing out of the potato into the hypertonic solution, whereupon Anke introduces the term "*diffuse*", but immediately afterwards considers it inappropriate. Katja elaborates that "*diffusing*" means something resembling mixing and that it does not fit here, but she is unsure about it. Anke seems to be irritated by the term "*flowing*". She instead proposes saying that the particles "*move*", but she is also unsure. In the end, Anke apologises for causing confusion. In this sequence, the group discusses what they should include as explanation in the protocol, and which wording would be correct. Instead of continuing to talk about what really happens in the experiment and negotiating the meaning of the word diffusion and how it might relate to their observations, Anke, who proposed this discussion, apologises in the end for "*causing confusion*". So, the group sticks to a reduction of uncertainty, with irritation being excluded. This reveals an orientation to *clarity*, which can also be found in other sequences. This orientation becomes also apparent when comparing what the groups discuss and what they write in the protocol. Often there are discussions, or in fact just the beginning of a discussion, taking place that cannot be found in the written protocol. This also means a reduction in complexity, which goes hand-in-hand with this orientation to clarity. If a group is unsure about something, they will rather skip this point in their protocol and present a product in which no uncertainties are mentioned. The protocol therefore serves more as a concluding record and joint agreement than an examination of the subject matter.

In the groups with an orientation to using the protocol as a flagship, there are also some process-related patterns concerning how the protocol is being integrated in the theoretical considerations and the experimentation process of the groups. These groups use the protocol for *planning and reflection*. Furthermore, they spend a long time concentrating on the writing process. They do not write the protocol on the side, but integrate writing phases in which they concentrate entirely on the preparation of the protocol. These "protocol phases" take place mainly at the beginning and after the practical part, but can also be embedded in pauses during the experiment. At the beginning of the group work, they are mainly used for planning, while at the end of the group work, they are also used for reflecting upon what the group has achieved. This shows the *high relevance* that the protocol has in these groups.

This is also reflected in the way that the students implement keeping records within the group. In these groups, the writing of the protocol is carried out *together*, although there is just one person appointed the protocol taker. All group members are informed about the content and form of the writing. This can be shown in a sequence from Group C, in which they phrase the hypothesis together after having discussed it:

Anke: *The higher the salt concentration in the water? #00:10:47-5#*

Katja: *No the. #00:10:48-0#*

Vera: *The higher the density? #00:10:49-3#*

Anke: *The de- (Katja writes) the density, #00:10:53-7#*

Vera: *Of the water #00:11:00-2#*

Katja: *By uh #00:11:03-4#*

Vera: *By the salt concentration #00:11:10-9#*

Anke: *The higher the potato swims? On the water surface. #00:11:16-6#*

Katja: *Yes, isn't it? #00:11:18-2#*

In this sequence, all group members contribute to the wording of the hypothesis. Thus, in a parallel mode of interaction, single sentence components and words are introduced by all group members, which are referred to, validated and partly also corrected by the others. Therefore, in the end, a common hypothesis is composed, to which all have contributed with regard to content and especially, with regard to the wording. It is a *transparent* way of writing, since every group member knows what their shared protocol consists of.

3.3. Orientation "The Protocol Used in a Pragmatic Manner"

In contrast to the Groups B and C, who spend entire time slots writing the protocol, in the Groups A and D, writing is often not part of the verbal communication and is just *done on the side* while the other group members are conducting the experiment. Therefore, in these groups, not all group members are informed about what the protocol looks like. Writing the protocol is rather something that a person takes care of from time to time.

Furthermore, the protocol is rather used and framed *pragmatically*, in the sense that it accompanies and supports the group's work but is not the main task for them. This becomes apparent in Group A, in which the protocol is used rather as a side element, e.g., for calculating something or for documentation. In the following example, the group wants to determine the quantities of salty solutions:

Ida: *I do have math; I, I have Bio (laughs, grabs pencil). #00:16:57-8#*

Laura: *(laughs) #00:16:59-0#*

Ida: *Uhm #00:16:59-5#*

Jan: *Otherwise, we have to calculate rule of three. #00:17:00-1#*

Laura: *Damn guys. Yes. #00:17:01-3#*

Ida: *Yes #00:17:01-6#*

Laura: *We have to. #00:17:02-4#*

Ida: *Because #00:17:04-1#*

Jan: *How should I do this briefly? #00:17:04-9#*

Laura: *So, one gram to hundred millilitres are #00:17:05-9#*

Jan: *If fifty are one hundred percent. Yes, fifty are one hundred. (Ida writes) #00:17:09-5#*

Here, the group realises that they need to calculate the rule of three to find out how much salt and water they need to prepare the solutions. Ida takes the pen in her hand to support the calculation in writing. In contrast to the groups above that use the protocol as a matter of performance record, here, the protocol is actively integrated into the running of processes during their group work. The calculations are something that they need for themselves in order to obtain results with which they can continue their experimental work. The protocol, therefore, is a practical/pragmatic tool to use rather than a product that is used for representation.

This pragmatic use of the protocol becomes also clear in statements such as "*I'm writing along*" (#00:15:18-2#, Group A, Laura) which Laura says while the other group members are engaged in conducting the experiment. She frames the writing as something that is done for purpose of documentation and happens on the side.

Additionally, in Group D, this can be reconstructed as an action-guiding orientation, which can be illustrated by a statement from Nico:

Nico: *(...) So. (takes a breath) (sighs). Let's just write it down. The higher? (writes) the temperature, and the con- uh salt concentration the (writes), let's take uh let's leave out the technical terms, the more #00:26:27-3#*

Similarly to Laura's statement, here, the writing is introduced as something that just happens ("*Let's just write it down*".). In contrast to Laura, Nico involves the other group members ("*us*"), although he is the one who is writing. He starts wording a hypothesis, which seems to be challenging for him. This becomes obvious through his sentence breaks, filler words such as "*uh*", and speech pauses. His reaction to this challenge is the conclusion that they should leave out the technical terms, which can be seen as a strategy to reduce the complexity of the task. That they need to use technical terms is introduced as a matter of course; still, it seems legitimate to leave them out in order to capture the essence of the hypothesis. This also shows that the content itself has priority, rather than the way in which it is presented.

In the Groups A and D, the role of the protocol taker is not as stable as in the Groups B and C that work on the protocol jointly. This is very obvious in Group D, who lacks a shared understanding of a "group protocol", causing irritation almost throughout the entire group work, which is illustrated in the following sequence:

Nico hands out one of the blank papers to each group member.

Melanie: *Do we have to we just need one protocol. #00:01:26-6#*

Ralf: *Right yes. #00:01:27-6#*

Melanie: *Just make one protocol #00:01:29-1#*

Ralf: *Mm, okay. #00:01:30-4#*

Nico: *So. If they again, want to have potatoes in salt solution. Then, we theoretically can? but wha- #00:01:38-1#*

By handing out blank papers to each of the group members, Nico nonverbally proposes the opportunity to keep records individually. At the same time, handing out the sheets is not in line with joint protocol writing, as is intended in the task (" . . . *so that you as group have a meaningful protocol*".). This is irritating to Melanie, who understands Nico's handing out of the sheets as a writing prompt, and interjects that they "*just need one protocol*". She first poses this as a question, but then formulates a statement, thereby increasing the urgency. This shows an orientation to the task and to joint protocol writing, which is also expressed by her use of the personal pronoun "*we*". While Ralf is validating her, Nico does not elaborate on this, but changes the subject from the protocol to the content of the task. Therefore, these diverging orientations persist almost throughout the whole group work, in which Melanie repeatedly suggests that they shall take group minutes and shows uncertainties on a nonverbal level about what and when to write something down individually. At the end of their group work, this is resolved by deciding that Nico's protocol is selected as the group protocol, which is proposed by Melanie (Melanie: "*yeah okay, then we'll just take yours*", #00:38:44-8#). In saying that the group takes "*his (protocol)*", again, it becomes clear that an actual group protocol was not written.

4. Discussion

The results of this study give detailed insights into the (group) processes of protocol generation in the context of an inquiry-based experimental learning setting. By using the documentary method, these insights go further than an analysis of the visible performance, and focus instead on which action-guiding orientations can be reconstructed for the students in the given situation.

Common for all the groups are two basic orientations, namely *task completion* and using the *protocol as means to provide structure and security*. *Task completion* connects to findings within documentary classroom research in general [33], as well as to earlier findings from the present research project referring to the experimental processes [37] These studies show that in learning situations within an institutional context, a learner orientation toward task completion and therefore performance is difficult to overcome. This is contrary to expectations in an inquiry-based learning setting, which is supposed to be about developing a spirit of inquiry in learners rather than representing an "assessment situation" in which they have to perform. The expected function of the protocol to promote scientific reasoning and learning in general [5,6] therefore seems to play a minor role in the present setting. Moreover, we could reconstruct that all student groups are using the *protocol as means to provide structure and security*. The members of the group implicitly share an understanding of which parts the protocol should consist of, and they do not need to negotiate how the protocol should be structured. This shared knowledge gives them a structure that guides them through the experimental setting that is rather open and uncertain. Although a research question is given ("*What happens to potatoes in salt solutions?*"), it leaves open the specific scientific content (namely osmosis) to be investigated, as well as the exact experimental procedure. In a previous study [37], we have shown

that a feeling of uncertainty exists among the learners in the experimentation process, whereupon, for example, the provided experimental material is used to secure their actions. Emerging ideas were examined and pursued according to whether or not the necessary experimental material was available. The protocol also has a supporting function because its structure is considered secure by the learners, which enables them to act in the uncertain situation. On an explicit level, it appears that the students are really going through a research process as they refer to the different phases of the inquiry circle. However, the reconstructed action-guiding orientations show that the protocol rather provides security for the experimentation process. Thus, it serves more as a guide through the process than a tool for scientific problem solving. For students as learners (learning to experiment), the protocol is needed as an assurance during experimentation.

Beside these "basic orientations" found in all groups, there are reconstructed action-guiding orientations that vary between the groups titled as "protocol as a flagship" and "protocol used in a pragmatic manner", which are discussed in the following. Those groups in which the protocol is used as a flagship for their work show action-guiding orientations towards *completeness and form* as well as towards *clarity*. Constructing the protocol as something that needs to be complete and corresponding to a certain form is associated with the findings of Hill et al. [28]. The authors showed that during lab report evaluations, a strong focus is on genre-specific conventions, which then also becomes established among the students themselves. Although our setting was designed to be assessment-free, namely taking place outside regular seminars and without grading the students' group work and protocols, two student groups worked on their protocols in such a way that showed they wanted to emphasise the high quality of their performance. However, the students primarily focused on how things were worded ("that sounds better", "just phrase it nicely"), rather than on the content itself. The students therefore treat the protocol as a certain text type that needs to be phrased carefully, rather than using it as a learning tool; this is expected in the WTL approach [4,6]. Furthermore, these groups are oriented to *clarity*. They do not use the protocol to raise questions or discuss different solutions to scientific problems, but make clear statements instead. They agree on which statements they can make with certainty. Thus, they create a narrative in which detours and uncertainties (which do occur in their mutual exchange) no longer appear (see also [38,39]). The question can be asked as to whether they want to tell a certain story of success. In any case, this manner of constructing the protocol is opposed to the positive effect on scientific problem-solving that should be attributed to keeping records [5,6]. Due to the fact that the phases in the inquiry circle are predefined, they seem to assume that they must follow this straightforward process in an inquiry-based situation, without deviations. However, it is important that students understand that this is an idealisation and simplification of the research process [40].

These reconstructed action-guiding orientations are accompanied by some process- and interaction-related aspects; the groups integrate "writing phases" either before, within or after practical parts of the group work wherein they fully concentrate on the writing part. This shows that the writing has a high relevance in these groups and does not happen on the side. At the same time, in these writing "slots", all group members are involved and therefore informed about the content and form of the protocol. In the beginning of the group work, the writing has a planning function, and at the end of the group work, the writing has a reflective function. The groups check their protocols and reflect on things left aside or aspects that still need to be included. Therefore, this is not a return trip to the content space as is mentioned in the model of Bereiter and Scardamalia [23], rather a check for gaps within the protocol, as is mentioned above (an orientation to *completeness*). They construct the protocol as a "group protocol" by either joint formulations or dictation forms; negotiations between group members still take place, but they focus on what they agree on.

In contrast to these groups, an orientation to *use the protocol in a pragmatic manner* was reconstructed in the other groups. The protocol acts not as a representation of the groups' work, but is used as a (supporting) tool within the process of experimentation. In

particular, the pragmatic use of the protocol for documentation (e.g., of what has been done; data logging) can be reconstructed; however, very practical things such as a calculation of the rule of three were also recorded in the protocol. This points in a similar direction to the results of Engl [5], who showed that the protocol was rather used by the pupils as a reminder to themselves. In any case, in our study, the flagship orientation is characterised by thinking of an external addressee (e.g., a teacher), while the pragmatists use the protocol more for themselves.

The construction of the protocol as a "pragmatic tool" is something which is not really present in the literature. Most often, it is expected that the protocol can promote scientific thinking and should be understood as a part of scientific activity. Still, the "pragmatic groups" use the protocol to support their experimentation process and to move forward with their work, namely using it for calculations and as a reminder to focus on the essential aspects. This makes it more of a tool within a process, rather than a representative end product as it is used in the flagship groups. One comparison that comes to mind with regard to the "real" scientific community is the parallel between the flagship orientation and the usual procedure for scientific publishing. Even in scientific publications, a success story is often told, with detours and failed attempts hardly reported. This is also reflected in publication bias, with null results seldom published [41,42], and by the use of pre-registration of studies as a solution to prevent bias at the end of data analysis [43].

Concerning process- and interaction-related aspects, in the pragmatic groups, writing happens on the side, and not all group members are informed about the content of the protocol. In one group, there was not even a common group protocol, but rather at the end of the group work, the group chose to use the protocol written by one student.

What needs to be considered concerning missing inquiry-based orientations for protocol writing in our data is that we did not use specialised approaches (e.g., the argumentative-driven inquiry (ADI) instructional model or science writing heuristic (SWH)) to promote scientific thinking during writing [6,10]. We consciously decided not to use an explicit instruction concerning scientific thinking, since we wanted to reconstruct the groups' own action-guiding orientations in this situation. Nevertheless, the students were informed about the inquiry-based learning context.

5. Conclusions

All in all, our analyses give insights into the *process* of collaborative protocol generation, focusing on how the learners shape and integrate protocol writing during group work within an experimental setting of inquiry-based learning. This differs from previous studies in that we are not evaluating the competencies of individual students or the performance of the group, but rather shedding light on what drives their actions and how they shape and understand keeping records. Our findings show that protocols function as a means of providing students with structure and security in a complex situation. They either use it as a flagship for their group's work or in a pragmatic manner. These are results that can only be detected by detailed, reconstructive analyses, as we have demonstrated using the documentary method. It is important to know how students act in such educational settings, and which action-guiding orientations are revealed in them, in order to include these findings in the design of learning arrangements. To promote scientific discourse, learners could explicitly be asked not to write a protocol of results, but a protocol of progress. Thus, the protocol would contain different proposals of hypotheses, procedures and/or data interpretations. Whenever different alternatives are available, the group members have to make a reasoned choice for an alternative with which they want to continue working, and this decision and its justification are also recorded in the protocol. Thus, reflection processes are explicitly demanded from the learners, and they are made aware of them during protocol writing. The effect of such a change from an outcome to a progress protocol on students' scientific discourse may be analysed in subsequent studies.

Author Contributions: Conceptualization, P.O., P.H. and K.S.; investigation, P.O.; writing—original draft preparation, P.O.; writing—review and editing, P.O., P.H. and K.S.; supervision, K.S. and P.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received external funding for the Article Processing Charge from the DFG (German Research Foundation, 491454339).

Institutional Review Board Statement: In Germany, as stated by the German Research Foundation (DFG) [44], the present survey did not require the approval of an ethics committee because the data collection did not pose any threats, risks, or high physical or emotional stress to the respondents. Nevertheless, we strictly followed all ethical guidelines and the Declaration of Helsinki [45], and the data storage complies with current European data protection regulations [46].

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author (Petra Olschewski).

Acknowledgments: We would like to express our sincere thanks to Britta Mörs for linguistic revision of the manuscript.

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

References

1. Krabbe, H. Das Versuchsprotokoll als fachtypische Textsorte im Physikunterricht [The experimental protocol as a typical text type in physics lessons]. In *Schreiben als Medium des Lernens*; Schmözer-Eibinger, S., Thürmann, E., Eds.; Waxmann: Münster, Germany, 2015; pp. 157–174.
2. Hoehn, J.R.; Lewandowski, H.J. Framework of goals for writing in physics lab classes. *Phys. Rev. Phys. Educ. Res.* **2020**, *16*, 010125. [CrossRef]
3. Müllner, B.; Bachler, T.; Möller, A. Herausforderungen und Chancen der Textsorte „Versuchsprotokoll" im Biologieunterricht für Schüler: innen mit Deutsch als Erst- und Zweitsprache [Challenges and opportunities of the text type "experimental protocol" in biology lessons for pupils with German as a first and second language]. *Z. Didakt. Biol. (ZDB)-Biol. Lehren Lern.* **2022**, *26*, 54–74. [CrossRef]
4. Moskovitz, C.; Kellogg, D. Inquiry-based writing in the laboratory course. *Science* **2011**, *332*, 919–920. [CrossRef]
5. Engl, L. Bedeutung des Protokollierens für den naturwissenschaftlichen Erkenntnisprozess [The importance of protocol writing for the scientific reasoning process]. Doctoral Thesis, Universität Koblenz-Landau, Mainz, Germany, 3 February 2017.
6. Keys, C.W.; Hand, B.; Prain, V.; Collins, S. Using the Science Writing Heuristic as a Tool for Learning from Laboratory Investigations in Secondary Science. *JRST* **1999**, *36*, 1065–1084. [CrossRef]
7. Brede, J.R. *Lernersprachliche Texte im Biologieunterricht: Eine Analyse von Versuchsprotokollen von Schülerinnen und Schülern mit Deutsch als Erst-und Zweitsprache [Learner Texts in Biology Classes: An Analysis of Experimental Protocols of Pupils with German as First or Second Language]*; De Gruyter Mouton: Berlin, Germany; Boston, MA, USA, 2020.
8. Bayrak, C. *Vom Experiment zum Protokoll: Versuchsprotokolle Schreiben Lernen und Lehren [From Experiment To protocol: Learning and Teaching to Write Experimental Protocols]*; Waxmann Verlag: Münster, Germany; New York, NY, USA, 2020.
9. Deiner, L.J.; Newsome, D.; Samaroo, D. Directed self-inquiry: A scaffold for teaching laboratory report writing. *J. Chem. Educ.* **2012**, *89*, 1511–1514. [CrossRef]
10. Sampson, V.; Enderle, P.; Grooms, J.; Witte, S. Writing to Learn by Learning to Write During the School Science Laboratory: Helping Middle and High School Students Develop Argumentative Writing Skills as They Learn Core Ideas. *Sci. Educ.* **2013**, *97*, 643–670. [CrossRef]
11. Bruckermann, T.; Schlüter, K. Forschendes Lernen im Experimentalpraktikum Biologie [Inquiry-based Learning in a Laboratory Course in Biology]. Springer: Berlin/Heidelberg, Germany, 2017.
12. Berry, D.E.; Fawkes, K.L. Constructing the Components of a Lab Report Using Peer Review. *J. Chem. Educ.* **2010**, *87*, 57–61. [CrossRef]
13. Bonnet, A. *Chemie im Bilingualen Unterricht: Kompetenzerwerb Durch Interaktion [Chemistry in Bilingual Education: Acquiring Competence through Interaction]*; Springer: Berlin/Heidelberg, Germany, 2004; Volume 4.
14. Isohätälä, J.; Näykki, P.; Järvelä, S.; Baker, M.J. Striking a balance: Socio-emotional processes during argumentation in collaborative learning interaction. *Learn. Cult. Soc. Interact.* **2018**, *16*, 1–19. [CrossRef]
15. Bohnsack, R. Documentary Method. In *The SAGE Handbook of Qualitative Data Analysis*; SAGE: Thousand Oaks, CA, USA, 2014; pp. 217–233. [CrossRef]
16. Bohnsack, R.; Pfaff, N.; Weller, W. *Qualitative Analysis and Documentary Method in International Educational Research*; Verlag Barbara Budrich: Opladen, Germany, 2010.
17. Parkinson, J. Use of personal pronouns in science laboratory reports. In *The Routledge Handbook of Language and Science*, 1st ed.; Gruber, D.R., Olman, L.C., Eds.; Routledge: London, UK, 2019; pp. 150–163.

18. Haagen-Schützenhöfer, C. Integrating NOS in LAB Work. In *The Role of Laboratory Work in Improving Physics Teaching and Learning*, 1st ed.; Sokołowska, D., Michelini, M., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 85–94.
19. Müllner, B.; Möller, A. Entwicklung eines Analyseinstruments zur Erfassung der sprachlichen und fachlichen Qualität von Versuchsprotokollen [Development of an analysis tool for measuring the linguistic and content quality of experimental protocols]. *Erkenn. Biol.* **2019**, *18*, 25–40.
20. Mayer, J. Erkenntnisgewinnung als wissenschaftliches Problemlösen [Acquisition of scientific reasoning as scientific problem solving]. In *Theorien in der Biologiedidaktischen Forschung: Ein Handbuch für Lehramtsstudenten und Doktoranden*; Krüger, D., Vogt, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2007; pp. 177–186.
21. Martius, T.; Delvenne, L.; Schlüter, K. Forschendes Lernen [Inquiry-based learning]. *MNU J.* **2016**, *69*, 220–228.
22. Keys, C.W. Investigating the thinking processes of eighth grade writers during the composition of a scientific laboratory report. *JRST* **2000**, *37*, 676–690. [CrossRef]
23. Bereiter, C.; Scardamalia, M. *The Psychology of Written Composition*, 1st ed.; Routledge: London, UK, 1987.
24. Curry, K.W., Jr.; Spencer, D.; Pesout, O.; Pigford, K. Utility value interventions in a college biology lab: The impact on motivation. *JRST* **2020**, *57*, 232–252. [CrossRef]
25. Kalaskas, A. Science Lab Report Writing in Postsecondary Education: Mediating Teaching and Learning Strategies between Students and Instructors. Master's Thesis, George Mason University, Fairfax, VA, USA, 5 December 2013.
26. Holschemacher, S.; Bolte, C. Subjektive Theorien zum Protokollieren im Chemieunterricht der Sek I [Subjective theories of writing protocols in chemistry lessons in lower secondary education]. In *Proceedings of the Naturwissenschaftlicher Unterricht und Lehrerbildung im Umbruch?* Gesellschaft für Didaktik der Chemie und Physik, Online Jahrestagung; Universität Duisburg-Essen: Duisburg, Germany, 2021; p. 549.
27. Hoehn, J.R.; Lewandowski, H.J. Investigating students' views about the role of writing in physics lab classes. In Proceedings of the 2020 Physics Education Research Conference, Virtual Conference, 22–23 July 2020; pp. 216–221.
28. Hill, C.F.C.; Gouvea, J.S.; Hammer, D. Teaching Assistant Attention and Responsiveness to Student Reasoning in Written Work. *CBE—Life Sci. Educ.* **2018**, *17*, ar25. [CrossRef]
29. Heinzel, F.; Krasemann, B.; Sirtl, K. Studierende bei der Gruppenarbeit im Fallseminar [Students during group work in a case seminar]. In *Studentische Praxis und Universitäre Interaktionskultur: Perspektiven einer Praxeologischen Bildungsforschung*; Tyagunova, T., Ed.; Springer: Wiesbaden, Germany, 2019; pp. 57–88.
30. Breidenstein, G. *Teilnahme am Unterricht—Ethnographische Studien zum Schülerjob [Classroom Participation—Ethnographic Studies on Pupil Jobs]*; VS Verlag für Sozialwissenschaften: Wiesbaden, Germany, 2006.
31. Zion, M.; Mendelovici, R. Moving from structured to open inquiry: Challenges and limits. *SEI* **2012**, *23*, 383–399.
32. Abels, S.; Koliander, B.; Plotz, T. Conflicting Demands of Chemistry and Inclusive Teaching—A Video-Based Case Study. *Educ. Sci.* **2020**, *10*, 50. [CrossRef]
33. Asbrand, B.; Martens, M. *Dokumentarische Unterrichtsforschung [Documentary Educational Research]*; Springer: Berlin/Heidelberg, Germany, 2018.
34. Fühner, L.; Heinicke, S. Der Einfluss der Dinge auf die experimentellen Handlungen im Physikunterricht [The influence of things on experimental actions in the physics classroom]. In *Dokumentarische Unterrichtsforschung in den Fachdidaktiken: Theoretische Grundlagen und Forschungspraxis*; Martens, M., Asbrand, B., Buchborn, T., Menthe, J., Eds.; Springer: Wiesbaden, Germany, 2022; pp. 137–154.
35. Nohl, A.-M. *Interview und Dokumentarische Methode [Interview and Documentary Method]*; Springer: Wiesbaden, Germany, 2017.
36. Przyborski, A. *Gesprächsanalyse und Dokumentarische Methode [Conversation Analysis and Documentary Method]*; VS Verlag für Sozialwissenschaften Wiesbaden: Wiesbaden, Germany, 2004.
37. Olschewski, P.; Herzmann, P.; Schlüter, K. Forschendes Lernen im Lehramtsstudium Biologie. Dokumentarische Rekonstruktionen studentischer Experimentierprozesse [Inquiry-based learning in biology teacher training. Documentary reconstructions of students' experimentation processes]. *ZfDN* **2023**, *29*, 2. [CrossRef]
38. Sonnenschein, I.; Koenen, J.; Tiemann, R. Wissenschaftliches Denken von Lehramtskandidaten–Eine explorative Studie im Fach Chemie [Scientific reasoning of teacher candidates—An exploratory study in chemistry]. In *Fachdidaktische Forschung in der Lehrerbildung*; Leuders, T., Christophel, E., Hemmer, M., Korneck, F., Labudde, P., Eds.; Waxmann: Münster, Germany, 2019; pp. 213–225.
39. Roehrig, G.H.; Luft, J.A. Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *Int. J. Sci. Educ.* **2004**, *26*, 3–24. [CrossRef]
40. Schlüter, K. Forschendes Lernen – Weshalb es wichtig ist und wie es sich in der Lehramtsaus- und -fortbildung umsetzen lässt [Inquiry-based learning – Why it is important and how it can be implemented in pre- and in-service teacher training]. In *Biologiedidaktische Forschung: Erträge für die Praxis*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 289–306.
41. Franco, A.; Malhotra, N.; Simonovits, G. Publication bias in the social sciences: Unlocking the file drawer. *Science* **2014**, *345*, 1502–1505. [CrossRef]
42. Ferguson, C.J.; Heene, M. A Vast Graveyard of Undead Theories:Publication Bias and Psychological Science's Aversion to the Null. *Perspect. Psychol. Sci.* **2012**, *7*, 555–561. [CrossRef]
43. Nosek, B.A.; Ebersole, C.R.; DeHaven, A.C.; Mellor, D.T. The preregistration revolution. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 2600–2606. [CrossRef]

44. Deutsche Forschungsgemeinschaft (German Research Foundation). FAQ: Information from the Humanities and Social Sciences. Available online: https://www.dfg.de/foerderung/faq/geistes_sozialwissenschaften/index.html (accessed on 1 March 2023).
45. World Medical Association. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. *JAMA* **2013**, *310*, 2191–2194. [CrossRef] [PubMed]
46. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the Protection of Natural Persons with Regard to the Processing of Personal Data and on the Free Movement of Such Data, and Repealing Directive 95/46/EC (General Data Protection Regulation). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016R0679&from=EN (accessed on 13 April 2023).