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Using *Tutorials in Introductory Physics* on circuits in a German university course: observations and experiences

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Abstract

We describe the implementation of *Tutorials in Introductory Physics* in a German university course. In particular, we investigate if the conceptual challenges that gave rise to the development of *Tutorials* are also found among German students, which hurdles to the implementation of *Tutorials* are encountered in a German context, and how *Tutorials* are perceived in this different context. To that end, video recordings from workgroup sessions and guided group discussions with students and teaching assistants, as well as interviews with faculty are analysed. It was found that German students enter introductory physics courses with a different set of prior knowledge than their US-American counterparts, which together with implementation hurdles and negative perceptions by students, teaching assistants, and faculty led to the discontinuation of *Tutorials* after only one semester.

1. Introduction

While physics is the same all over the World (or, for that matter, all across the Universe), the approach to teaching this subject varies greatly between countries, particularly in introductory university courses. For example, while in Germany it can be expected that every university student had some meaningful physics instruction in high school, this cannot be assumed in the United States. US-American universities traditionally favor a textbook-centric and numerical approach to physics, while German university courses tend to be less structured and focus more strongly on making the students perform symbolic derivations. There are different cultures of teaching physics, and even if there is some evidence that student difficulties in introductory physics are universal, there is no guarantee that methods and materials that work in one cultural context will also do so in another.

Tutorials in Introductory Physics [1] (*Tutorials* for short) have been successfully implemented across a wide spectrum of courses in the United States, and their usage and effectiveness has been extensively researched (e.g. [2–17]). Very few studies exist however regarding their implementation elsewhere, with the exception of Argentina [18], Finland [19], France [20], Mexico and Germany [21, 22]. In this study, using a German translation of *Tutorials* [21, 23], we compare and contrast observations and experiences in a German university course with those made in the United States. It was found earlier that *Tutorials* appear to be more successful in terms of gains on concept inventories when used in the English original rather than in the native language of the country [22], but reasons for this likely extend deeper than simply language: the implementation details are crucial [6, 22], and it might even be speculated that if *Tutorials* are used in a native language context, more of the local teaching culture might interfere with their implementation. This study provides some support that this might in fact be the case. As *Tutorials* follow a carefully structured sequence of steps ('elicit, confront, resolve') to address student difficulties, we are also interested in whether the same triggers elicit the same conceptual challenges, and whether the German students of our study will be able to follow through by confronting and resolving these difficulties, using the same materials.

We are investigating how the German national and cultural context influences different aspects of using *Tutorials*:

1. Do German students encounter the same conceptual challenges that gave rise to the development of *Tutorials* in US-American context?
2. How does the German national and cultural context affect the implementation of *Tutorials*?
3. How do student and faculty experiences vary in the German national and cultural context?

Section 2 describes the course setting, section 3 describes the applied research methodology, and section 4 presents the results of our study with regards to learner conceptual challenges (section 4.1), implemention (section 4.2), and experiences (section 4.3). Section 5 discusses these results, and section 6 provides our conclusions.

2. Course setting

The course under investigation is a first-semester component of the electrical engineering curriculum at a German university of applied sciences. The explicit learning goal of the course was for students to 'critically reflect on and reason about logical and technical facts gathered in real life', and to realise that 'some unquestioned understandings of technical relationships may upon closer observation turn out to be misconceptions'. Students in this course come from a variety of backgrounds: some of them just having finished high school, while others having completed vocational training are sponsored by their employers to get a university degree while working in parallel.

A German translation of the Determining and Interpreting Resistive Electric Circuits Concepts Test (DIRECT) [24] was prepared by the authors and administered as a pretest, with an average score of 16.2 ± 4.6 out of 29. This places the first-semester students in our course approximately at the same level before instruction as university students in the United States after traditional lecture instruction [24]. In other words, the German students began the course with a conceptual understanding of DC-circuits (as measured by DIRECT) that was to the level after traditional university instruction in the United States, likely as a result of high school physics instruction. As it turns out, the pretest scores are also comparable to the posttest scores in the Argentinian study after using *Tutorials* [18] (the Argentinian showed dramatic increases in DIRECT scores between pre- and posttest).

The scores are widely spread, which posed a challenge for our course, as we had a wide range of incoming understanding of direct current circuits, see figure 1. We attempted to address this by randomly assigning the students into work groups of typically three, instead of allowing them to chose their own partners, in an effort to split up groups with similar backgrounds.

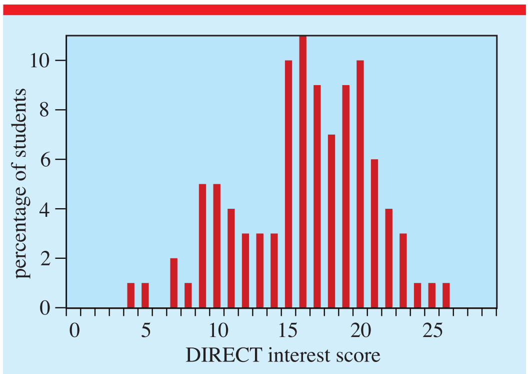

Figure 1. DIRECT pretest scores of students who participated in *Tutorials* ($N = 100$).

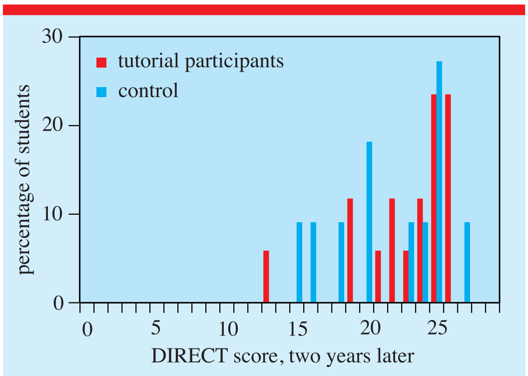

Figure 2. DIRECT results, two years after the end of the *Tutorials* course (red, $N = 17$), as well as control group results of students at approximately the same stage in their studies (blue, $N = 11$).

The course had two parallel sections taught by two faculty members (with the assistance of a third faculty member) and three undergraduate teaching assistants, with about 50 students in each section for a total of 100 students. For curricular reasons the course had been set up as a dedicated, standalone course. Consequently there was no direct connection to the corresponding lecture covering the content of the *Tutorials*, not even on an informal level.

Over the course of the semester, four tutorials including pretests were deployed: a model of circuits I, II, and III, as well as capacitance. Due to the shortness of the allotted time slots, tutorial chapters were generally split into two or three sessions. Prior to the first tutorials, faculty and teaching assistants underwent a training session, where they themselves worked through the tutorials and discussed matters of educational approach and logistics.

Due to logistical constraints, a DIRECT posttest could not be administered at the end of the *Tutorial* course. However, two years after the end of the course, we were able to contact the original participants, and 17 students (out of 94 invited) volunteered to work through the DIRECT again. In addition, 11 students (out of 184 invited) at a similar stage in their studies who did not participate in the course volunteered to work through the DIRECT for the first time. Figure 2 shows the results. Neither were the average scores significantly different, i.e. 23.0 ± 2.1 for the participants, and 21.6 ± 3.9 for the control group, nor were the distributions, based on a t-test ($p = 0.16$). After two years of additional studies, all students had made significant progress in their understanding of DC-circuits, and at least in this small, self-selected sample, any possible residual benefits of *Tutorials* are undetectable.

3. Methodology

Finkelstein and Pollock argue that cognition depends not only on individuals, but that the environmental structures that constitute the educational experience are no less significant to the learning process [6]. They thus studied the implementation of *Tutorials* within nested levels of frames of context (figure 3) [25], which had the department at the highest level. It is generally accepted that the outer levels more strongly direct the inner levels than *vice versa* [25]; in our study, the outermost level is a whole different country, language, school system, and long, well-established tradition of physics teaching. We thus extended the framework by a national/cultural level.

3.1. Conceptual challenges

Conceptual challenges among US-American students were documented by McDermott and Shaffer [26, 27], and these challenges guided the development of *Tutorials*. Video analysis provides an efficient way of gaining insights into student interactions with *Tutorials* [9], and we used this technique to detect whether or not there is evidence for the challenges among German students. Two research assistants made video recordings of work groups at the tutorial sessions (two groups in each of the two sections of the course), leading

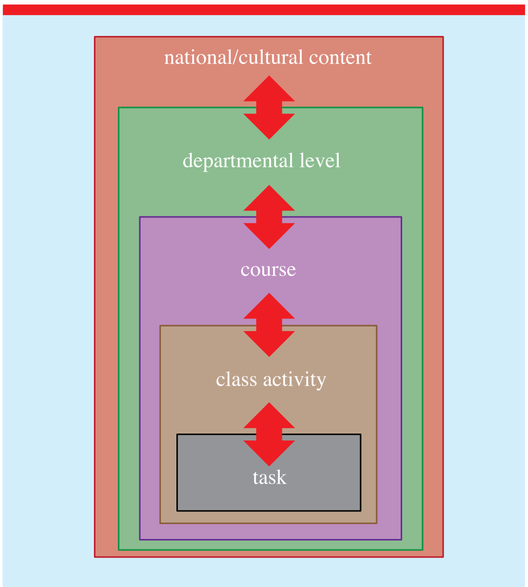

Figure 3. Frames of context: *Tutorial* tasks are embedded in nested levels of context [6], which for the purposes of our study was extended to include the national/cultural context.

to 35 h of video. The videos were transcribed in the original German, and the dialog was analyzed for evidence of the conceptual challenges identified in [26, 27].

3.2. Implementation

The national/cultural context has wider and at times unexpected implications: we documented logistical and organisational hurdles encountered along the way, which are on the one hand anecdotal, but on the other hand can be expected to be encountered in most German higher education settings when attempting to use *Tutorials*.

3.3. Experiences

We attempted to elicit participant expectations and beliefs through guided group discussions with students and teaching assistants (2.5 h) and interviews with course faculty (1 h). This component of the study is exploratory in nature, as the authors are not aware of an existing framework for analyzing the national/cultural Frame of Context. Instead, we grouped interview statements into common themes; it turned out that some of these themes changed in character between the early and the late phases of the course.

3.4. Translations and language usage

Any quotes appearing in this paper have been translated by the authors with particular effort to preserve their original tone and level of colloquialism. In general, translations of technical terms are quite literal such as when we will translate ‘*Potential*’, ‘*Potentialdifferenz*’, and ‘*Spannung*’ into ‘potential’, ‘potential difference’, and ‘voltage’, respectively. For ‘*Strom*’ (technically ‘current’), however, there is an ambiguity as the term is also used in everyday language for ‘electricity’ in general—for example, people frequently refer to their electrical energy bill as ‘*Stromrechnung*’, charging them for their ‘*Stromverbrauch*’ (literally, ‘current consumption’). Nevertheless, any occurence of the term ‘*Strom*’ will be translated into ‘current’, resulting in ‘*Stromstärke*’ to be translated into ‘amperage’ and ‘*Stromquelle*’ into ‘current source’ (while technically, of course, establishing a constant potential difference). In the latter case one needs to judge within a given context whether a student attaches the meaning of source of constant voltage or source of constant current to this term.

When we quote student dialogue, if multiple students participate, they are labelled by numbers; we interacted with a large number of students, and these numbers are starting anew from ‘1’ in every quote. For faculty and teaching assistants, we used consistent labels A, B, and C, throughout the paper.

4. Results

4.1. Conceptual challenges

The tutorials we are using are based on extensive research into learner conceptual difficulties and challenges [26, 27], carried out at the University of Washington, building among others on studies conducted with German high school students [28]. While some of these same challenges have already been identified in the more advanced context of alternating currents in answers to quiz and exam questions at other German universities [29], in this section we endeavor to investigate if their presence can be reproduced during actual tutorial sessions at the introductory level in particular for a student population showing relatively high scores on the DIRECT pretest.

The following headings refer to identified difficulties and challenges that have been directly taken or slightly adapted from McDermott and Shaffer [26].

4.1.1. Lack of concrete experience with real circuits. This difficulty mostly relates to translating circuit diagrams into circuits. In all observed groups, this did not appear to be a problem, as no evidence could be found in the dialogues or in the video recordings of students setting up the circuits. Students appeared to be familiar and comfortable with using batteries, lightbulbs, and crocodile clip cables, as well as with the process of translating circuit diagrams into real circuitry and *vice versa*, likely because they had done this already in high school or during vocational training.

4.1.2. Failure to understand and apply the concept of a complete circuit. In their research, McDermott and Shaffer frequently found that students would draw incomplete circuit diagrams, for example, only attaching one terminal of the battery. We did not find any evidence of such overtly incomplete circuitry, but we did find more subtle issues surrounding the current through the battery.

[neighboring group asks a question]
Student 1: He is asking, 'why is there a current through the battery?'
Student 2: Well, you know, because it is a closed circuit and has to be. Because without a closed circuit no current can flow.
Student 1: No, he defines it this way [gets piece of paper and draws], that a battery is like a chamber; up here, it's positive, down there negative. Meaning: the particles want to reach equilibrium, so they come in down here, equalising. The next particles flow. But why would that now be a current from here to there?
Student 2: Yes, so the battery ... it changes the charge of the negative particles. That means in this area there is no current. How should I explain that? Based on the theory, you are right, but in the battery there is a flow ... I don't exactly know how it works, but in the battery there is the same current, in any case.

Student 2 is encountering a conflict between on the one hand knowing that there is current through the battery, but on the other hand believing that the 'particles' inside the battery actually change charge from negative to positive—Student 2 agrees that the circuit is actually not closed, because there is an area without current. The task still works in this context, but not necessarily in the way intended.

4.1.3. Belief that current is being 'used up' as it flows through a circuit. McDermott and Shaffer found that students frequently worry about the direction of the current in a circuit, as in their thinking, current is 'used up' along the way. For example, with the simple series circuit in figure 4, they found that students believed that the second bulb (in whatever direction they assumed the current would flow) would be darker than the first bulb, as part of the current was already 'used up' in the first bulb [26]. For introductory courses, this problem might be aggravated by the colloquial German term '*Stromverbrauch*' ('current usage') for what actually is 'electrical energy consumption' (see section 3.4).

While we found evidence of this in the corresponding pretest, we were unable to find evidence in any of the groups that were observed, even though the tutorial carefully attempted to elicit this conceptual challenge and at one point even explicitly asked if current is 'used up'. Instead, in typical discussions, students immediately applied Ohm's Law and prior knowledge about series circuits:

Student 1: So, we have double the resistance, right? [other students nod] Because we have two bulbs. So, the voltage ...
Student 2: ... the voltage stays the same. In a series circuit, the voltage is divided up.
Student 1: The voltage emanating from the battery stays the same.
Student 2: Yes, but what you measure at the bulbs ...
Student 1: Yes, but that is different. You calculate with the total voltage.
[...]
Student 1: The current decreases since the total resistance increases, since we inserted a bulb. [...] The current overall decreases. It is equally distributed among the individual bulbs, but overall, the current gets smaller. Since you have a second resistor.

While the formulation 'the current is distributed' is somewhat ambiguous, from the remainder of

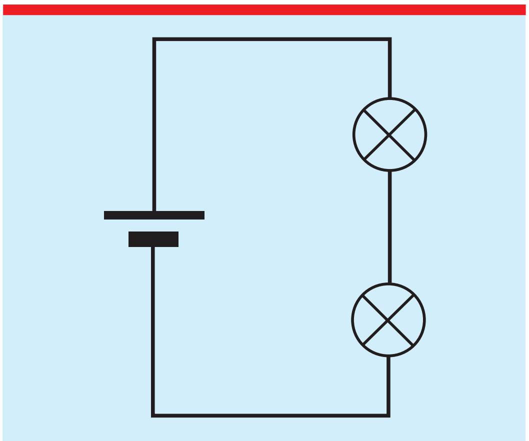

Figure 4. A series circuit. A typical misconception is that current is being 'used up' in a circuit, which would lead to the prediction that the first bulb in line is brighter than the second (section 4.1.3). Some of the standard circuit symbols are different in Germany than in the United States. Light bulbs are indicated by the crossed circles, and the terminals of batteries not only have different lengths but also different thicknesses.

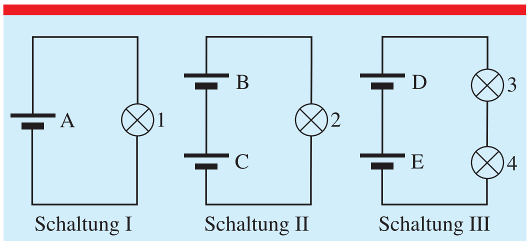

Figure 5. Batteries in series. These circuit diagrams address the misconception of batteries as constant current sources, section 4.1.4.

the discussion it becomes clear that the students completely missed the point of the exercise. Most of the discussion in the group centered around how to make their knowledge fit into the given questions, and the students started becoming annoyed and sarcastic. Here, the cultural/national frame of context strongly influenced the task, which essentially became counter-productive.

4.1.4. Treating a constant voltage source as a constant current source. While there are proven fundamental problems in understanding the difference, the German language unfortunately adds an additional subtle quirk: even professional physicists frequently refer to a voltage source as a '*Stromquelle*', which directly translated means 'current source' as already described in section 3.4.

We did in fact find some evidence of this. The students were supposed to rank-order the brightness of the light bulbs in figure 5. For a while, both students in this discussion agreed that the current is added up, they are only arguing on how to write the answer to the question.

Student 1: 2 is the largest. Then 3 and 4, and then 1.
Student 2: Here the current is added up [middle panel]. And here the current is also added up [right panel]. But that means because here [right panel] we have double the resistance compared to here [middle panel], this one [bulb 2] is brighter than that one [bulb 3], and that one is brighter than this [bulb 1].
Student 1: No, you would have 2 greater, ...
Student 1 and 2 together: ... 3 and 4, greater 1.
Student 2: Why greater 1?
Student 1: 'Why greater 1?'
Student 2: Yes.
Student 1: Because ... if you assume that the current sources are equally large, then you for sure have a greater current here [right panel], and it is not divided, the current, it flows through both. And since it is double of what it is here [left panel], the diminishing of brightness, ..., yes, it does not become half. In any case, the two bulbs are brighter than the one. I would say.
Student 2: I would have said here ... here is where the currents are added up. But if the currents are summed up ...
Student 1: In principle, I would claim, you can view this [both batteries] as one current source. Which happens to be double the size, if that is easier for you. But based on our understanding ...
Student 2: Yes, yes, the same current flows through 3 and 4. Understood. But isn't it the other way around?
Student 1: What do you mean, 'the other way around?' That 1 is greater then 3 and 4?
Student 2: Current sources in parallel-connected circuits?
Student 1: Part of the consideration ...
Student 2: Well, I am of the opinion, that ... I don't exactly remember all of it. If you have one current source and another current source in parallel [scribbles on paper], you have the same voltage, yes?
Student 1: Here are five Volts and here are five Volts, or something like that. But the current

increases, with the same resistance, theoretically. Some also flows in this one. And when they are on top of each other like this, the current is the same and only the voltage stays constant.
Student 2: You mean the current, if you add another current source, just somehow vaporises, or what?
Student 1: Well, theoretically [point to right panel], five Volts and some inner resistance, if you want. That means here's the same current [one battery] as here [other battery]. [Long pause] And the voltage across this is ten Volts.
Student 2: But we are supposed to only argue with the current. We are not supposed to consider the voltage, if I understood this correctly.
Student 1: [points to title of the Tutorial, which is 'Voltage']

The students then proceed to solve the problem correctly using the Kirchhoff loop rule, and then they independently verified their (now correct) solution using a textbook to look up rules for batteries in series and parallel. Eventually they call the teaching assistant to make sure.

The dialogue is interesting in many respects:

- Both students initially argue in terms of constant current sources.
- Via a detour of considering batteries in parallel, one of the students somehow arrives at considering voltages.
- The other student points out that he is violating the rules of *Tutorials* in that he was not supposed to think in terms of voltages.
- After the first student points out the title of the tutorial sheet, the students feel like they now have 'permission' to apply what they know, and are using Kirchhoff rules.
- The students again look toward authority (textbook and teaching assistant) to verify their solution.

The students probably would have solved the problem correctly immediately if they had not felt the constraint of the tutorial worksheet. Left to their own devices, they struggled. While they are capable of correctly applying rules, they had not fully understood the concept of a constant voltage source. Their cultural/national context had given them the means to correctly solve the task, but not the conceptual understanding of the situation. Once again, the task still worked, but not as intended.

4.1.5. Failure to distinguish between branches connected in parallel across a battery and connected in parallel elsewhere. While common in the United States, this problem has not been encountered in any of the recordings of German students. As already found in section 4.1.1, students have experience with circuitry and circuit diagrams, and terms like 'parallel' appear to be correctly understood in the context of the whole circuit.

4.1.6. Failure to distinguish between potential and potential difference. Many students resort to a water analogy:

Interviewer: Okay, what is voltage?
Student 1: The potential.
Interviewer: What is the potential?
Student 1: Uhm, nope, I don't know. I'm speechless.
Student 2: Well, I would explain that with water. Using the water pressure difference, so to say.

It is fairly clear that the students are using all three terms interchangeably. This ambiguity gets slightly resolved when students refer back to formal definitions, however, at this point 'energy' gets added to the discussion:

Interviewer: What is voltage?
Student 1: A potential difference.
Student 2: Yes.
Interviewer: What is a potential difference?
Student 3: Well, that is when charges are separated from each other, then, uhm, the one potential is higher than the other one, because for example ...
Interviewer: What is a potential?
Student 1: You can envision this pretty well in mechanics and with the potential. If you lift up something, then it has a higher potential ... then it has higher energy than before. And as we have added energy, and then let it fall again, it gets its energy back.
Interviewer: So potential is energy?
Student 1: No.
Interviewer: But?

Student 1: Potential difference. Difference, meaning change in energy.
Interviewer: A potential is a change in energy?
Student 1: Also not exactly.
Student 3: So actually as you know already, potential is described as an energy difference. So, when you for example separate charges, then energy is stored in the electric field between the charges. Then you have a zero-potential and a higher potential, and the difference between the potentials corresponds to the energy in the field. Between those, meaning generated by the charges, meaning separation of charges.
Interviewer: So potential is energy after all?
Student 2: Well, actually yes.
Student 1: Energy per charge.

The analogy is well-known in both German and US-American context, including the confusion between (potential) energy and potential [30].

4.1.7. Tendency to focus on the number of elements or branches. The issue here is that some students tend to simply count the number of, for example, light bulbs—regardless of how they are connected—and make simple conclusions such as 'three times more bulbs means three times more power drawn'. We have not encountered this, as the German students appear to have been able to consider the circuit elements in their contexts.

4.1.8. Failure to distinguish between the equivalent resistance of a network and the resistance of an individual element. A typical scenario that brings this problem to light is shown in figure 6. When the switch is opened, the resistance of the whole network changes. In one student group under observation, this was clearly identified:

Student 1: Because the parallel resistor is now gone, the resistance of the whole circuit increases. Because two in parallel ...
Student 2: Yep.
Student 1: ... is certainly smaller. That's why the resistance of the whole circuit increases, and I_{total} becomes smaller. And therefore the bulb (points to top one) becomes darker.

Unfortunately, this was not a group discussion; Student 1 clearly took leadership, the other students just wrote down what Student 1 said. None of the groups appear to have had problems with this concept.

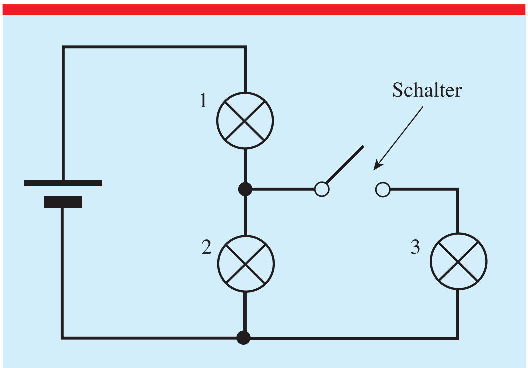

Figure 6. Three light bulbs and a switch (indicated by the German word 'Schalter'). This circuitry is supposed to elicit the difference between the equivalent resistance of a network and the resistance of an individual element, discussed in the student dialogue in section 4.1.8.

4.1.9. Difficulty in identifying series and parallel connections. This problem was also not encountered in our course. Together with the concepts described in sections 4.1.1, 4.1.5, 4.1.7 and 4.1.8, this concept is concerned with the understanding of circuits and considering circuit elements in context.

4.2. Implementation challenges

As opposed to the United States, German university courses are not permitted to assign mandatory textbooks, i.e. a student cannot be forced to buy a certain book in order to attend a venue. Thus, the publisher decided to also market the German version of *Tutorials* directly to students as a self-study book, and encourages students to work through the tutorials in small self-organised groups; in case there are difficulties, the publisher encourages students to discuss the scenarios in faculty office hours. Usage of instructor-prescribed workbooks in courses is currently rare, as financial arrangements are somewhat cumbersome. Given the German policies of no tuition, fees, or mandatory purchases, the first implementation hurdle was how to get the material into the students' hands. It took lengthy negotiations to overcome these challenges, posed by the national/

cultural context, with the publisher to arrive at a deal whereby the university is authorised to print a limited number of copies of publisher-provided files, and pay the publisher a fee for doing so.

Another challenge is giving rewards for participation: students generally cannot be forced to attend lecture, and generally no points can be awarded outside of official examinations. A frequently stated reasoning is that university should not be like high school, and that students need to take responsibility for their own learning. Here, the departmental frame of context is heavily influenced by the national/cultural frame of context, which has very different value systems for school and higher education. The inflexibility of the reward structure is due to the fact that examinations are highly regulated; changes in form, duration and other exam-related aspects require changing the corresponding legal documents for exam regulations (*'Prüfungsordnung'*). In our case, the corresponding document had to be amended in an elaborate departmental process to make attendance and homework mandatory in order to allow the worksheets to be reviewed and graded by the teaching assistants.

These policies of infrequent assessment almost directly translate into extremely high attrition rates, but those are widely tolerated; in STEM disciplines it is not unusual for more than half of the students to drop out of their chosen majors. While on a national level, attitudes towards these attrition rates are changing, within departments, this process is still frequently seen as 'natural selection', and activities that provide frequent, mandatory formative assessment are frowned upon as 'school-like'.

4.3. Experiences

4.3.1. Observations in Tutorial sessions. In group work, it became apparent that frequently two students were talking to each other and collaborating exclusively on building the circuits; whether or not the third student (or in the handful of larger groups, also the fourth student) contributed depended on the individual group dynamics, but in the most cases, the group performance reflected the work of only two students. The episode of section 4.1.8 is quite typical of this.

In extreme cases, no collaboration whatsoever occurred: the strongest student appears to have done all of the work without consulting with others, while the other students simply copied; even if this individual verbalised their reasoning along the way, no discussion ensued. In rare situations where disputes ensued, the tutor was called in as an arbiter, rather than asked to resolve the conflict within the group. Finally, another dysfunctional group dynamic was observed, where the group members looked at a problem, agreed on an answer ('Which bulb is brightest?'; '1', '1', '1', 'okay!'), and then each student wrote down their own explanation, which in some cases led to the group apparently agreeing on the same answer, but having different and possibly wrong reasons. Group-disruptive behaviour occurred when students played with their smartphones or even left the room to make a voice call.

These behaviours may be explained by group work having no tradition in German higher education, as in most STEM disciplines it is not an established part of the national/cultural context. While in laboratory classes, students frequently work with one 'lab partner', all other instruction, at least in the lower semesters, is geared toward individual work. In the United States, small group work has a much longer tradition [31]. Particularly descriptive and conceptual components of problem-solving could benefit from group work [32], where groups can outperform their best individual members. While it was already found that group work requires careful problem design and structuring [33], it also appears to require an existing culture and accepted epistemology [34] and value system [6, 8]—after all, *Tutorials* are carefully designed and structured around group work.

The cultural context adds to the responsibilities of tutors. In addition to serving as a socratic adversary they would have to nurture and faciltate group work. Tutors considered that to be a difficult task (see section 4.3.3).

4.3.2. Student experiences. Early in the course the German students frequently characterised *Tutorials* as 'annoying', oftentimes because they are 'moving too slowly'.

Student 1: One is forced to give terminology one already knows a wide berth, just to describe them somehow differently, even though in fact ...
Student 2: ... one already knows them.
Interviewer: So you say you already know the terminology, but you are not allowed to use it?

Student 2: Exactly.
Interviewer: And when you say the tutorials are too easy, or that the level is too ...
Student 2: Yes!
Interviewer: But you all have hope that ...
Student 1: ... that eventually something real comes? Definitely!

Particularly in the first tutorials, students felt that they were not allowed to apply concepts and terminology they already knew. This is not surprising, as all students would have encountered the terms current and potential in high school. But also in the United States, it is not unusual that *Tutorials* are initially perceived as 'too easy' by student and teaching assistants [9].

Interviewer: After this tutorial, is the difference between current and potential clear to you?
Student 1: Yes.
Student 2: But that was already clear beforehand ...
Interviewer: What is current, and what is potential?
Student 1: Yes, the term 'current' means, so to say, uhm, yes, the number of electrons, which—if I may already say so prematurely—, which flow through the circuit. Meaning, the strength of the current.
Student 2: Yes, potential is the pressure how eagerly the electrons want to move through the circuit.

The danger in the initial tutorials is that if students have indeed moved beyond the initial conceptual difficulties, the elicit-confront-resolve cycle becomes transparent and tedious.

Student B: You are supposed to discuss this as a group, but actually it's clear and makes sense, but if you have to do this for every task, like explain it, it somehow becomes a little annoying. 'Cause it's always the same. I think the last three tasks were somehow always the same.

The students are working hard to stay within the perceived constraints of the tutorials, trying not to apply 'prematurely' what they already believe to know. As a substitute, somewhat naïve metaphors are used, where electrons 'want' to flow through circuits due to pressure. The existing knowledge that the students want to apply, however, appears to be mostly formal definitions, without actually understanding what these definitions mean:

Student 1: We have not yet really dealt with potential, the term.
Student 2: But current.
Interviewer: So, could you quickly describe what current is?
Student 2: Charge per time.
Interviewer: Maybe a little bit ...
Student 2: Q divided by t.
Interviewer: Without formulas, just describe what 'current' means for you.
Student 2: Little gremlins, which ...
Student 1: No, just like he said, charge per time. How many charges in which time, meaning, depending on how many can pass through, and so on. Simply how many can move through, that's current.
Interviewer: Move through what?
Student 1: Well, through a conductor or a resistor.

There is a strong perception that the final, 'real' physics is in the formal definitions, and that *Tutorials* are holding the students back. Similar beliefs are found in the United States, and they may often be driven by a combination of student epistemology [35] and perceived value-systems of courses [36].

Student attitudes changed as the course progressed. A few weeks later, after the end of the current tutorials, the initial annoyance turned into frustration. By this time, the students had moved beyond the tutorials being too easy, and they now started to worry about their own knowledge and 'remembering things wrong'.

Interviewer: How do you feel when you think about Tutorials?
Student 1: OMG, not again!
Interviewer: Why?
Student 2: I think, you get relatively a lot of information, and that's good, that you work it out yourself, but every now and then one would need: 'This is the way it is, period!'
Student 3: Well, man, yes, it's always the same, and if you make a mistake and get the wrong idea, then this propagates through the whole exercise, and then this is wrong, and that is wrong. And

then you need to start again. But I think it's good that something like this exists. Because relatively many wrong concepts resolve themselves.
Student 4: Only that sometimes they resolve themselves too late. And then the danger is too high that you remember them wrong, and then you first have to work to erase them again.

As a possible solution to these concerns, students suggest to eventually move back to a plenary format:

Student 1: I would find it helpful if we were to write down these rules again, together.
Interviewer: Together, meaning, in a plenary session or as a group with the tutor?
Student 2: That you perhaps do it as a group and then compare, not that one has it one way, and the other the other way.
Student 3: Yes, the final general rules.
Interviewer: What rules, for example?
Student 3: What it is like with current and potential. Is it increasing, does it divide, stuff like that.

American students also tend to ask for authoritative answers and answer keys [5, 11], which is likely a reflection of a somewhat binary epistemology where knowledge is handed down by authority [35]. However, in at least one instance, it was reported that this expectation decreased over time, because 'it appears that by the end of the course the students had adapted to the new style of teaching/learning and had become less dependent on the teacher' [5]. Particularly in the German setting, where taking responsibility for learning is one of the guiding principles of universities, one would have hoped for the same effect.

Along the same lines, students apparently wish for more lecture-style instruction.

Student: Well, I would have expected a little more instruction. Kind of give us the tasks and then somebody explains,... actually have them explained beforehand, like in a normal lecture.

4.3.3. Teaching assistant experiences. Teaching assistants' buy-in is crucial for the successful implementation of *Tutorials* [7, 17, 37, 38]. The teaching assistants did not feel very comfortable in their role, and they have a very authoritarian view of the course faculty.

TA A: It's a hard sell, I have to say.
Interviewer: The role as a teaching assistant, who says how things should be run?
TA A: Yes, no, ..., more to convince students of your competence in the subject area. [...]
TA B: You just need to have more background. That is actually what the professors have. You know, when [Faculty B] stands there, and he poses penetrating questions, he just has more background, with which he can counter wrong concepts, and he can also explain better.
[...]
Interviewer: Do you think that only professors and graduate students should be tutors?
TA C: Not necessarily. Because students are closer to how students feel. With professors and graduate students ... those are mature engineers ... they oftentimes cannot stoop so low as to understand how the students think. [...] For us it's easier to communicate with the students on the same level; I think for the students it's more relaxed. [They think,] 'with a professor I cannot say that I haven't understood something.'

In Germany, teaching assistants are not used to the role of facilitators of learning, but frequently simply work as graders or presenters for faculty-provided materials. Thus, in spite of one week of training sessions, the teaching assistants felt not sufficiently prepared for their role:

TA C: In the beginning, they said the training would not be about the subject matter, but about the educational approach, and that is what I would have expected. I found it important that we worked through the tutorials first and kind of have a sample solution, and I personally don't find it so hard to help students find a solution themselves through asking questions, but what [Faculty A] expected, that if we notice that there is a problem, that we would dive deep into it—we cannot do that as students ourselves.

It is however not immediately clear if more advance training would have been helpful: instead, it seems that oftentimes *Tutorials* benefit more from being firmly embedded in the institutional culture [10]—something that is not the case in German universities, which are very faculty-centric.

The teaching assistants sometimes found the faculty to be addressing misconceptions that, in their opinion, the students did not really have:

TA B: One is closer to the students, like when [Faculty A] sees problems, which he defines totally differently, I sometimes sit there and think: 'the students probably don't see it like that.'
TA C: Like the problem we recently had on the blackboard ...
TA B: ... with the concept, with the misconception, of the current source ...
TA C: ... where [Faculty B] always said ...
TA B: ... 'that is the misconception of a current source'—but [the students] do not have a concept at all! They have the concept that in a series circuit the current is the same everywhere, they do not think in terms of 'voltage source' and 'current source,' and they do not think about how the source behaves—they just say there's this battery thing, and it does something, and that is always the same.
[...]
TA C: Some problems are dramatised.

A point of contention is that students seem to feel quite comfortable with inexact definitions and ambiguity, and the teaching assistants sympathise, while course faculty (understandably) insists on exact definitions.

The teaching assistants were aware of the non-functioning of many groups, but found it difficult to cope with that.

TA B: When reviewing results with such groups, we should care more to directly address students by saying 'Tell me, how do you think about that?'
TA A: That is difficult.
TA C: That is hard.

4.3.4. Faculty experiences. In the end, faculty are the decision makers regarding the implementation of research-based instructional methods [39–41]. The first faculty reaction regarding *Tutorials* was not surprising:

Faculty A: I found [Tutorials] very taxing, regarding organisation, both before and after. During the tutorials, the didactic part, was relatively okay, like expected, but the organisation required a lot more effort than anticipated; and also requiring more effort than other teaching venues.

Other faculty found the sessions themselves taxing:

Faculty B: There were taxing tutoring conversations. I don't want to say that I did not like that.

It was clear that within the German system, *Tutorials* are highly unusual:

Faculty A: I did notice that the teaching format is unfamiliar, that it does not correspond to the expectations of the students, and that they also do not know this form of teaching from school. [...]
Interviewer: And what was it that the students did not like? [...] What bothered them?
Faculty A: Well, formulating answers, the whole text-based approach. Meaning, not with formulas, but really writing answers in textual form; understanding things, and not just apply a formula, that of course is what is a little uncomfortable. That, in the end, is also where we want to put some salt on the wounds, and that certainly succeeded, but [...] that hurts a little bit.

The formulation 'a little uncomfortable' may be an understatement, as students over the course of the sessions frequently interjected complaints about 'all the writing', and stating that they would rather work with formulas, 'since it is so much quicker to express things that way'. The latter may actually be correct at a higher level: mathematical expressions, correctly understood, are a language.

There were some misunderstandings and potentially over-emphasis of the writing and textual components of the course:

Faculty A: The subject matter is not in the foreground [...] The way I understand Tutorials, in the beginning one has very easy subject matter, but that one practices to read tasks and formulate answers.

Interviewer: Is it possible that that was too much work writing?
Faculty A: Well, yes.

Of course students take cues from their instructors, as do teaching assistants. The unusual format of *Tutorials* was, in spite of the preparatory training, not well supported by the teaching assistants. Apparently, they tended to capitulate to student pressure:

Faculty B: It doesn't matter into which room I went, I always found the teaching assistants standing up front by the blackboard—which was a big weakness in the implementation.

5. Discussion

The national/cultural context had considerable influence on the deployment of *Tutorials* in the German setting. As figure 1 shows, students came into the course with a considerable range of prior knowledge. It seems, however, that this knowledge is of a mostly formal nature, as frequently declarative statements occurred:

- *In a series circuit, the voltage is divided up.*
- *Without a closed circuit no current can flow.*
- *(Current is) charge per time.*
- *(Potential is) energy per charge. In the battery there is the same current, in any case.*

The students expect the same kind of declarative rules out of *Tutorials*, and when *Tutorials* fail to deliver these, they start to worry about memorising 'the wrong thing'.

The students also expected to be able to use the rules that they already know, and perceived the strong scaffolding of the tutorials as a constraint. While the initial tutorials slowly work toward Ohm's Law, many of the students were already familiar with the full set of Kirchhoff rules—this started off the whole course on the wrong footing, and by the time that the tutorials became truly thought-provoking and challenging, the students had already formed an opinion of them being 'annoying'. Students were also ill-prepared for the point in the course when their rule-based approach would for one reason or another suddenly break down, and they started to worry that they would now memorise 'wrong rules'.

Another reason for frustration are lengthy elicit-confront-resolve cycles designed to address conceptual challenges and difficulty that the students do not have or believe not to have. This is particularly true for tasks associated with understanding circuits and considering circuit elements in context. Those are perceived as mere busywork and thus resented.

The German students objected to 'all the writing' and at times apparently longed to use formulas, but apparently never realised that those parts of the tutorials that required 'all the writing' urge them to check for consistency. The *Tutorials*, like many physicists, highly value consistency and use it as a working tool. One cannot expect, however, that first year students share and value this desire for consistency, and in fact this consistency is frequently lacking: in spite of the students being able to repeat definitions and being successful on the DIRECT by applying rules, they even at the end of the course were not able to verbalise several key concepts. In that respect, DIRECT does not appear to have worked as a truly conceptual test for circuits; the students got pretest scores comparable to typical American university posttest scores, apparently mostly due to application of formalisms and rules.

In Germany, some of the earlier *Tutorials* would likely be better suited for high school physics courses, before the rule formalism is taught and engrained. For university use, *Tutorials*-like materials are essential, but less scaffolding may go further. Students should be allowed to apply their full set of rules and mechanisms from the start: *Tutorials* being as challenging as they are, sooner or later students will automatically reach the point where they need to question their understanding of those rules, but they may be less ill-disposed if one would first let them try with less guidance.

It would take further studies to disentangle the influence of the national/cultural context on faculty and teaching assistant beliefs and values from personal preferences (e.g. using the frameworks [10, 17]), but unfortunately usage of *Tutorials* was discontinued based on the experiences presented in section 4.3, making this another example of a reform effort that was abandoned before it could be established [16, 39, 40].

6. Conclusions

In spite of the different national/cultural context, it was possible to introduce *Tutorials* into a first-semester venue at a German university. However, the material was somewhat ill-matched, as many of the students came in with a large base of definitions, formalisms, and rules already at their disposal, which they had gathered in high school or vocational training. In particular, an understanding of circuit diagrams and the necessity for considering circuit elements in context was already present for most students. For these students, the strong scaffolding of *Tutorials* was a hinderance, as it distracted from the conceptual gains that these students could have achieved: having the formalism at their disposal for many students did not imply that they had understood and were able to verbalise the concepts; keeping the students from using these mechanisms and making them formulate 'the same thing' several times made them ill-disposed to taking advance of the learning opportunity. The situation was aggravated by lack of TA buy-in and training, which turned out to be particularly essential, as the desired role of TAs is very different from the cultural norm. Finally, in order to implement tutorials, a number of logistical and legal hurdles had to be overcome. As a result of the experiences with *Tutorials*, their usage was discontinued after only one semester.

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