Chapter 24
Implementation Processes: Sustainable Integration of Biotechnology Experiments into Schools

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24.1 Theoretical Background

Teachers are challenged to stay up-to-date with rapidly growing knowledge and technology (Borko, 2004). Molecular biology is a fast-expanding field with the ongoing development of new applications (Martin et al., 2021). The underlying basics, such as polymerase chain reaction (PCR) or gel electrophoresis (GE) are integrated in the German school curriculum (ISB, 2015). However, the teaching of these basics remains at a solely theoretical level. Some possible reasons for this circumstance are schools' lack of the necessary equipment and reagents, teachers' low confidence and content knowledge (Nerdel & Schöppner, 2021; Hanegan & Bigler, 2009; Borgerding et al., 2013). Especially in interdisciplinary domains like biotechnology, professional development (PD) can bridge these gaps by connecting teaching practices with innovations (King, 2014; Merchie et al., 2018). The general assumption is that PD improves teaching quality and, thereby, students' outcomes if it is just effective enough. However, PD and lesson teaching take place in a multidimensional structure and are influenced by factors on different systemic levels beyond the lesson or PD event itself.

Various models have been developed to represent this complex interplay and are based on the process product paradigm (Brühwiler et al., 2017; Lipowsky, 2010). Lipowsky claims PD can be effective on up to five levels (2020). First, teachers

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must be satisfied with the PD so that further engagement with the content takes place. Second, the PD content should enhance teachers' cognition and knowledge. Third, the quality of teaching should increase when teachers implement the PD content. Fourth, students' outcomes improve by the implementation. The fifth level is positioned beside the other four and concerns school development, which can be stimulated by PD (Lipowsky & Rzejak, 2020). These levels are generally seen as a causal chain, although their causality has not yet been empirically proven (Davis et al., 2017).

Based on Lipowsky's model, several studies assessed different characteristics that enhance PD effectiveness and should be considered while planning a new PD, for example, the duration or teachers' active role (Sims & Fletcher-Wood, 2021).

Particularly in subject-specific PD, teachers seem to benefit from a pedagogical double play in which they anticipate themselves with the learning process. Those PD showed effects on both teachers' knowledge and classroom behaviour, if they were confronted with similar challenges during the PD as their students during lessons (Lipowsky & Rzejak, 2021). This form of cognitive activation can thus be counted among the quality features of PD that facilitate implementation of PD content.

Implementation research itself postulates the influence of additional factors, for example, support by the school administration (Gräsel & Parchmann, 2004). For implementation, which in a broader sense represents the third level of Lipowsky's model, effectiveness is not defined uniformly, but rather two approaches emerged: Defined by the number of teachers implementing it or the quality of implementation (Gräsel, 2010; Gale et al., 2020). Assuming causality in the Lipowsky model, high-quality PD should be followed by implementation. In order to understand what teachers actually perceive helpful about PD for implementation, we need to know their approach to implementation.

A PD programme focussing on molecular biology contexts addresses both keeping teachers up to date with growing amounts of knowledge in biotechnology and enable them to implement experiments into their lessons (Schöppner et al., 2022). Following Lipowsky's model and recommendations from presented studies, we designed the PD accordingly with a high focus on cognitive activation as teachers can perform the biotechnology experiments themselves during the PD (Nerdel & Schöppner, 2021). The PD has been evaluated on the first of Lipowsky's levels and teachers are satisfied (Nerdel & Schöppner, 2021). After participating, teachers can borrow the equipment needed for implementation, such as thermocycler and reagents, free of charge, which addresses the stated problem of schools lacking these (Schöppner et al., 2022). Based on the theory, we expected participation in pairs and at schools directly to reduce implementation barriers regarding implementation quantity (Gräsel & Parchmann, 2004). This study aims at this implementation (Lipowsky's layer four). With respect to the PD's goals, two main questions arise: How did they implement the biotechnology experiments into their classroom? To what extent did the PD influence the implementation procedure? Both questions link the Lipowsky layers two and three in order to get a deeper understanding of their causality. What occurs following the participation and borrowing of equipment by teachers? We examined how teachers execute molecular biology experiments at their schools. Insights into the process and the different formats teachers used for implementation are presented.

24.2 Method

24.2.1 Professional Development

The starting point of this study is an evaluated PD that addresses experiments in DNA analysis and is aimed at biology teachers. It was extensively described previously (Nerdel & Schöppner, 2021; Schöppner et al., 2022). We embedded the DNA analysis into four different contexts (s. Fig. 24.1) firmly connected to the Bavarian biology curriculum (ISB, 2015). The contexts vary in thematical and methodical difficulty. Therefore, teachers may choose one that meets their needs ideally. Figure 24.1 shows an overview of the contexts starting with the thematically and methodically easiest: Crime scene.

Implementation refers to teachers who borrowed the equipment and carried out the practical molecular biology methods presented in Fig. 24.1 with their students at school in biology classes. Teachers are entirely free in their realisation regarding grade level, time spent or student numbers. Within the PD, we presented the modules in such a way that they can be implemented either in a regular 90-min biology lesson, or in two successive biology lessons with a break after PCR, which widens the possible implementation formats.

Analysing the various implementation formats that emerged in detail should give first insights into Lipowsky's third layer implementing PD contents (Lipowsky & Rzejak, 2020).

Module 1: *Crime Scene*		polymerase chain reaction		agarose gel electrophoresis
Module 2: *Circadian Rhythm*	DNA extraction	polymerase chain reaction		agarose gel electrophoresis
Module 3: *Bitter Taste Reception*	DNA extraction	polymerase chain reaction	restriction digest	agarose gel electrophoresis
Module 4*: *Lactose Intolerance*	DNA extraction	polymerase chain reaction	restriction digest	agarose gel electrophoresis

Fig. 24.1 Within the PD, teachers learn the theoretical background and perform the experiments of two modules. The modules grow in difficulty in both methodical scope and theoretical complexity. Module 1 is the easiest, as the reagents used are prefabricated DNA samples. Module 4 is advanced, requiring extensive genetic knowledge and clear practical procedure to ensure visible results

24.2.2 Sampling

Since 2017, a total of 289 teachers from 98 secondary schools have participated in the PD. Teachers from 38 schools borrowed the equipment and implemented the experiments at least once; 20 of those schools implemented the experiments more often. Implementation is described on a school level, as mostly one teacher carries out the borrowing process. However, more teachers are involved in the implementation process. Both participation in the PD and implementation occurred in groups of teachers.

In order to achieve the broadest possible coverage of participants, we followed theoretical sampling (Flick, 2006, p. 73) to include all known variables and their combination:

1. *Secondary school type:* gymnasium, upper secondary school, vocational high school
2. *PD participation mode*: alone, with colleagues
3. *Locations of PD*: school, university
4. *Implementation mode*: alone, with colleagues

We have to add that the PD mainly addresses teachers from German higher secondary schools (Gymnasium) and was specially designed for their curriculum (Nerdel & Schöppner, 2021). However, we wanted to include viewpoints from other school types as they show a significant interest in both the PD and implementing the biotechnology experiments. Therefore, we recruited teachers for the interviews via email, and they participated voluntarily. We interviewed a total of 20 teachers from 18 schools who implemented the biotechnology experiments. One interviewee presented the most complex implementation process in this study. For broader insights, we recruited a second interview partner from the same school.

24.2.3 Descriptive Statistics of the Sample

For the interviews, we recruited teachers for each variable and its expression. We even found a new combination of variables: Teachers who implemented the modules practically into their classes without attending the PD. Instead, they were trained internally by participating colleagues.

Regarding the *implementation mode*, the number of 20 interviews was exceeded as some teachers implemented more often. If they implemented several times alone **or** with colleagues, we counted them together, but if they implemented several times alone **and** with colleagues, we counted them separately. The following list shows the variable coverage of our interview partners. Notably, those variables do not correlate, e.g., the 13 teachers who participated with colleagues are not the same 13 teachers who implemented cooperatively.

Secondary school type: Grammar school: 16 Upper vocational school: 3 Comprehensive high school: 1	*Participation mode:* Alone: 5 With colleagues: 13 Not: 2
Location of PD: University: 10 School: 10	*Implementation mode:* Alone: 9 With colleagues: 13

We stopped recruiting due to information saturation and are therefore not covering all possible combinations of these variables. However, when looking at the variables alone, their different expressions seem not to impact implementation as it takes place in each.

24.2.4 Interviews

We conducted semi-structured interviews. The order and concrete wording of the open questions could vary (Krüger et al., 2018, p. 125). We asked our interview partners to describe the implementation process directly: 'Please describe how implementation was carried out in your classroom/school.' We started with face-to-face interviews (in February 2020) but switched to phone interviews due to the COVID-19 pandemic. The last interviews took place in May 2020. The duration of the interviews was M = 20 min (SD = 10). The interviews were transcribed following simple rules based on Dresing and Pehl (2020).

24.2.5 Examine Teachers' Implementation Formats

We summarised each interview as an individual case (Kuckartz et al., 2008) and mapped the individual implementation processes by the typecasting strategy of Mayring (Mayring & Fenzl, 2019). This four-step analysis generalises statements to identify types or categories: (1) paraphrasing (remove language that does not carry information), (2) generalising (abstract statement to a consistent level), (3) selection (select all abstracted statements that carry relevant information), (4) integration (summarise all statements that carry the same information). During mapping, we followed these steps. We focussed on actions undertaken by teachers and worked in pairs to verify decisions by continuous communicative validation.

In this paper, we present the *implementation strategies* that emerged from typecasting the 20 interviews and focus on a particular case: two interviews of teachers from the same upper vocational school. We call the two teachers Anna and Lisa, regardless of their true gender. In more detail, we extracted their implementation procedure to examine the interrelationships of factors predicting PD effectiveness and their implementation outcome as best practice examples corresponding to the research question.

24.3 Results

24.3.1 Implementation Strategies

Within the 20 interviews, we could identify three main implementation formats: *regular lessons* (N = 9), *block lessons* (N = 9) and *special event* (N = 6).

Teachers implemented the biotechnology experiments within the standard time frame of biology lessons during regular lessons. This strategy is presented within the PD (Sect. 24.2.1). It was supposed to reduce the organisational effort. Within *block lessons,* experiments were implemented with an expanded time frame. Teachers either exempted students from their following lessons or organised an afternoon session. In both cases, the participation for students was mandatory. Within a *special event,* teachers organised a whole project day or week. Thereby the participation of students was voluntary. Voluntary afternoon events also fall into this category.

Some interviewees implemented several times: If they implemented following the same strategy, we counted them together. If they implemented the following different strategies, we counted them separately. Therefore, the total number of implementations counted exceeded 20 interviews.

We were able to find every implementation strategy within every variable and its expressions which we defined in Sect. 24.2.3, with one exception: Teachers who did not participate in the PD only implemented cooperatively. Additionally, *block lesson* tends to be implemented cooperatively. However, further studies are needed to verify that tendency based on the sample size (N = 20) and the fact that some implemented block lessons alone. For the *participation mode* and *location of the PD*, this data shows no tendency towards an implementation strategy.

This was further supported by teachers who repeatedly implemented as they tended to choose the same implementation strategy again, regardless of the variables they fall into. We identified three scenarios:

Teachers who implement PD into one class either in *regular lessons* or *block lessons,* repeat this in the following year(s) if they teach a suitable class again.

Second, teachers who implemented the experiments collaboratively with the whole biology faculty for all biology students in the suiting grade level and repeat this annually.

Third, teachers who implemented it collaboratively with their colleagues in either *block lessons* or *special events,* and additionally implemented experiments with another class within *regular lessons*. Hence, teachers seem to only choose different implementation strategies when the implementation takes place in the same year.

From that, we drew two conclusions: Firstly, the variables defined in Sect. 24.2.3. have no influence on the chosen implementation strategy by teachers with the one stated exception. Secondly, a new characteristic to hint at quality emerges: annual repetition. In itself, repetition is a quantitative characteristic, but the practice that accompanies it could increase the quality of implementation in the long term. This gives a significant indication of PD quality because the PD content seems to be accepted and suitable for teachers to use it repeatedly. Teachers who implement repeatedly have the potential to adapt and develop their implementation process by gaining practice and routine. For PD addressing a specific content, this could define a first measure of success, as annual repetition automatically serves implementation quantity, not by the number of teachers implementing, but the coverage of students reached.

The only variable that could enhance this quality definition is cooperation: having many teachers repeatedly implementing together enhances the possibility of strengthening the implementation process through cooperation features, for example, feedback and team support. Additionally, if all teachers work together, they can address the whole grade level and create equal opportunities for all students. Subsequently, this scenario has great potential for sustainable integration of the PD content into the school curriculum. In the interviews with three teachers from two different schools, we found this described scenario. That proves that single PD events can initiate school curriculum development (fifth layer of Lipowsky's model) through collaborative work on innovative subject content for the classroom. In the following section, we closely focus on the implementation procedure and further development of that one school as we consider it a best practice example.

24.3.2 One School as a Role Model: Sustainable Integration of PD Content into Curriculum

Anna is involved in teaching pre-service teachers and continuously seeks for innovation as she wants young teachers to learn new teaching concepts to stay up-to-date. Consequently, she learned about PD early on. In a first step, she discussed the PD offer with the other biology teachers at her school. As a result, they decided democratically to attend the PD and implement the content collaboratively.

> *Anna came up with the idea and democratically put [it] up for debate. We all thought it made a lot of sense because our students do not have any opportunity to practise biotechnologically.* – Lisa

The teachers had two primary motivations for implementing the experiments: They highly value the chance for students to experience practical biological work, but suffer from the lack of equipment. In line with that, all students of suitable grades (12th and 13th) who selected biology as a subject should experience practical work. In their view, *block lessons* were more suitable. They divided things into different tasks to manage such an important occasion. Anna took over the superordinate organisation: contacting the school administration and all the teachers affected, finding a suitable week, etc.

> *Of course, the school organisation is another hype, […] it is difficult to schedule [this event] correctly.* – Anna

Lisa and the others shared tasks like preparing teaching material and students theoretically. In 1 week within defined time frames, all the biology classes went through the practical work one after another, while the teachers shared supervision and received support from student teachers. Thus, the students were released from their regular classes during their participation. Students evaluated the event regarding their satisfaction with sticky dots. Subsequently, the biology faculty reviewed the event, discussed the procedure and decided on adaptions. They went through this overall process over the following years, further defining their implementation procedure and establishing it as a fixed event at their school.

In summary, it can be stated that the faculty had both well-established cooperative processes into which the PD content was included and a change agent (Anna), continuously looking for improvement. This enables the faculty to define implementation success and reduce implementation barriers.

Figure 24.2 gives an overview of these findings.

The faculty decided on the following adaptions:

In **year two,** 13th graders should be able to implement module 3 (circadian rhythm), as they know module 1 from the previous year. The PD content directly enables this procedure of teaching over different grade levels. We assigned the different contexts to the factor of *adaptivity,* allowing teachers to implement it into various thematic fields of the national curriculum. This faculty used this as a learning opportunity, for the reason that students can focus on the higher thematic complexity of the content, as they know the handling of experiments, e.g. pipetting,

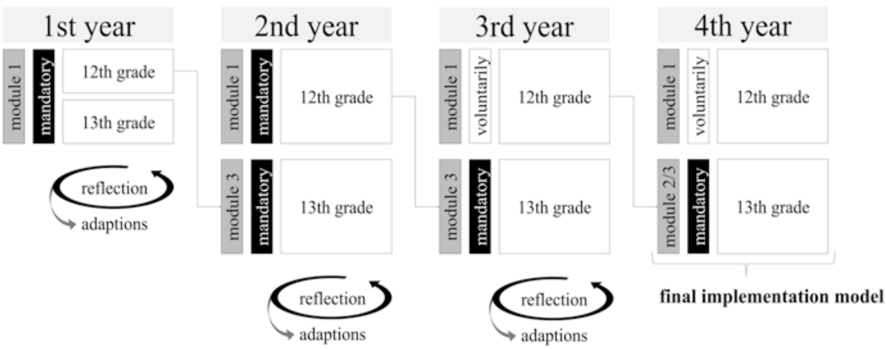

Fig. 24.2 Implementation strategy and its development over four years of an upper vocational school. First year: Whole biology faculty implemented the first module (crime scene), *blocked lessons* over one week, all biology students (12th and 13th grade). Second year: Same strategy, but 13th grade implemented module 3 (bitter taste perception). Third year: Same strategy, only 13th graders participated mandatorily, working groups reduced. Fourth year: 13th graders could choose between module 3 and 2 (circadian rhythm). This implementation module remained

from the previous year. In terms of the desired vertical connection of knowledge in school, this could directly influence teaching quality, the third layer of the Lipowsky model. During this implementation, no student teachers supported the biology faculty. They split the biology classes for implementation, so that one teacher supervises only half a class in the **third year**.

> *The principal has now also approved having someone who does not teach a class still supervising students [at the event].* – Anna

This impressively showed how cooperation allows teachers to reduce implementation barriers by themselves and adapt their teaching flexibly. As the accessibility of student teachers could be an omnipresent barrier, this procedure is even more noticeable. Twelfth graders' participation was not mandatory anymore. This was to give the event a 'special flair', as it addresses only interested students, while assuring that everyone choosing biology in the 13th grade experiences biotechnology practically. With this change, their implementation procedure became a mixed version of *block lessons* and *special events* held in the same time frame. This combination of mandatory and voluntary participation could function as a factor for implementation quality by creating equal opportunity for everyone and simultaneously fostering interests. After the third implementation, the faculty was satisfied with the outcome. Despite many 12th graders joining the event, they had some remaining capacity and opened it for interested teachers with other subjects. They were rather surprised at how many of their colleagues participated and reflected on cross-connections of the experiments within the context of their own subject.

> *In the meantime, [the organisational issues] have been well solved with a lot of talking and arguing within the school.* – Lisa

In **year four**, 13th graders were able to choose the context they are most interested in, either circadian rhythm or bitter taste perception. The faculty's growing security with supervising the practical work made this flexibility possible. Within 4 years, this biology faculty established the experiments as an annually repeated event at their school and gained the support of other teachers, the principal and the whole school management. Consequently, they successfully integrated the PD content into their school curriculum. This allows us to draw three conclusions:

1. Regular repeated implementation (annually) is possible even if the PD is a one-time event. This is highly dependent on the teachers' school environment.
2. Teachers' scripts and beliefs (layer two) within a faculty could be understood as collective, affecting each other and contributing to the school environment. In this concrete case, this manifests in new teachers being obligated to participate in the PD and implement it cooperatively.
3. A faculty with established cooperative structures can reduce implementation barriers themselves.

24.4 Discussion

The PD underlying this study is in line with the constructivist view that learning with authentic contexts can increase students' scientific interest, in general, due to the close linkage of molecular biology topics with social issues, such as the COVID-19 pandemic (Nordqvist & Aronsson, 2019). With the option to borrow the equipment needed, teachers can allow students to analyse their own DNA and experience what it means to work in a molecular biology laboratory (Schöppner et al., 2022). Since this PD is a single event, it is affected by the critique of the current discussion on PD effectiveness, which generally questions the impact of such offers (Lipowsky & Rzejak, 2020). This study's goal was to evaluate teachers' implementation approaches to assess the PD's influence on implementation, which conforms to the overarching goal of the PD to counteract the missing equipment and enable teachers to implement molecular biology basics practically at school (Nerdel & Schöppner, 2021; Huang et al., 2018). As a starting point, we draw on Lipowsky's model of PD effectiveness (Lipowsky & Rzejak, 2020).

Our biotechnology content was presented in a regular lesson format. This should reduce implementation barriers due to connecting the content to classroom instruction and bringing innovation in line with existing teaching practice (Yurtseven Avci et al., 2020; Gräsel & Parchmann, 2004). Contrarily, we found more teachers that used other implementation strategies instead: *block lessons* or *special events*. Either the organisational effort in classroom management is not as crucial for our PD or overpowered by other factors influencing the implementation of the experiments, e.g. equipment borrowing. To make a conclusive statement about these linkages, we need to take a closer look at teachers' decision-making processes and reasoning. From our analysis, a new factor emerged: annual repetition. PD represents one of three main themes contributing to curriculum development (Langelotz & Olin, 2022). Annual repetition is the first step towards curriculum development, which, according to Lipowsky's model, is the fifth layer impacted by PD (2020). Curriculum development is a collaborative practice, and teachers remain the main agents in this process (Langelotz & Olin, 2022). In the past few decades, a conceptual change to merging top-down and bottom-up strategies shifted decision-making competencies and responsibilities to the individual school level (Maier-Röseler & Maulbetsch, 2022). Some researchers went a step further and expected teachers to not only implement innovation, but shape and influence the respective development themselves (Kneen et al., 2021). The presented case study impressively shows that teachers can shape their school development process with organisational communication on several school levels. We extracted several influencing factors, which are in line with current literature: change agent, highly cooperative structures, joint mission (a.o. Fussangel & Gräsel, 2009). Future studies should analyse the whole sample of teachers who implemented the biotechnology experiments in school for further evidence of correlations and their influence on implementation quantity. Nevertheless, those factors could influence the implementation strategies chosen by the teachers.

All these results must be confirmed by future studies in different PD settings and other subjects, as this study is limited by both sample size and the indications for teachers' self-statements. Nevertheless, our data first shed light on the implementation process's complexity. We could extract that *annual repetition* is a suitable predictor for PD effectiveness in the form of implementation that opens opportunities for school development via new topics and methods in the biology school curriculum. Thereby, we could demonstrate that a single PD addressing a certain topic can initiate school curriculum development if certain conditions are present, for instance, embodying a joint mission and cooperative structures at school. In the case presented, this could even lead to a feedback loop from school practice to PD because new teachers must contribute to the established PD content and are expected to participate in the PD. In terms of the Lipowsky model, this reveals a complex view on the postulated causality, because higher layers (e.g. implementation) influence lower layers (e.g. participation) in PD. Thus, at least for the present PD concept, it could be shown that one-time PDs are legitimate in the teacher training landscape.

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