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Reflections on a Three-Year-Long Teacher-Centered, Participatory Action Research Experience on Teaching Chemical Bonding in a Swiss Vocational School

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Abstract: Chemistry is considered to be a difficult subject and chemistry education courses are not very popular among many students. Innovations in the curriculum and pedagogy may help to overcome difficulties in learning as well as motivational problems. Participatory action research (PAR) seems to be a suitable approach for developing such an innovation for the chemistry classroom. This paper reflects on the adoption of a PAR model to teacher-centered action research. A project is discussed aiming at iteratively improving lessons on chemical bonding in a Swiss vocational school. The lesson was focusing on self-determined, autonomous learning in small groups in a multimedia-supported learning environment to foster student motivation for learning. The project is based on the cooperation of a chemistry teacher and a PAR expert group of chemistry teachers operating far away from the school. The cooperation was implemented by synchronous and asynchronous digital communication. The lessons have been cyclically developed over three consecutive years of teaching. The findings from the current study indicate that the implemented practice of action research helped to both improve the teacher's pedagogical repertoire for his chemistry lessons and contributed to the teacher's continuing professional development in terms of better understanding how student-centered his lessons should be.

Keywords: action research; vocational education; chemistry education; curriculum development

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1. Introduction

Chemistry education is a subject that is considered by students to be difficult and not very popular among many of them at the secondary and post-secondary educational levels [1]. Therefore, the curriculum and practice of teaching chemistry are subject of constant debate and change in general [2], and in vocational chemistry education in particular [3]. Change in the curriculum and pedagogy should focus on making chemistry education more motivating and also more relevant to the student, namely, to raise the individual relevance for learners' daily as well as professional life, today and for their future [4].

Problems contributing to the low motivation of students to engage in chemistry education are attributed to the prevalence of mainly content-driven curricula and mostly teacher-centered pedagogies [5]. Consequently, many students lack understanding and are not very motivated for chemistry lessons [6]. Although many reform initiatives strive for more context-based and student-active learning, these approaches are generally not implemented sufficiently in the chemistry teaching process in general (e.g., [7]), and in vocational chemistry teaching in the German speaking countries in particular [8].

Modern chemistry education recommends using student-active modes of learning [9]. Corresponding pedagogies are justified by constructivist learning theory [10] and positive effects on students' motivation [9,11]. Constructivist learning strives to expose students to real situations that elicit their conceptual knowledge and promote self-directed development of applicable knowledge. This is an active process fostered by autonomous and cooperative learning strategies [9]. Corresponding learning strategies in chemistry might be based in or supported by contemporary information and communication technology (ICT) (e.g., [12,13]).

Change in the curriculum and pedagogy of chemistry teaching is needed in many different dimensions; among them the curriculum with its associated objectives, media, and pedagogy [14]. It is evident that it is always the teacher who is the key for successful implementation of change in the classroom [15] and for the success of teaching [16]. However, specific guidance for change of curriculum and pedagogy is not always available for teachers, and this is certainly the case for vocational chemistry education in southern Switzerland.

This paper reflects the process and learning experiences of a teacher in a teacher-driven action research approach to curriculum innovation in southern Swiss vocational chemistry education. It describes a project at the "Gewerbliche Berufsschule" (Vocational School) in Chur, Switzerland. The topic of the teacher's curriculum innovation interest was teaching chemical bonding according to ideas of student-active learning. The focus of the intervention and research was to promote self-directed and autonomous learning supported by modern ICT inspired by the idea of the "Tour de Chemie" [13] and modern learning environments grounded in the software PREZI [17]. In this paper, the action research design, experience from the curriculum development, and ways of supporting teacher-centered design by a remote participatory action research (PAR) network are discussed. Selected evaluation results and the teacher's reflections show how the action research process contributed to a change in teaching and the teacher's continuing professional development.

2. Theoretical Framework

Change in chemistry education is not always accomplished by integrating theoretical knowledge, research evidence, and practice of teaching [18]. Essential aspects of practice of teaching tend to be neglected in many research approaches, as the biggest part of explorative and descriptive empirical research is done under well-established theoretical and methodological frameworks, but quite regularly does not recognize practical needs and constraints among practitioners [19]. Such research focuses mainly on identifying or measuring learners' cognitive development, students' misconceptions, or learning difficulties (e.g., [20]). However, this research is often not very useful to practitioners, as without further transformation it generally does not provide applicable guidance for the classroom teacher [18].

In contrast to what we might call pure empirical research in chemistry education, chemistry education curriculum development is generally performed as a design activity. This design, however, is quite frequently not based on empirical knowledge and research evidence [18]. Evidence-based practice improvement—which might also be called developmental [21] or educational design research [22]—needs both: recognizing empirically informed knowledge about teaching and learning, and at the same time incorporating the field of practice [19]. Ideally, it is based on the integration of the results of basic research with curriculum design and evidence/experience from testing the design in practice.

One way to overcome the gap between research and practice for evidence-based curriculum development is action learning [23] or the adoption of action research in science education [24,25]. Action research can, at the same time, transform the perspective of a teacher on educational practices [26]. Based on Whyte, Greenwood, and Lazes [27] and Grundy [28], Eilks and Ralle in 2002 suggested using a specific model of participatory action research for the integration of research, curriculum development, and practice improvement in chemistry education [19] (see also [29,30]). The approach integrates (1) systematic analysis and translation of basic science education research to teachers; (2) curriculum design; and (3) testing, evaluation, and further development of the designs in authentic teaching practices. These components are implemented by systematic, participatory support of a group of teachers. The approach suggests using curriculum design and teaching practice as an authentic base for domain-specific educational research [18].

In the literature, many different forms and interpretations of action research related to science education can be found [31]. Basically, three modes of action research are suggested: technical, participatory, and emancipatory action research [28]. In technical action research, the classroom serves as a field for testing research-motivated pedagogical interventions implemented by teachers. Teachers organize and provide feedback from the classroom to an external researcher. Emancipatory action research, on the other end of the spectrum, puts the emphasis on the teacher's side. The role of the external researcher is merely a supporting one. Between the two extremes of technical and emancipatory action research, participatory (also 'collaborative' or 'interactive') action research suggests equal contribution of both the teacher and the researcher [29]. Participatory action research for the field of chemistry education, as suggested by Eilks and Ralle [19], is characterized by a close cooperation and mutual understanding of teachers and researchers, taking different but equally important roles in the process [29,32].

Participatory action research in science education investigates the process of jointly developing, implementing, testing, evaluating, and reflecting pedagogical innovations in the science classroom. It uses a cyclical approach, which is typical for any kind of action research [29]. It is aimed at integrating research-based knowledge on teaching and learning with teachers' practical experience. It is supposed to generate results relevant both to the researcher and practitioner communities (Figure 1; [19,29]).

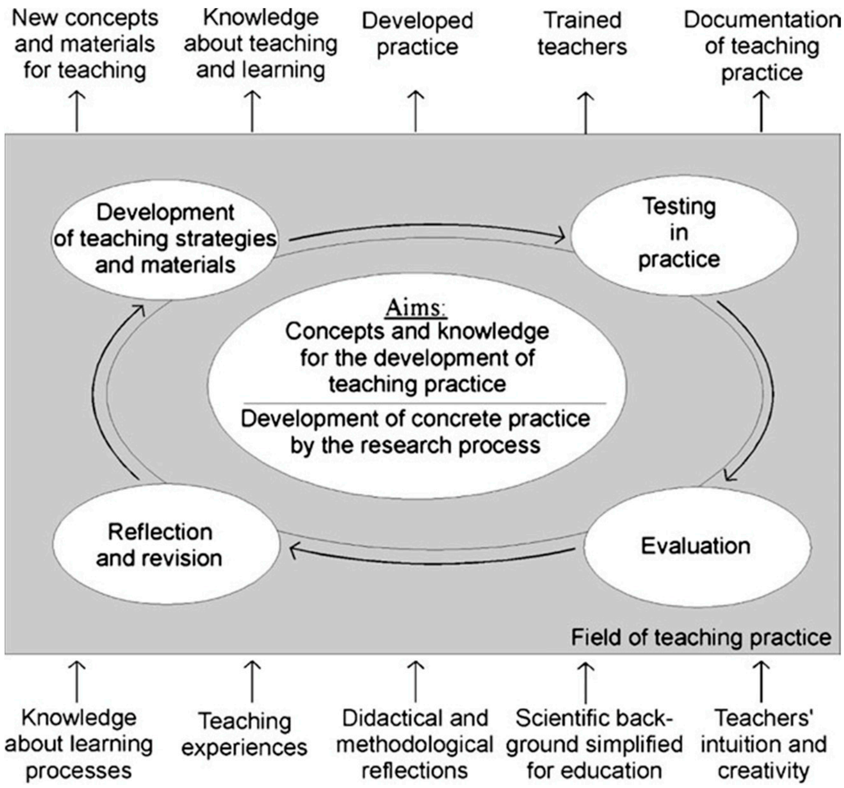

Figure 1. Participatory action research in domain-specific educational research according to Eilks and Ralle [19].

3. A Case on Teaching Chemical Bonding in a Swiss Vocational School by Student-Active Pedagogies

3.1. Context of the Study

In applying participatory action research to chemistry education, it is suggested that the close, regular, and personal cooperation of the teachers and external researchers is one of the key components of success in teachers' professional growth [30]. However, in practice, this is not always possible. Qualified external science educators may simply not be readily available at the site of the school. The same might hold true for creating a sufficiently big group of teachers for a participatory initiative if the environment is rural or either the field of practice is small or the research interest quite specific.

The aforementioned limitations hold true for the field of chemistry education in Swiss vocational schools in general, and for the region of southern Switzerland, namely the area of Graubünden, in particular. In this quite isolated environment—in terms of support for action research in chemistry education at vocational schools—action research in a participatory setting as suggested by Eilks and Ralle [19] needs to look for alternative ways of implementation. One form of organizing participatory components in action research in a remote environment might be cooperation of a teacher with a network of action researchers at a different place via synchronous and asynchronous online communication. This might cause, however, challenges both for the teacher and the action research group.

In the case described in this paper, the teacher interested in action research (author I.L.) and the accompanying researcher (author I.E.), identified by the teacher because of his relevant expertise in the field of study, were located at different sites: in southern Switzerland and northwestern Germany. The only available network of teachers experienced in participatory action research and skilled to support the development of the intended innovation on chemical bonding was located in the west of Germany. The network (henceforth, 'participatory action research network' or 'PAR network') consists of about 10 chemistry teachers cooperating on research and development concerning the particular nature of matter and related concepts for almost 20 years now [30]. The teachers from the PAR network, however, were educated to teach in general school education in Germany, not in vocational schools, and not in Switzerland. Nevertheless, cooperation and communication of the practitioner and the PAR network was started and organized using communication tools such as email, Dropbox, and Skype.

3.2. Content and Concept

Vocational training in Switzerland is provided by specific vocational schools, where school education accompanies training on the job. Teaching chemical bonding is part of the curriculum for vocational training for different professions in Switzerland, e.g., for workers in pharmacies and drugstores. Chemical bonding (ionic, covalent, and metallic bonding) is one of the most central concepts in chemistry. It is essential to understand the different behavior of salts, metals and molecular substances and also to understand chemical reactions on the level of particles and atoms.

Generally, chemical bonding (ionic, covalent, and metallic) is acknowledged as a central but difficult and complex topic to teach in secondary chemistry education [33]. The problems in teaching bonding are related to competing models, various visualizations [34], and the generally difficult nature of models in science [35] that must be understood for informed handling of chemical bonding. Lots of the difficulties reported by research were also experienced by the action research teacher (I.L.) when starting the initiative for his project of action research and curriculum innovation on chemical bonding.

With respect to chemical bonding, the research literature suggests competing curricular concepts. One option would be to start with each one of the bonding types [36]. A more ground-breaking alternative suggested is to start from single atoms toward a continuous understanding of bonding types [37]. Research does not provide a clear answer of which sequence of teaching chemical bonding is most effective for learning [34], and there is no governmentally-suggested strategy in the syllabus for vocational schools in Switzerland either. Therefore, the teacher decided to teach the three types of chemical bonding—namely covalent, ionic, and metallic bonding—in an approach that enables the students to find their own way through the content as part of a student-centered curriculum approach.

In order to give freedom to the students in finding their own pathway through the bonding types, a comprehensive learning environment was developed by the teacher using the software PREZI. Used on laptop or tablet-PCs, the learning environment offers a holistic picture of the bonding types. The idea was to provide equal access to the information about the bonding types, so students could work their way through the material. ‘Holistic’ in this context means that material provided to students allowed discussion and comparison of the bonding types. However, the development of the learning environment and teaching concept underwent several changes in the three years of this action research project.

3.3. The Lesson Plan

The lesson plan and the associated teaching and learning material were originally designed by the teacher inspired by the idea of the “Tour de Chemie” [13]. The “Tour de Chemie” is a lesson plan developed for self-directed learning with ICT-based self-assessment tests that originally was developed for repeating essential chemical concepts from lower secondary classes at the beginning of upper secondary education. It is a multimedia-based chemistry pedagogy. Its structure is depicted in Figures 2 and 3. Figure 4 provides an illustrated sketch screenshot from the learning environment.

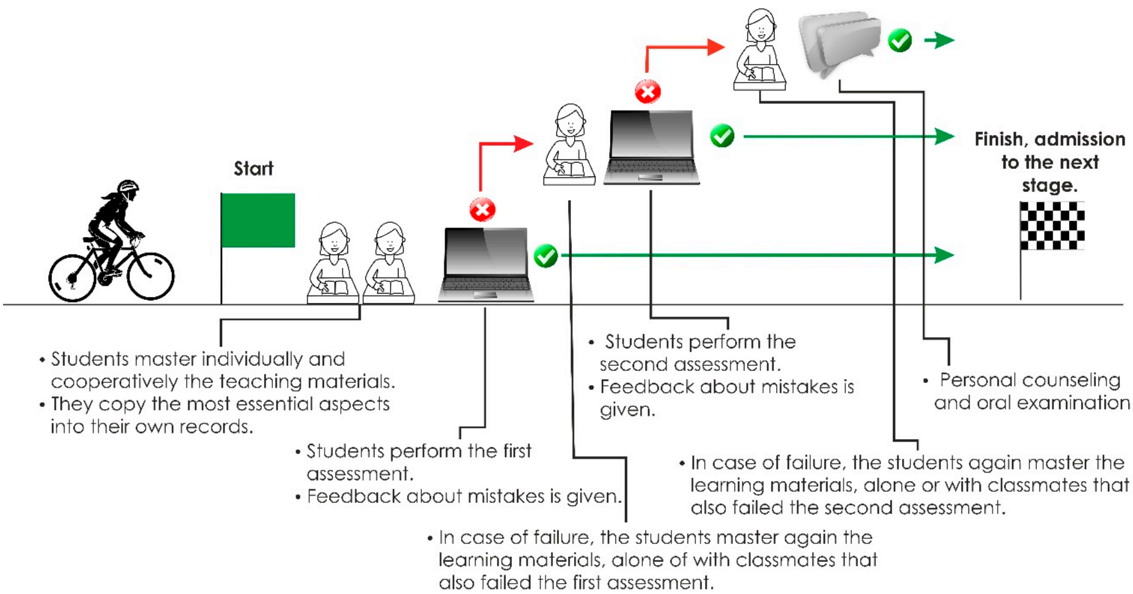

Figure 2. The idea of the “Tour de Chemie” [13].

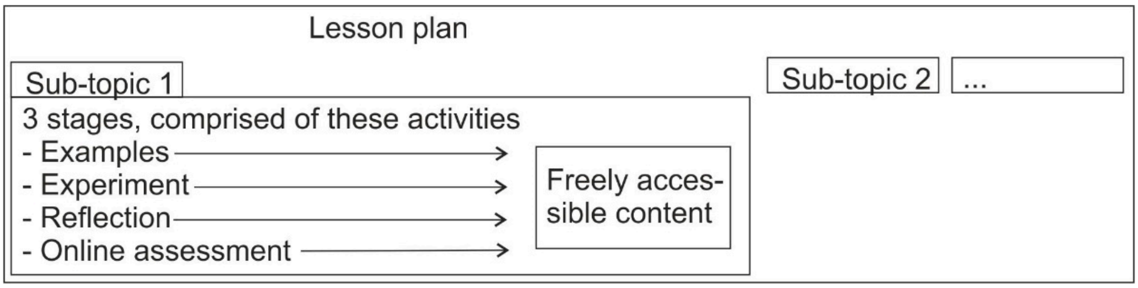

Figure 3. General structure of the chemical bonding lesson plan.

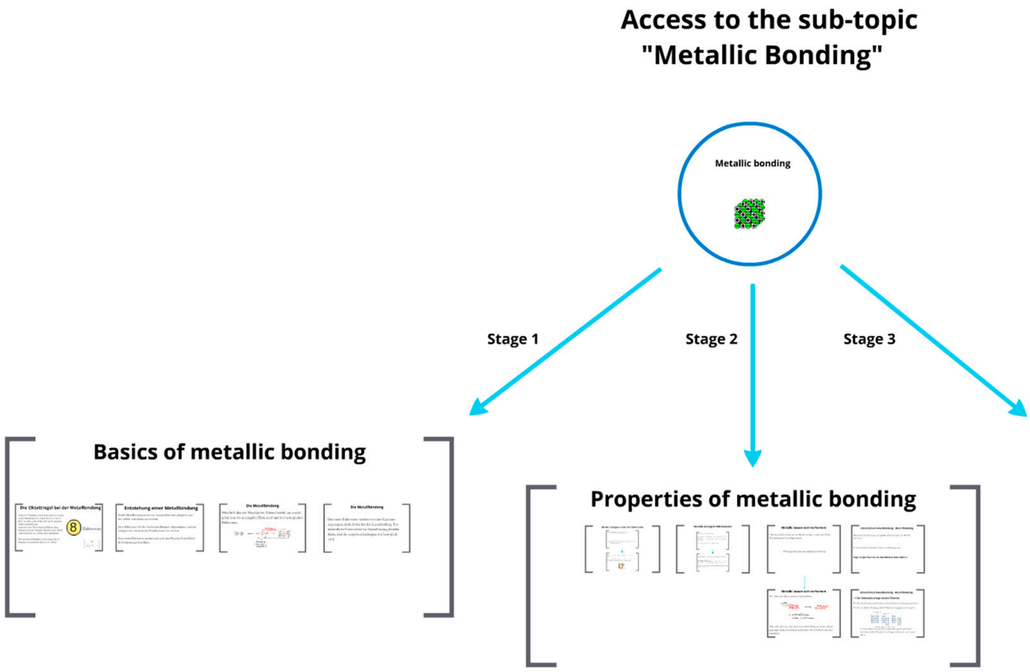

Figure 4. Partially translated and illustrated screenshot from the PREZI environment (originally in German). Part on metallic bonding that leads into the different stages and activities.

The lesson plan is organized into three sub-topics: ionic, covalent, and metallic bonding (Figure 3). Each sub-topic is organized into three 'stages' representing progressive difficulty of the content of that sub-topic. Each stage is comprised of four activities. In the first activity ('example'), content is introduced referring to everyday examples by presenting the content related to meaningful situations. The examples are suggested to exemplify the theoretical concepts of chemical bonding by practical issues. As an example from metal bonding, a question is asked: Why does metal conduct heat? The learner is led to compare a metal scoop used in a kitchen with a wooden scoop, reflecting about the difference in heat conduction. In the second type of activity ('experiment'), the students are asked to perform experiments on the content introduced here. Descriptions are provided for the experiments, but information about the experiment, the setup, processing, and evaluation have to be acquired by the students autonomously. For example, the learner is led to obtain sodium chloride from soda and hydrochloric acid. The third type of activity is 'reflection'. The students are encouraged to reflect observations from the experiments how it is connected to their theoretical knowledge, that is knowledge about the types of chemical bonding. Here, they autonomously look for relevant information relating to the issues reflected on. For example, the students are asked to reflect upon the difference between brittle and amenable substances in terms of ionic and metal bonds. The fourth type of activity is self-assessment. With this tool, students evaluate their current knowledge before they proceed to the next stage. In each of the activities, the teacher originally planned to give only minimal input and help. The design of the lesson has some commonalities to the approach of modeling instruction as emphasized by Posthuma-Adams [38]. In this approach, students are encouraged to derive explanatory models from everyday experience and chemistry experiments. The role of the teacher shifts to facilitate reflection and thinking, not to impart knowledge. Our approach extends the modeling instruction approach by imposing structure and the action research process. Within each type of activity, the content handled in it can be accessed freely and individually by the students because it is organized in a non-linear way in the PREZI learning environment available for laptop and tablet computers to allow for autonomous navigation [17]. The free access of the different types of content is depicted in Figure 4 referring to 'metallic bonding'. The figure shows the stages (within the big brackets) and the activities within these stages (small brackets). The learner might navigate freely to the activities, but he/she might as well let the learning environment guide him/her from left to right. After completion of each stage and successful self-assessment, students move further to the next stage and then to the next sub-topic.

The whole unit takes about seven weeks (two to three lesson periods per week). As there are nine stages altogether, each stage takes a bit less than a week (two to three lesson periods of 45 min each). The students are encouraged to work either alone, in dyads, or in small groups of three to four [13].

The "Tour de Chemie" was originally developed by members of the PAR network from the west of Germany that was integrated into this project. When adapting, re-designing, and further specifying the learning environment for the current project on chemical bonding, feedback loops with the PAR network were established via periodic Skype meetings. Feedback provided by the PAR group led to re-designs of the learning environment and lesson plan. The exchange was continued when the lessons were conducted, i.e., progress and reactions of students were presented and discussed. The design of the lesson and material, the course of teaching, receiving feedback from the PAR network, and redesign was organized according to the cyclical process of Figure 1.

3.4. Research Population

The central person in this research was the action research teacher (I.L.). The teacher had about 10 years of teaching experience in chemistry at a vocational school in Switzerland prior to this study. He was accompanied by a university chemistry educator, who also had a background in high school chemistry teaching, but now has been working since 2004 as a chemistry education researcher and teacher educator at the university level (I.E.). The students involved were chemistry students aiming at a training qualification to work as employees in pharmacies. The students were generally 16–19 years old. Three groups in consecutive school years participated, 68 students in 2014, 59 students in 2015, and 17 students in 2016. The process was accompanied by a remote PAR network with 10 teachers teaching chemistry at high schools at the lower and upper secondary levels. Teaching experience of these teachers was varied from 15 to more than 30 years.

3.5. Experiences and Findings

3.5.1. Overview

As already mentioned, the action research project was conducted in three years, in 2014, 2015, and 2016 (subsequently referred to as the 'three cycles'). In each of these years, the lesson plan was conducted with several groups of 16- to 19-year-old vocational school students participating in seven-week-units on chemical bonding (in the final year the teacher had only one class learning this topic). After each cycle of intervention, the students were asked for written feedback, based on a questionnaire consisting of several open and Likert-type items referring to the multimedia learning environment, material, and structure of the lesson plan. Motivation was evaluated by a Likert-questionnaire with questions asking for satisfaction, understandability, relevance, opportunities for participation, and cooperation in the classroom [39]. Students' perception of the intervention and any changes in motivation were discussed with the PAR network, leading to further changes in the structure of the lesson plan and learning materials (Figure 5). Influence from the PAR network in the beginning was critically evaluating texts, figures, and tasks in the original material. In later cycles, the feedback from students was presented and it was jointly reflected how to react to criticism mentioned by the students. Changes in the design were then discussed within the group to provide support in improving the teaching materials and activities. Because of time constraints in the work of the teacher, the pre-post-questionnaire referring to motivation was only completed by some of the students. Data on the students' perception of the learning environment in the open questions was evaluated by qualitative content analysis according to Mayring [40] and descriptive statistics.

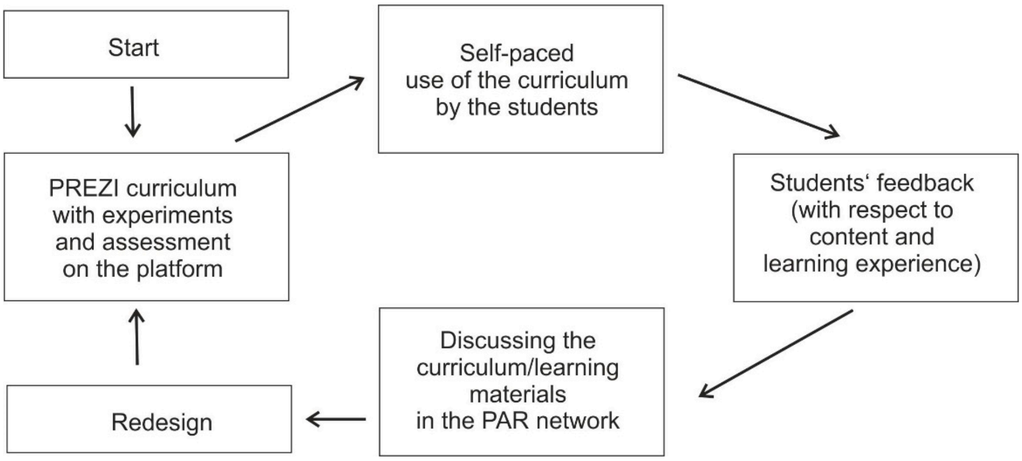

Figure 5. Course of the PAR project.

On the open questions, most students made several statements: 147 (=2.16 per student) in 2014, 153 (=2.59 per student) in 2015, and 44 (=2.59 per student) in 2016 (Table 1). In all cycles—2014, 2015, and 2016—a majority of the students faced the lesson plan initially with insecurity because they were not used to acquiring information autonomously in their chemistry lessons and felt very pressured (between 25% and 31% of all students' comments). In each cycle, a substantial group of the students complained that they had to acquire relevant information on their own, and they felt it was very difficult and demanding. A few students even judged the autonomy in the acquisition of information and derivation of conclusions completely negatively. They were very reluctant to tackle any problem on their own. The autonomous access to the theory behind the everyday examples and the experiments was suggested to be difficult and demanding, and it was disliked by some of the students. Some also complained on the complexity of the topic and limited time. There were also complaints about the structure and missing variety in the learning material basically in Cycle 1. Corresponding students' comments made up 12.3% that later turned down in Cycles 2 and 3 to 7.3% and 9.1% correspondingly. It was, basically, the negative comments on the complexity of tasks and illustrations that decreased from roughly 12 to below 7% (see also the discussion on the positive comments below). Other students, however, judged the pedagogy positively. Statements identified as positive in the different categories concerned autonomy, learning pace, motivation, support for the learning process, and structure. Some students even mentioned feeling both too high demands and positive appreciation of autonomy. The positive statements considered the lesson to be more exciting and more active than conventional lessons. Corresponding answers made up about 35–45% of the comments in all three rounds. These students also appreciated being able to learn at their own pace and rhythm, and to have enough time for everything. These students appreciated the opportunity for repeating previously learned content on their own choice (between some 12% and 20%). Another group of positive statements in this context was that working together would be more efficient. As one student put it: "You can help others and they help you". There were not too many differences, but some tendencies between the three cycles with respect to students' feedback. The trends concerned the decrease in students' negative comments on the teaching materials, tasks, and explanations that decreased from some 12 to below 10% on the one hand, and where the students stating positive comments on the teaching materials, activities, and explanations increased from below 10 to above 25%. As a trend, the data from the Likert-questionnaire on motivation seemed to mirror some issues of the open feedback although there were no statistical differences identified. For some students, the open pedagogy seemed to be motivating while others were pressured and, due to this, their motivation was not increasing. Improvement was clearly recognizable in the pedagogy and teaching behavior of the teacher.

Table 1. Overview about students' responses grouped in bigger categories

	Example(s)	2014	2015	2016
Positive		79 (53.7%)	98 (64.1%)	28 (63.6%)
Autonomy	Self-determined work You can repeat if something is left unclear You learn at your own rhythm/pace Enough time	37 (25.1%)	37 (24.1%)	10 (22.8%)
Motivation	Was fun Dry theory presented in convenient ways Good variety It was exciting	28 (19.0%)	22 (14.4%)	6 (13.6%)
Learning process and structure	Personal coaching very good Questions well explained You can help others and they help you Learn more efficiently You really got to understand Like the method—teacher answers questions Well-structured material Tests are good Experiments are good Cooperation is positive	14 (9.6%)	39 (25.5%)	12 (27.2%)
Negative		68 (46.3%)	55 (35.9%)	16 (36.4%)
Motivation	Monotonous Had enough after 4 steps Not enough relation to daily acvtivities	4 (2.7%)	-	1 (2.3%)
Demand	I didn't like to derive the theory by myself Difficult; complicated Prefer expository lesson You had to acquire everything on your own More difficult/more effort. You need more time	46 (31.3%)	44 (28.8%)	11 (25%)
Materials and structure	Make smaller units More visual material More experiments Not clearly arranged Not enough time More input by the teacher wanted Too much work on the computer Use more paper	18 (12.3%)	11 (7.3%)	4 (9.1%)

3.5.2. Experiences in and Changes after Cycle 1

Most critical remarks mentioned by the students in the first round of testing concerned the high demand in learning caused by the high degree of expected autonomy in learning (31.1%) and issues of the structure and variety of the learning materials (12.3%). The experience of the first cycle led to some modifications that were decided on after discussion with the PAR network:

- In order to improve clarity of arrangement, the material for the lesson plan was split up into five (instead of three) sub-topics with three stages each: Foundations of ionic bonding; ionic bonding with nomenclature; foundations of covalent bonding; covalent bonding; and metallic bonding. As before, each stage was structured into different activities to be freely accessed by the students.
- In the first cycle, there had been a few stages without an experiment. This was remedied; at least one experiment was implemented for each stage for the second cycle.

- The new structure was accompanied with more self-assessments (self-assessments were possible now at the end of each lesson period).
- Communication between the students and the teacher was intensified.

3.5.3. Experiences in and Changes after Cycle 2

In the second cycle, the students seemed to be more motivated as they knew that in each stage there was an experiment waiting for them. The new groups of students appreciated the more clearly structured arrangement of the material (increase from 4.8% to 16.3%). They also appreciated that the teacher continuously provided further explanations and tried to answer questions more thoroughly than he did in the first cycle. Positive aspects of coaching, good explanations, and understanding received 9.2% of the students' comments, after 4.8% in the first round. The reflection in the PAR group suggested that, because of the more intense interaction with the teacher, the students felt less (albeit somewhat) insecure. In this cycle, some of the students asked for receiving a short presentation by the teacher at the end of each lesson period in order to summarize the results and provide more security. Again, some feeling of monotony in learning arose after some time, but later than in the first cycle. As a result of the evaluation and reflection in Cycle 2, short summary presentations by the teacher were integrated to provide anchors for student learning. In addition, the lesson plan was again modified. More experiments were integrated and the connection of the experiments to the content of the respective stage was more detailed.

3.5.4. Experiences in and Changes after Cycle 3

As a result of adjustments, more students participating in Cycle 3 seemed to appreciate self-determined work more than the students did in Cycle 1 and 2 (20.5% of the comments, after 12.2% and 13.7% in the first two rounds correspondingly). Maybe this was because the feeling of insecurity seemed to decrease even further. The latter apparently was due to even smaller steps in the stages in conjunction with short presentations of the teacher. In addition, the students appreciated the teacher's answers and explanations to questions more than in the second cycle. Corresponding positive comments increased from 4.8% and 9.2% toward 18.2% in the third cycle. Answering questions by the teacher and explaining was judged positively more than three times as often in Cycle 3 as compared to Cycle 1. All positive comments concerning understanding increased to 18.2% (after 4.8% and 9.2% in the first two rounds correspondingly). This suggests that a learning process of the teacher for improving his teaching and his competence to explain had taken place. Altogether, the development of the lesson in the three cycles is summarized by Figure 6 based on the teachers' perception and an interpretive analysis of the different forms of student feedback.

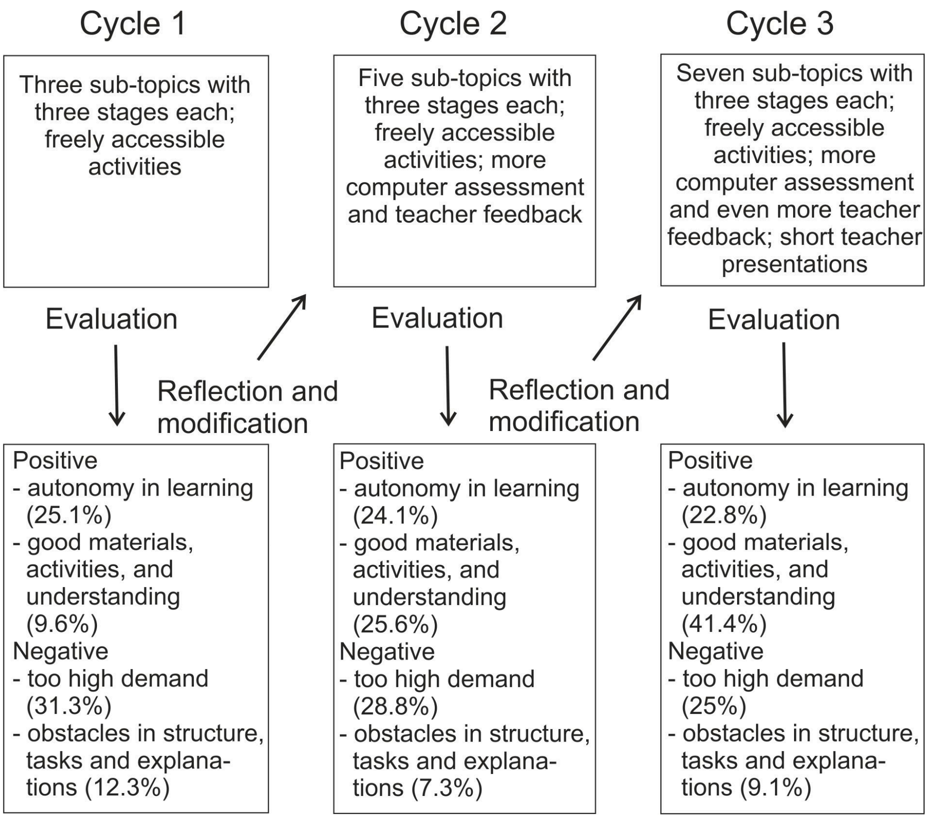

Figure 6. Course of the project and changes based on the students' feedback and teacher's perception.

4. Reflections and Conclusions

In vocational schools in southern Switzerland, ex-cathedra teaching is still widespread. This causes challenges, especially with a subject that is not very popular and perceived as difficult among many students, such as chemistry. In this paper, a teacher-centered action research project is described that was utilized for designing and interactively improving teaching of chemical bonding in a vocational school. Inspired by the participatory action research model by Eilks and Ralle [18], the project was based on continuous cooperation between a chemistry teacher, a chemistry education researcher, and an expert group of chemistry teachers experienced in PAR.

The outcomes of the project can be reflected from three different perspectives, namely teaching practice, teacher professional development, and the process of action research.

The successive improvement of the lesson in terms of feasibility and motivation—which, of course, should be evaluated in a more rigorous way in upcoming studies—was only one effect of this cooperation. A teaching method was implemented that emphasizes self-determined, autonomous learning in small groups guided by a digital learning environment (see also [41]). The results show that the students in a vocational school in southern Switzerland have difficulties with and reluctance toward this type of learning. Due to the course of the project, it was possible to successively adapt the lessons more to the needs of the students, thereby reducing some of the initial problems and stressing the benefits of the lesson. The results indicate that a learning environment that is very open and student-centered, as e.g., proposed in [42], might not always be ideal, as it might be too demanding. This is different from other cases described for chemistry education in a similar age level, e.g., [13]. Thus, a learning strategy adaptive to the—possibly changing—needs of the learners seems most suitable, both to the learning group as a whole and the individual learners in particular [43]. The project suggests that it is possible to develop such a learning strategy step by step within action research cycles as described and implemented in this study.

Another point of reflection is the contribution of the action research experience to the teacher's continuous professional development. The experience of iteratively designing and evaluating the lesson plan and cooperating in a PAR network initiated a learning and development process in the teacher. Within the process, the teacher learned to listen more thoroughly and more deeply to the students to improve his skills in explaining. He benefitted from the rich experience within the PAR network and was able to integrate many suggestions raised in the Skype discussions with the group into his teaching. Professional development is a process of utilization of methods systematically to improve a process, its efficiency and quality, and to contribute to standardization. By this means, the process of designing, applying, evaluating, and reflecting on the lesson plan contributed to the professional development of the teacher. The professional development addressed different domains. Following the Interconnected Model of Teacher Professional Growth (IMTPG) by Clarke and Hollingsworth [44], effective teacher professional development consists of a process based on self-reflection and action that is determined by four domains—namely, the personal domain (beliefs, attitudes, and earlier experiences), the practical domain (the teacher's authentic teaching practices), the external domain (topic requirements, media, and curriculum aspects), and the domain of consequences (goals and effects). In the present case, the teacher intensified his reflections on his beliefs and experiences in the pedagogy of teaching in general and on chemical bonding in particular; the process took place in the teachers' authentic classroom practice; it focused on changes in the curriculum, pedagogy, and media use; and all this was done with the aim in mind to make teaching more motivating and involving a broader set of goals. As also discussed by Mamlok-Naaman and Eilks [27], action research by its nature has a lot of potential to come up with suggestions of the IMTPG for effective professional development; and the current case supports this argument. Also, Girardet [45] suggests factors for effective change in teachers' classroom management to include activities focusing on (i) reflecting on prior beliefs, (ii) studying alternative practices, (iii) enacting those practices, and (iv) reflecting on action in a collaborative learning environment seem to be successful in eliciting. Also, these elements emerged in the action research project described here.

A third point of reflection in the project was to re-think the PAR model as originally suggested by Eilks and Ralle [19]. In the case of curriculum development for pre-service chemistry teacher education, Burmeister and Eilks [46] already showed that the model can be transferred to different educational settings. The current work shows that major PAR elements can be realized via digital media supporting communication of remote actors. Communication flow helped to continuously improve the lesson plan and provided input to the researchers as well. In the teachers' reflection he explicitly addressed to the value of discussing his designs and student feedback with experienced colleagues to gain a better and collaboratively-developed understanding. The model showed its potential for joint learning of the teacher(s) about practice and of the accompanying teacher educator about everyday-life problems in teaching practice and the professional development of the teacher, as e.g., described also in [47].

One of the next steps in research might be to evaluate the effects of the lesson in a more systematic way, with more teachers and learning groups involved. Such a kind of upscaling was originally suggested by Eilks and Ralle [18] in the original description of their PAR model. Additional foci might be on effects on learning outcomes and cooperative learning skills. A further step might also be to test the action research design employed in this case on other topics and with a different group of persons involved.

The case reported in this article has many limitations. It was operated by one teacher in one school. It worked in a very specific educational setting with the advantage of having a PAR group available with almost 20 years of experience [29]. Nevertheless, we hope it might allow some hints and indications for future projects of similar type.

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