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ARTICLE

Using Action Research to Innovate Teacher Education Concerning the Use of Modern ICT in Chemistry Classes

Moritz Krause
SZ Geschwister Scholl Bremerhaven and University of Bremen, Germany
m.krause@uni-bremen.de

Ingo Eilks*
University of Bremen, Germany
ingo.eilks@uni-bremen.de

This paper describes action research on teacher education aiming at innovating a course on the use of modern ICT in science education. It was carried out at a German university focusing an educational course for pre-service chemistry teachers. The course was cyclically refined over a time span of three years by participatory action research. The accompanying research revealed several effects of the course on the student teachers. The research focused on changes in student teachers' attitudes and self-efficiency beliefs concerning the use of digital media in general and in chemistry education in particular. The background of the action research project is presented below and experiences and effects are also discussed.

Keywords: Action Research, Teacher Education, Chemistry Education, ICT

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Introduction

The use of modern information and communication technologies (ICT) in science education is both a challenge and a chance. ICT provides many opportunities to enrich the practice of science and chemistry education (Dori, Rodrigues & Schanze, 2013) and many different applications of ICT in science education became available in recent decades (Rodrigues, 2010). Yet broad and well-reflected use of ICT in educational settings remains somewhat limited in most German schools (Brüggemann, 2013). This is the case despite numerous developmental measures such as equipment offerings by ICT companies, more initiatives for teacher in-service professional development, software collections on the Internet, etc.

Practically speaking, ICT use in educational settings is becoming increasingly easier and more flexible. This is due to the progressive development of ICT and various improvements in equipping schools with the corresponding devices. In teaching practice, however, resistance to such measures often appears. Initiatives such as merely installing more equipment obviously cannot overcome such obstacles. Many teachers tend to stick to traditional media and methods, rarely expanding their use of newer digital media beyond Internet searches (Breiter, Wellings, & Stolpmann, 2010; Gysbers, 2008).

This situation presents educators with a somewhat paradoxical situation. Most teachers consider media literacy and the integration of digital media education into their classes to be essential. However, many of them still do not design their own lessons accordingly, a glaring contradiction. Gysbers calls this a "significant discrepancy between teachers' self-image and teaching activities". The reasons for this paradox are still unclear. It seems that many teachers do not want changes or are incapable of adapting their teaching to the quickly developing digital media landscape. This might also reflect the fact that teachers are the acknowledged experts in a classroom setting with respect to content matter and pedagogy, yet often are less experienced in using digital media than many of their learners.

It has been widely acknowledged that teachers are the key for any innovation in the classroom (Anderson & Helms, 2001; Hattie, 2009). With regard to the use of ICT, investment in education and training in this area are required to better prepare teachers and to provide them with the necessary skills. Teacher trainees need to be familiarized with ICT concepts, applications, and specific examples in order to prepare them to use ICT effectively in the classroom from the start. The same is true for a continuing investment over time to maintain their technological pedagogical content knowledge (TPACK; Koehler & Mishra, 2008) and keep it up-to-date and accompanied by improving technologies. A number of other factors beyond teachers' technical skills and their TPACK, however, play a role in ICT use in their classrooms. In particular these include positive attitudes towards ICT as a tool and self-efficacy in its use (Joo, 1999; Lim, 2007).

This article describes a continuous innovation process in pre-service teacher education for the use of digital media in chemistry lessons. The process was guided by the participatory action research model in chemistry education as suggested by Eilks and Ralle (2002), supported by the interpretation for developments in teacher education provided by Burmeister and Eilks (2013). The continuous development of the course was carried out as part of a Ph. D. project during three consecutive years of study (2011-2014) at the University of Bremen, Germany (Krause & Eilks, 2015), and has continued since then. The course aims to achieve at a high degree of practical activity among the participants, to promote positive attitudes among them, and to raise the level of self-efficacy in the use of digital media in teaching. Accordingly, the focus of the accompanying action research has been placed on these areas, while not losing sight of the inherent aim of continuous development in course structure and content.

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* Corresponding author

Theoretical background

A person's attitudes and self-efficacy beliefs influence any action. According to Baron and Byrne (1991), attitudes can be defined as individuals' general considerations about themselves, other people, and objects. Smith (1968) suggested that attitudes consist of three components: cognitive, affective and behavioral aspects. It's not just whether someone believes they can achieve a specific goal, but whether they think it is right and how they view the impact of their actions on others. Self-efficacy beliefs are statements about a person's ability to exert influence on events affecting both, his or her personal life and professional actions. Self-efficacy beliefs determine how people feel, think, motivate themselves, and behave (Bandura, 1993). In other words, they represent a person's belief in his ability to successfully accomplish a task. Self-efficacy can greatly influence whether and how people tackle a task, how they implement it, and whether a chance of success exists (Francis-Pelton & Pelton, 1996). In the current case this means the use of modern ICT in chemistry classes. It is therefore important to not just to consider a particular action as meaningful, but also to have trust that one can successfully implement it.

In terms of media use at school, both aspects (attitudes plus self-efficacy beliefs) influence whether or not a teacher tends to use digital media in the classroom. It has been shown that the successful integration of digital media into the classroom is strongly dependent on teachers' attitudes (Kersaint, Horton, Stohl & Garofalo, 2003). But this alone is apparently insufficient. A number of studies have shown that teachers may possess positive attitudes towards digital media (Tezci, 2001), yet still only use them to a limited extent. One reason is perhaps a fear of failure when applying the technology. There appears to be skepticism among teachers when it comes to the ability to organize effective learning for students in an ICT-based classroom (Jimoyiannis & Komis, 2007). Another reason might be computer anxiety among teachers that intensively was researched in the 1990s (e.g., Russell & Bradley, 1997), a phenomenon that, however, should be decreasing with the changing media world of today. One contributing factor may also be doubt about the overall dependability and reliability of available ICT resources in schools. This includes computer and Internet accessibility, hardware compatibility, software costs, lack of sufficient learning stations for class-sized activities, system maintenance issues, and a lack of technical support or dedicated in-school ICT staff.

The recent project assumed that the integration of ICT in chemistry teaching largely depends on teachers' attitudes towards modern ICT and their self-efficacy beliefs about using it in the classroom. It recognized that domain-specific educational courses in science teacher education effectively improve attitudes and self-efficacy for the use of modern ICT in chemistry classes (Krause, Pietzner, Dori & Eilks, 2017). The aim of this action research was to cyclically improve a pre-service chemistry teacher education course on ICT use and to document its effects.

Action Research for curriculum innovation in teacher education

In 2002, Eilks and Ralle suggested a model for applying participatory action research (PAR) to chemistry education curriculum development, teaching innovation, and classroom research. This model proved itself effective in many projects for secondary school curriculum innovation (e.g. Marks & Eilks, 2010; Eilks & Feierabend, 2013) and continuous professional development of teachers (Eilks & Markic, 2011; Mamlok-Naaman & Eilks, 2012).

The PAR model was originally inspired by research borrowed from economics (Whyte, Greenwood & Lazes, 1989). The model suggested thoroughly connecting domain-specific educational research in science education to both curriculum development and teaching practice. Action research following this model systematically uses empirical research evidence and links it to transformative actions in the classroom in order to improve teaching practices (**Figure 1**). The process was originally performed in participatory groups of teachers and accompanying researchers. Teams composed of science educators from the university and teachers in schools are formed. They then conduct the entire research and development process in a partnership setting (Eilks & Feierabend, 2013). More individualized interpretations of the model were also later reported later to be quite successful (Laudonia & Eilks, 2018).

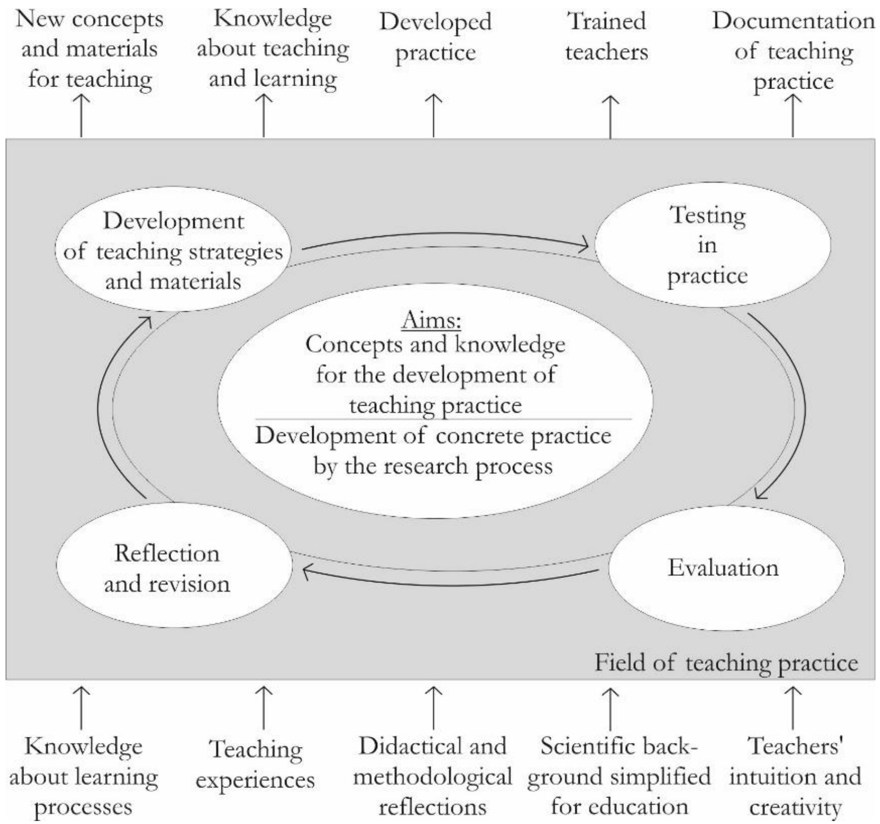

Figure 1. *Participatory Action Research within domain-specific education (Eilks & Ralle, 2002)*

In 2013, Burmeister and Eilks described a project which transferred the PAR model by Eilks and Ralle (2002) to innovations in pre-service chemistry teacher education. Unfortunately, not all assumptions of the initial model proved to be valid regarding such transfers, but the basic idea remained the same. Just as for school education, the new PAR application sought to cyclically optimize teaching practices with the support of research evidence. Equally-valued information resources were employed to construct the beginning of the process. This included research evidence about teaching and learning in the specific domain, analysis of classroom curricula, the practitioners' personal experience, and the intuition and creativity of experienced teachers in the field (Eilks & Ralle, 2002). Such a combination of various resources takes both empirically-validated research and experience-based teacher knowledge into consideration. These factors comprise the two ends of the evidence spectrum of teaching and learning. Each of them is important and has its own strengths (McIntyre, 2005). The teacher education application of the PAR model also recommended keeping the cyclical analysis of innovation and the targeting of similar domains of results. Specifically, this included evidence about teaching and learning, developed curricula, improved teaching practices, and better-trained educators.

The major difference in the PAR transfer to teaching innovations as described by Burmeister and Eilks (2013) concerned the relationship between the people involved. Action research is generally described as either the autonomous activity of an individual practitioner or, conversely, a cooperative process involving several practitioners and external experts (Laudonia, Mamlok-Naaman, Abels & Eilks, 2017; Mamlok-Naaman & Eilks, 2012). The PAR strategy described by Eilks and Ralle (2002) is one of the latter models. In their applications, projects are driven by groups of teachers supported by external science educators. In the case of German pre-service teacher education, however, both groups – practitioners and accompanying educators – fall into the same category. At most universities it is seldom possible to form sufficiently-sized groups of chemistry education teaching staff. However, the suggestion was made to maintain the team structure by building diads made up of a teacher and an observer/supporter. This approach proved suitable for gathering external viewpoints regarding teaching practices, which is where innovation is actually believed to take place (Burmeister & Eilks, 2013).

The research process in the original PAR model (Eilks and Ralle, 2002) was meant to respond to reports of deficits in either teaching practices or empirical research. PAR would then be used to eliminate or reduce any problems in the corresponding teaching practices. This was the case when Burmeister and Eilks (2013) transferred PAR to the realm of innovation in teacher education. Their particular case was the incorporation of Education for Sustainable Development (ESD) into pre-service chemistry teacher education in Germany. Research began with a thorough analysis of the relevant literature. Discussions among the research partners were used to determine what aspects a potential innovation should have addressed. The discussions also reflected upon whether or not the evidence and ideas documented in the literature were actually feasible for offering help in the specific educational setting targeted by the project.

The current project followed a similar path. An existing ICT course for chemistry education at the University of Bremen, Germany, was analyzed and found to be outdated in parts of its content matter and technology. A PAR project was then initiated to invest in innovations in the course and to research their effects.

Structure, content and development of the course

The course in question focuses on different aspects of ICT in chemistry classes. It is divided into several theoretical and practical phases. The seminar initially consisted of six classroom sessions of four hours apiece. It was later expanded by a seventh session on digital data collection and analysis using Wifi- and USB-based sensors and corresponding calculation tools.

The core idea of the course was that students learn about and practice with devices, software and digital media strategies in chemistry teaching. The pedagogy was rooted in a high degree of self-directed activity, with only shorter presentation phases in-between to introduce any necessary technical equipment, software, or teaching scenarios. Single elements of the course will be discussed here to illustrate how changes in technology and student feedback led to changes in the seminar design.

The seminar introduced the use of interactive whiteboards, which have already been installed in Germany in many schools. Accordingly, the students were asked to familiarize themselves with the technical operation and pedagogical use of interactive whiteboards in chemistry lessons. Practical examples were presented, e.g. handling quantitative results from chemical experiments to create corresponding diagrams. In a later course of the seminar, however, two different presentation techniques were compared, namely interactive whiteboards and the combination of an iPad with an Apple TV Box and a video projector. The students were asked to reflect upon the advantages and disadvantages of both technologies. In the first years of the project, using the interactive whiteboard took up quite a lot of time. This proportion was continuously reduced in later cycles. The reason was that the student teacher feedback criticized the potential of interactive whiteboards to make their lessons student-centered. The student teachers saw little added value compared to simply using a blackboard or notebook with a projector. The prohibitive costs of equipping an entire school with whiteboards and maintaining them at peak efficiency possibly contributed to this attitude. With the inclusion of the iPad connected to an Apple TV Box and video projector, this criticism became even stronger. As a result, other parts of the seminar were strengthened, particularly discussions about the possibilities of using presentations and interactions based around tablet PCs.

Another reason for the increasing use of tablet PCs was the growing number of tablets either owned by teachers or installed in German schools. In the beginning, the focus was mainly on the teaching side of the equation. The aim was to first give prospective teachers confidence in using the new digital devices, before presenting application examples for their future pupils. Student teachers were initially asked to learn about apps such as the interactive periodic table, mind mapping software, and educational apps like Explain Everything. With the growing rate of tablets available in schools and also the growing number of student teachers using such devices, the seminar shifted its focus to how students in schools can independently use tablets to create demonstration videos, Stop-Motion animations, or presentations. Another change based on student feedback was growing differentiation within the course. An increasing number of students entered the course with software skills in Excel (a spreadsheet program) and ChemSketch (software for drawing chemical structures and laboratory setups). This caused a split in which skilled participants were set to work on more advanced tasks, while the participants unfamiliar with these programs were given initial introductions and instruction.

Aside from changing technologies, the media themselves were altered, based on current digital developments in combination with student feedback. Within the seminar student teachers were asked to rate various multimedia offers for chemistry lessons. In previous courses, these tended to be primarily offline offerings such as CDs and DVDs with chemical content. Today's lectures focus exclusively on Internet offers. The students evaluated the offerings according to various criteria centering around content, (professional) didactic quality, functionality and practicability. The individual offers were then discussed with the entire group. Again, there were clear changes away from hard media to Internet services, since many pupils in school today have mobile devices with no hard drives. The availability of wireless Internet also continues to increase apace. Feedback from the students in this area also influenced changes in seminar design. Personal suggestions from the students for frequently used websites were gradually integrated into the seminar. This helped to align the selection process in order to make the course closer to the experiences, interests and needs of the students.

Media literacy is not just about using media, but also about designing media. The aim is to better understand the possibilities and limitations. Correspondingly, the course shifted directions to also ask the students to create their own learning environments, e.g. by creating WebQuests or learning environments based on the software PREZI (Krause & Eilks, 2014). **Table 1** provides some overview on selected changes implemented over time.

Effects of the course

Since 2011 innovation in the course has been based on student feedback in each winter semester at the University of Bremen, Germany. Feedback from the students was obtained after each round and influenced the following academic year. The project is still underway and includes further innovations in course structure, content, and pedagogy. In addition, a multipage online survey was employed to collect data on students' attitudes and self-efficacy expectations for the academic years 2011-2014.

The online questionnaire collected general data on age, sex, program of study, and year of study. Attitudes and self-efficacy expectations were assessed in a post-design phase using four scales with 10 Likert items, each based on the research tool documented in Krause et al. (2017). The following dimensions were put into focus:

(1) Attitudes about using ICT in teaching in general
(2) Self-efficacy beliefs about the use of ICT in general
(3) Attitudes about using ICT in chemistry teaching
(4) Self-efficacy beliefs about the use of ICT in chemistry lessons

Table 1. *Selected changes in the course structure over time*

2011
• Implementation of a detailed instruction of how to use interactive whiteboards • Design of a self-regulated learning task to develop a potential activity on how to use the interactive whiteboard in class • Integration of a short presentation on legal restrictions in the use of digital media content • Re-focusing the tasks on using various programs for drawing chemical formulae and set-up sketches with the computer to only use ChemSktech
2012
• Reduction in the analysis of pre-designed learning environments • Reducing the tasks on drawing chemical formulae and set-up sketches with the computer • Tasks on evaluating chemistry education media packages for interactive whiteboards • Integration of a critical discussion on how the ICT industry is imagining the future of digital media learning
2013
• Explicit introduction of scenarios how tablet-PCs and corresponding apps can be used by teachers in chemistry teaching • Self-regulated learning with selected apps on the tablet-PC • Implementation of a discussion on the advantages and disadvantages in the use of tablet-PCs as an alternative to interactive whiteboards
2014
• Skipping the analysis of offline media (CDs, DVDs, etc.) • Design and evaluation of learning environments created by the software PREZI
2015
• In-depth use of tablet-PCs and corresponding apps in small groups by installing an iPad pool • Creating and learning with stop-motion-videos for visualizing chemistry content • Design of cartoons with digital media for experimental instructions • Implementation of documenting and reflecting the course by a digital learning diary

The questionnaire has been developed as part of a broader study involving about 250 students and teacher trainees (Krause et al., 2017). **Table 2** below provides examples of the items used in the respective dimensions. All items were carried out using a five-point Likert scale (ranging from 1 = "agree" to 5 = "disagree"). The reliability of the individual scales is acceptable to good with a Cronbach alpha value between 0.77 and 0.86. A total of 27 students took part in a pre- and post-test within the first three consecutive academic years from 2011-2014. The sample consisted of 16 female and 11 male students.

Table 2. *Selected items to illustrate the different dimensions*

Dimension	Selected items
1) Attitudes about using ICT in teaching in general	ICT is a great help for effective learning.
	ICT is over-estimated; traditional media are regularly more effective.
2) Self-efficacy beliefs about the use of ICT in general	I feel competent in the use of ICT.
	I am reluctant about the growing use of ICT in our lives.
3) Attitudes about using ICT in chemistry teaching	ICT has the potential to support the learning of essential aspects of chemistry.
	Chemistry is an experimental science. This is why the digital world should not play a prominent role in chemistry education.
4) Self-efficacy beliefs about the use of ICT in chemistry lessons	I feel competent in the use of ICT in chemistry education.
	I fear that I will be overwhelmed if I am asked to use ICT in chemistry education.

An initial analysis of the mean scores indicated positive trends, especially in the areas of domain-specific attitudes and domain-specific self-efficacy beliefs (**Table 3**). However, average mean values can be only be used to a limited extent in Likert questionnaires. Nevertheless, they indicate trends. The findings indicate solid tendencies toward more positive attitudes and a growing self-efficacy expectation. Whether trends identified were also statistically significant was verified with a Wilcoxon test.

Table 3. *Mean values of the pre- & post-test (smaller values indicate more positive attitudes and more positive self-efficacy beliefs correspondingly)*

Dimension		Mean
1) Attitudes about using ICT in teaching in general	pre-test	2,6259
	post-test	2,2519
2) Self-efficacy beliefs about the use of ICT in general	pre-test	2,1769
	post-test	2,0000
3) Attitudes about using ICT in chemistry teaching	pre-test	2,1926
	post-test	1,9852
4) Self-efficacy beliefs about the use of ICT in chemistry lessons	pre-test	2,6600
	post-test	1,9960

A more in-depth analysis was performed using the Wilcoxon signed-rank test (Raab-Steiner & Benesch, 2010). Positive and negative ranks indicate in which direction the significant changes in the post-test attitudes occurred. In the questionnaire agreement to a statement was indicated by low numbers (1 = "agree"). When calculating the Wilcoxon test using SPSS, the assumption is that consent is shown by high numbers, so the Likert scales were adjusted accordingly to perform the evaluation.

Below **Table 4** gives an overview of the changes in each category identified by the Wilcoxon test, both before and after the seminar. It turned out that positive changes could be found in all of the categories, but they are not significant for self-efficacy expectations in general at the 5% level. All other changes proved to be significant. The comparison of the positive and negative ranks confirms that the clearest changes were recognizable in domain-specific self-efficacy beliefs. In terms of domain-specific self-efficacy beliefs about the use of ICT in chemistry lessons, there were 23 positive and zero negative ranks. This result is highly significant.

Table 4. *Results of the Wilcoxon test*

Category (dimension)		Average rank	*Z*	*P*
1) Attitudes about using ICT in teaching in general	negative ranks	6	- 3,047	0,002
	positive ranks	19		
	bindings	2		
2) Self-efficacy beliefs about the use of ICT in general	negative ranks	9	- 1,775	0,076
	positive ranks	13		
	bindings	4		
3) Attitudes about using ICT in chemistry teaching	negative ranks	8	- 2,174	0,03
	positive ranks	17		
	bindings	2		
4) Self-efficacy beliefs about the use of ICT in chemistry lessons	negative ranks	0	-4,203	< 0,001
	positive ranks	23		
	bindings	2		

Conclusion

Modern ICT is continuously changing and develops at quite a fast pace. Dealing with ICT issues in education has become more important than ever in recent years, suggested also be educational policy for at least 20 years (Khvilon & Patru, 2002). It is important that school students learn to be productive using modern ICT and that they realize the broad spectrum of uses for it in addition to just chatting, using Facebook or sending emails (Rodrigues, 2010). If teacher education seeks to achieve this goal, it must begin by providing student teachers with the necessary concepts, ideas and opportunities (Khvilon & Patru, 2002). This cannot be accomplished solely with lectures or theoretical inputs. It must also include the practical and domain-specific usage of digital media. The results of this action research study show that an ICT-based course such as this one, which aims to promote hands-on knowledge about the practical use of digital media in chemistry lessons, can significantly improve both personal attitudes and subject-related self-efficacy (see also Krause et al., 2017). This is particularly true for the latter aspect.

In addition to the development of practical teaching approaches and the further development of the seminar content, the structure and availability of the current course content has also been further modified. In the last two years, we developed a website which bundled the digital teaching concepts and provided the students with direct access to all of the teaching materials and sample videos (www.digitale-medien.schule). The script for the course has been digitally embedded in the website and allows close networking between the teaching concepts and practical phases in the seminar. With the help of a digital learning diary, students' work during the seminar and in their school internships is now digitally documented, which allows further development of the seminar every year. Research showed that digital learning diaries can be fruitful for learning beyond hand-written alternatives (Gleaves, Walker & Grey, 2008). The development of the course allows for further reflection upon how important the continuous investment in the content, structure and pedagogy of a course on ICT in science education really is.

A further consequence of this action research project concerns reflection on the model of participatory action research for innovation in teacher education. This project supports the positive experiences of Burmeister and Eilks (2013) or Tolsdorf and Markic (2018). The direct use of feedback from the student teachers, the incorporation of an accompanying person into the development process and the cyclical strategy all proved to be helpful for innovating teacher education practices. Less relevant content was therefore reduced and replaced by content better fitting the needs and interests of the learners. This suggests that action research should not only be promoted as a strategy for teacher research and innovation or the content of teacher education courses. We also need more investment in applying action research to teaching practices in pre- and in-service teacher education. The case described in this paper might serve as an example of good practice.

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