RISTAL

Research in Subject-matter Teaching and Learning

RISTAL 1 / 2018

Research in Subject-matter Teaching and Learning

Launch issue

Citation:
Hofer, E., Abels, S. & Lembens, A. (2018). Inquiry-based learning and secondary chemistry education – a contradiction?. *RISTAL, 1*, 51–65.

DOI: https://doi.org/10.23770/rt1811

RISTAL. Research in Subject-matter Teaching and Learning 1 (2018), pp. 51–65

Inquiry-based learning and secondary chemistry education – a contradiction?

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Abstract

Even though inquiry-based learning (IBL) has been a component of various curricula and standards for more than ten years and its implementation has been supported by several funding programs, it is still applied only rarely. The reasons for this are not only frequently mentioned obstacles, but also the teachers' beliefs regarding IBL. In this article, it is exemplified what IBL means to five Austrian chemistry teachers and what contradictions between IBL and the curriculum emerge from this. For this purpose, a group discussion is analyzed to discern what teachers think IBL is. The results are contrasted with relevant literature as well as with the Austrian curriculum for chemistry. The findings are finally used to derive implications for designing an appropriate professional development program.

Keywords

inquiry-based learning, chemistry education, curriculum, professional development, beliefs

1 Introduction

Although inquiry-based learning (IBL) originates in Dewey's pragmatism in the 1960s, it has become meaningful for science education mainly in the last two to three decades, at least in political and pedagogical debates. The fact that education policy assesses IBL as important is reflected in policy documents like educational frameworks (e.g. 21st century skills (NRC, 2013), K-12 science education framework (NRC, 2012), PISA 2015 Science framework (OECD, 2016)), standards (e.g., National Science Education Standards (NRC, 1996), Next Generation Science Standards (NGSS Lead States, 2013), national science standards (BIFIE, 2011; KMK, 2005)) and many other national curricula (Abd-El-Khalick et al., 2004). The increasing number of studies on IBL (cf. Rönnebeck, Bernholt & Ropohl, 2016) and the huge number of implementation projects (e.g. European projects like S-TEAM, PROFILES or TEMI) indicate that also science education research evaluates IBL as relevant. Although advocates consider inquiry activities as essential elements of science education (Barron & Darling-Hammond, 2010; Roberts & Bybee, 2014), studies show that IBL is applied only rarely in schools (Crawford, 2014; Engeln, Euler & Maass, 2013). The reasons for this are numerous and various: obstacles and barriers like students' knowledge and abilities, material and organizational resources, teachers' methodological skills, beliefs and values towards the Nature of Science or teaching and learning in general (Anderson, 2002; DiBiase & McDonald, 2015; Wallace & Kang, 2004). But as education policy and science education research want teachers to implement IBL more frequently, it is indispensable to examine not only teachers' doubts and concerns, but also the underlying causes. Incorporating the teachers' perceptions in professional development programs (PDP) is essential to address their specific needs. Consequently, it is prerequisite for a gainful implementation of IBL.

DOI: https://doi.org/10.23770/rt1811

2 Theoretical Background

Inquiry learning, classroom inquiry, inquiry-based learning, teaching through inquiry – these are only a few of the many different terms used in the context of IBL. The variety regarding IBL is not limited to the terminological level, but is manifested also on the conceptual level. Anderson (2002, p. 3) states that IBL "means so many different things to different people". This disagreement also appears in several papers which use the term IBL analogously to terms like discovery learning, problem-based learning or open learning (cf. Abrams, Southerland & Evans, 2008; Blanchard et al., 2010; Hmelo-Silver, Duncan & Chinn, 2007; Rönnebeck et al., 2016). However, IBL is not characterized by a specific structure, practice or organizational framework, but by students' activities which are referred to as "Essential Features of Classroom Inquiry" by the NRC (2000) (Table 1). In this light, IBL can vary in topics, tasks, openness and the underlying didactical concept(s). IBL can be context- and/or problem-based, more or less self-regulated ('open') and it can be realized not only within the framework of projects (project-based learning), but also in regular lessons (Crawford, 2014; Oguz-Unver & Arabacioglu, 2014; Mayer & Ziemek, 2006).

Table 1: Essential Features of Classroom Inquiry (NRC, 2000, p. 25)

➢ Learners are engaged by scientifically oriented questions.
➢ Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions.
➢ Learners formulate **explanations** from evidence to address scientifically oriented questions.
➢ Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
➢ Learners communicate and justify their proposed explanations.

In the National Science Education Standards (NSES), inquiry is defined as "activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 2000, p. 23). Abrams et al. (2008) express this definition by formulating three aims of IBL: "learning about inquiry", "learning to inquire" and "constructing learner's scientific knowledge". They argue that IBL is "a complex set of ideas, beliefs, skills, and/or pedagogies" and to "select a singular definition of inquiry may be an unsurmountable and fruitless task" (p. xv). Moreover, they emphasize the importance of a wide and adaptable definition which should be applicable for the greatest possible number of practitioners.

From the perspective of professional development, Lipowsky (2010) argues that PDP have to be compatible with both the teachers' features and the school system as organizational framework. Hence, information about teachers' knowledge, beliefs and values as well as the role of IBL within the curriculum is needed. To obtain this information, relevant literature and the Austrian curriculum for chemistry[1] are analyzed in the following section.

[1] In Austria, there are two different curricula for chemistry in secondary education: one for lower secondary education (grade 5 to 8) and one for upper secondary education (grade 9 to 12). Because of the similarity regarding the aspects of IBL included within both curricula, quotations refer to the curriculum for grades 9 to 12 for the sake of convenience.

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2.1 IBL within the Austrian curriculum for chemistry

In the Austrian curriculum for chemistry, the three aims "learning about inquiry", "learning to inquire" and "constructing learner's scientific knowledge" are included through the integrated competency model as well as the specified didactical principles (BMB, 2016). The competency model consists of three dimensions: the content-related dimension, the action-related dimension and the dimension of complexity. The content-related dimension refers to "constructing learner's scientific knowledge" and the action-related to "learning about inquiry" and "learning to inquire". Within the action-related dimension, inquiry activities for students are listed corresponding to the NSES.

The third dimension of the Austrian competency model, the dimension of complexity, refers to the extent of students' self-responsibility. Within the model, two stages are distinguished: to work on a task under instruction (stage 1) and to work on a task largely independently (stage 2) (BMB, 2016). Such a gradation of self-responsibility is also mentioned in the NSES, where "variations" of the essential features are formulated (NRC, 2000, p. 29). The given variations (three to four per feature) range from minimally-guided to fully-guided inquiry activities and represent what Schwab (1962) and Colburn (2000) name the different levels of IBL (cf. also Abrams et al., 2008; Blanchard et al., 2010). While the Austrian competency model differentiates solely two levels, Blanchard et al. (2010) name four different levels of IBL: verification (Level 0[2]), structured (Level 1), guided (Level 2) and open (Level 3). The first two can be related to stage 1, the latter two to stage 2 of the Austrian curriculum for chemistry.

In both the NSES and the Austrian competency model, IBL is intended as a student-centered but teacher-guided approach. It is explained that the teacher is responsible to create an appropriate task (adapted to the students' age, knowledge, abilities, skills, interest …) and to guide and facilitate the students' learning processes (Abels, 2015). In the Austrian curriculum for chemistry, it is explicitly mentioned that an alternation between deductive and inductive approaches should be strived for and that students' prior knowledge has to be considered in order to prevent overextension. Lederman (2008) recommends to develop competencies regarding IBL gradually and emphasizes that "instruction should gradually and systematically move from Level '0' activities with the ultimate goal being some Level '3' activities" (p. 32). Others rather recommend a balance of openness and structure as ultimate goal, i.e. guided inquiry (cf. Abels, 2015; Bunterm et al., 2014; Scruggs & Mastropieri, 2007).

2.2 IBL as an effective instructional approach

The effectiveness of IBL as an instructional approach has been investigated for more than 20 years. This resulted in a huge number of studies and several meta-studies, too (e.g. Furtak et al., 2012; Minner et al., 2010; Schroeder et al., 2007). Hmelo-Silver et al. (2007) claim to not ask whether IBL is effective or not, but to ask under which conditions it works and what it is effective for. In consideration of this perspective, the effectiveness of IBL is discussed in relation to three aspects in the following section: crucial elements of IBL, the level of openness and the role of the teacher.

Minner et al. (2010) analyzed 42 comparative studies and found positive effects on students' learning and retention of scientific content in 55% of all studies. In these studies, students in

[2] To avoid confusion, the levels defined by Blanchard et al. (2010) are capitalized throughout the remaining part.

DOI: https://doi.org/10.23770/rt1811

settings with "higher amounts of inquiry saturation" (emphasis on students' active thinking and engagement in inquiry activities as well as self-responsibility for their own learning) performed significantly better than those in settings with lower amounts of inquiry saturation. Instruction following constructivist approaches like investigation cycles (see Figure 1) resulted in "improved student content learning, especially learning scientific concepts" (p. 493). These findings are strengthened by Blanchard et al. (2010, p. 607), who found best results, highest growth and long-term retention regarding conceptual knowledge when using "more reformed teaching practices and a stronger implementation of inquiry methods". Both studies thus confirm the evaluation of the 5E instructional model[3] by Bybee et al. (2006). In classrooms with medium or high consistency to the model, students' learning gains were nearly twice as high as those in classrooms with low consistency. Additionally, Furtak et al. (2012) showed in their meta-analysis that combining the different "domains of inquiry" (procedural, epistemic, conceptual, social) is more effective for students' learning of science than concentrating merely on the conceptual domain.

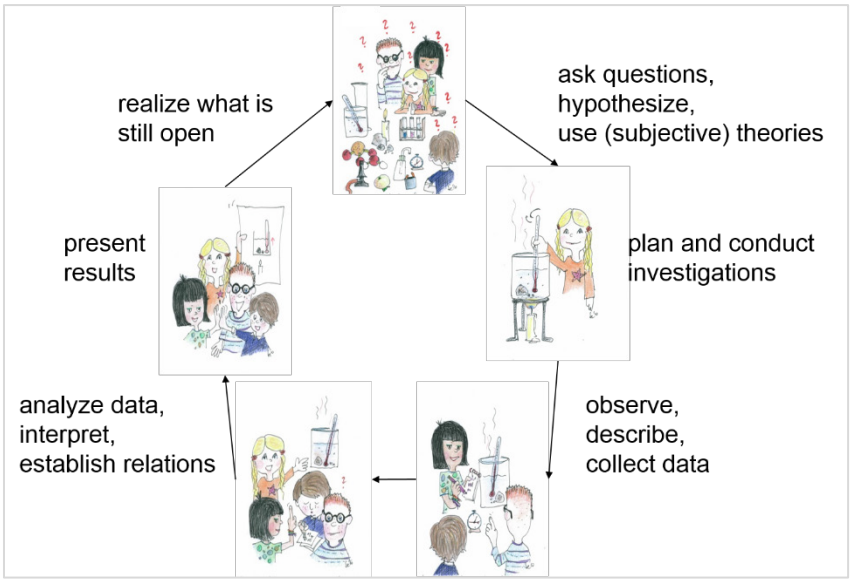

Figure 1. Inquiry cycle (Lembens & Abels, 2016, p. 2545)

Apart from specific elements of IBL, the level of openness is regarded as relevant variable for its effectiveness. Jiang and McComas' (2015) analysis of the PISA 2006 data indicates that structured IBL causes the highest effects on student science achievement, whereas higher levels of IBL have a beneficial effect on students' attitude toward science. Blanchard et al. (2010) compared guided IBL with traditional (verification) lab and found a positive impact of guided IBL on students' procedural skills, but not on their conceptual knowledge. These results are supported by the findings of Fang et al. (2016), who found that students involved in guided inquiry activities attained better results regarding procedural skills, those involved in structured inquiry activities had a greater increase in content knowledge.

Moreover, the effectiveness of IBL strongly depends on the role of the teacher. Blanchard et al. (2010, p. 607) describe IBL as a complex approach which requires "a great deal of skill on the part of the teacher". Following Jiang and McComas (2015), adjusting IBL to predefined aims, conditions and students' prior knowledge and skills is indispensable, because "not all

[3] The 5E instructional model is a constructivist learning cycle developed in the 1980s by the BSCS (Biological Sciences Curriculum Study) and consists of five phases: Engagement, Exploration, Explanation, Elaboration and Evaluation.

DOI: https://doi.org/10.23770/rt1811

versions of it [IBL] are equally applicable in all instructional situations for all students with all contents" (p. 573). Hmelo-Silver et al. (2007, p. 99) state that teachers have to "provide extensive scaffolding and guidance to facilitate student learning" in IBL settings. 'Open' IBL must not be confused with minimally-guided approaches, which are assumed being less effective or ineffective (cf. Blanchard et al., 2010; Kirschner et al., 2006; Minner et al., 2010; Schroeder et al., 2007). Blanchard et al. (2010) even claim that verification labs are preferable to IBL when the latter includes a badly structured student-teacher interaction.

2.3 Teachers' beliefs of IBL

So far, we have discussed the variety with which education researchers define IBL. Studies have shown that teachers hold diverse views about IBL similarly. DiBiase and McDonald (2015) conducted a survey among 257 middle school and secondary science teachers and found "a lack of understanding of inquiry and how it is implemented in the classroom" (p. 31). In their comparative baseline study across twelve European countries, Engeln et al. (2013) were faced with relevant country-specific differences and found that IBL is not widespread in some of the countries. In both studies, the majority of teachers consider IBL as important to develop problem-solving skills and to acquire knowledge about scientific inquiry. Nevertheless, only few of the teachers apply it regularly in their own classes. Reasons given are that IBL would be very time-consuming and hence, it would not be appropriate to comply with curricula and contents of final exams. Moreover, teachers query whether the students would use the time productively when IBL is implemented and if they would be able to construct scientific knowledge from those lessons. Other often-named constraints are an inappropriate class size, a lack of time, material and spatial resources as well as insufficient qualification of the teachers (methodological and subject-specific). Moreover, the teachers' attitude towards IBL is influenced by their views about the Nature of Science, their perception of teaching and learning in general and what they regard as the purpose of science education. If their views are incompatible with how the conceptualize IBL, teachers are less willing to implement it – or they apply it in a way which fits their predominant beliefs and, hence, inhibits a reform of teaching (see also Anderson, 2002; Cheung, 2011; Crawford, 2014; Wallace & Kang, 2004).

2 Purpose and Aims

The fact that IBL is considered difficult and implemented rarely is known not only from literature, but also from experiences made during the project TEMI[4]. For this reason, a follow-up PDP was developed to foster the implementation of IBL in Austrian secondary schools. In this PDP, the teachers are engaged in planning, applying and reflecting on IBL units in collaboration with researchers to develop successful strategies for implementing IBL autonomously in their own classes. To design such a PDP which meets the participating teachers' needs as much as possible, knowledge about the teachers' existing idea of IBL is needed. This article aims to describe this knowledge by answering the following questions:

[4] TEMI (Teaching Enquiry with Mysteries Incorporated) was a project under the Seventh Framework Programme (FP7) of the European Commission (Grant Agreement N. 321403) with the aim to foster the implementation of inquiry-based science education across Europe. http://cordis.europa.eu/project/rcn/108650_en.html (29.12.2017)

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1) What does IBL mean to the participating teachers?
2) What are the differences between the teachers' idea of IBL and that one incorporated in the Austrian curriculum for chemistry?
3) Which contradictions between IBL and usual chemistry lessons held by the teachers emerge from these differences?

4 Research Design

After the TEMI workshop-series was completed in January 2016, participating teachers from Vienna received an invitation per e-mail to collaborate with the Austrian Educational Competence Centre for Chemistry in the framework of a follow-up PDP. Eight of these teachers were interested to continue working on IBL and participated in an informal meeting to talk about their needs. To subsequently address their needs while gaining further insights into their idea of IBL, a semi-structured group discussion with five of the participants was arranged for the first working session (see Figure 2). Drawing on the insights from the informal meeting, experiences from TEMI and findings from the literature, the following questions were used to stimulate the discussion and to ensure that the participants did not get off task:

- What is your [the discussants'] general idea of IBL?
- What should students be doing and what should teachers be doing during IBL units?
- What is the purpose of IBL?
- What can be challenging when implementing IBL?

The method of group discussion was chosen, because it is considered conducive to raising opinions, beliefs and attitudes because of the necessity to argue one's own views as well as to negotiate a common position within the group (Flick, 2014). The group discussion took place in March 2016, lasted 43 minutes and was audiotaped.

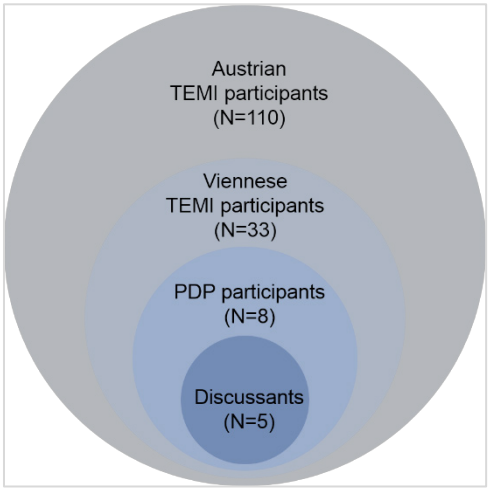

Figure 2. Research Sample

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4.1 Sample

The discussants (N=5) are all female[5], but diverse in their age (from 36 to >50 years), teaching experience (from 3 to >20 years), age of students they teach (from 10 to >20 years) and number of chemistry/science lessons given in the respective type of school (from one to five hours/week including laboratory work). What they all have in common is their teaching activity in chemistry or science on the one hand and the attendance in a workshop series as part of the project TEMI on the other hand (see Figure 2). In four TEMI sessions, the teachers got to know, among other things, the 5E instructional model, the different levels of inquiry and aims of IBL (cf. Hofer, Lembens & Abels, 2016).

4.2 Data Analysis

The group discussion was fully transcribed. The transcript served as the main source for the analysis; however, the audio file was used additionally to clarify sarcastic or especially stressed statements. To analyze the data, a qualitative content analysis following Mayring (2010) was applied. To address both the predefined points of discussion (the above listed guiding questions) and the special interest in the beliefs and attitudes of the participating teachers, a combination of deductive and inductive analysis was applied. In a first step, we organized the teachers' statements according to the four guiding questions, where the units of analysis ranged from one word to one train of thought. In doing so, we observed that the teachers talked rather about the concrete implementation in their own classes than about IBL as a superior instructional approach. The discussion concerned largely the design of learning environments as well as arguments for and against the implementation of IBL. Considering these findings, the statements were reorganized and the following four dimensions emerged: (1) Learning Environment, (2) Objectives, (3) Scaffolding and (4) Obstacles. After a further run of classifying, the statements of each dimension were labelled with codes in order to inductively develop categories and subcategories for each dimension. In the first coding cycle, the codes were intended to be as close as possible to the original statements. To achieve this, various types of coding which partially originate from the Grounded Theory Methodology[6] (Charmaz, 2006) were combined: in vivo, value, versus, descriptive and process coding (Saldaña, 2012). The generated codes in turn were analyzed in a second coding cycle through applying pattern coding and focused coding (Saldaña, 2012). In this way, the level of abstraction was increased so that 14 categories, whereof three are divided further in subcategories, emerged from the data (see Table 2). Through applying this elaborated system of dimensions, categories and subcategories to the data, a detailed coding manual was developed (an excerpt thereof is given in the Appendix).

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[5] From our experience, the gender distribution is quite in line with the engagement in professional development courses in Austria. The amount of male participants in TEMI in Austria was less than a third of the overall number of participants.

[6] Mayring (2010) himself relates his inductive coding procedure with Grounded Theory.

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Table 2: Table of dimensions, categories and subcategories

Dimensions	Categories and subcategories
Learning Environment	Engaging setting
	Openness
	Practical work
	Teamwork
Objectives	Exploring
	Posing questions
	Methodical skills
	Applying and transferring
Scaffolding	Before an IBL unit
	During an IBL unit
Obstacles	Students' features • Abilities • Attitude • Familiarity with IBL
	Teachers' features • Content knowledge • Methodical skills
	Resources • Human resources • Organizational resources • Financial resources • Spatial resources
	Effectiveness and efficiency of IBL

Because of the transcripts' complexity (simultaneous talking, referring to others' statements), the length and structure of the context units varied massively. Since that would have made interrater-reliability too burdensome to use for validation, the method of argumentative validation was applied. Using a coding manual (see Appendix), both the coding and the system of dimensions and categories were discussed in different settings: all codes and the associated quotations were revised in one-on-one conversations with two colleagues; the system of dimensions and categories was verified through discussion with three colleagues and in a research team (N=4).

5 Results

The results of the qualitative content analysis are presented by illustrating the four developed dimensions 'Learning Environment', 'Objectives', 'Scaffolding' and 'Obstacles' with teachers' statements.

5.1 Learning Environment

During the group discussion, the teachers agreed on what they see as characteristic for IBL. For them, IBL settings are inspiring, arouse the students' interest and encourage them to get to the bottom of phenomena. Students acquire new knowledge by working in teams and

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investigate phenomena through experimenting. However, it is noted that "*inquiring is not necessarily solely experimental*" [7] *(T1-07:52)* – there could also be "*another type of IBL*" *(T5-32:52)* without practical work, like theoretical considerations or computer simulations. The tasks for IBL are open (or at least more open than those for usual units) and "*students may introduce their own ideas as regards the conduct of investigations and the findings from these investigations*" *(T2-04:46).* What is crucial is that the students work and think independently instead of "*following merely a predefined recipe*" *(T4-05:25).*

5.2 Objectives

In the group discussion, aims for IBL were mentioned both explicitly and implicitly in the form of intentions or purposes. The teachers would implement IBL to make their students deal intensively with a subject, a question or a phenomenon. By exploring (planning and conducting investigations, analyzing and interpreting data) they should learn to ask questions *("our aim is to achieve questioning"; T5-31:02),* acquire technical skills *("writing lab reports, using terms exactly and drawing conclusions"; T3-31:58)* and gain the ability to "*apply all their already existing knowledge and experiences to a problem*" *(T5-08:22)*. Not only through practical work, but also through research in books, the Web or provided material, the students should gather information to finally explain the investigated phenomenon.

5.3 Scaffolding

The dimension 'Scaffolding' comprises what teachers see as their tasks within the frame of IBL. Prior to an IBL unit, teachers regard as their job to create a task and to prepare the related material. They feel responsible to look for a topic, prepare an instructional sheet, keep reagents and equipment ready for practical work and consider the structure of the unit. During an IBL unit, they see themselves in the role of a coach. This means to support the students, e.g. through answering questions or facilitating, and to make sure that everything takes place in an orderly manner. However, one teacher clarifies *"I must not show the answer to them [the students] immediately, I may support them along the way there […]." (T5-28:55)*.

5.4 Obstacles

Although the teachers outline IBL as quite positive and desirable, they have several concerns about it. Mentioned aspects refer to different levels (personal, institutional and system level) of teaching and learning and are not just seen as challenging, but rather as hindering.

Concerning the students, the teachers mention a lack of content knowledge and technical skills as well as difficulties to apply and transfer their knowledge and skills to new contexts. Other factors seen as hindering are the students' attitude and the issues they have with thinking and working independently as well as staying on task for a longer time. Moreover, the teachers declare that students would not be familiar with IBL and that they *"would need to review, discuss and practice it systematically with them" (T3-18:50*. Teachers perceive that they themselves are relatively unfamiliar with IBL too. Insufficient knowledge regarding the

[7] Teachers' statements were translated from German as close as possible to original wording. The abbreviation 'T2' denotes statements made by teacher 2; the time specification refers to the audio recording.

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preparation and implementation of IBL as well as the requirement of extensive content knowledge restrain the teachers from implementing IBL.

In addition to these person-related challenges, the teachers mention unsuitable conditions for IBL: a lack of material and spatial resources as well as organizational problems like a small number of lessons, an overfilled curriculum, large classes and the invariable length of the lessons. Furthermore, the teachers have a very critical view on the effectiveness and efficiency of IBL. They question whether there is any added value of IBL compared to verification labs. Some of them doubt the effectiveness of IBL generally. At any rate, the teachers share the view that *"effort and output [of IBL] are disproportionate" (T5-19:55)*.

6 Discussion and Limitations

This article aims to show what IBL means to five Austrian chemistry teachers, how their idea of IBL differs from that included in the Austrian curriculum for chemistry and what contradictions emerge from these differences. In this section, these three questions as well as the limitations are discussed.

Analyzing the teachers' statements revealed discrepancies regarding the idea of IBL not only among the discussants, but also within the individuals. There is a kind of circular reasoning, what is exemplified through the following two points:

a. Teachers regard skills like asking questions, formulating hypotheses or drawing conclusions as important and agree that IBL would be effective at helping students acquire these skills (see section 2.3) and at the same time they describe a lack of these skills as an obstacle for implementing IBL. So they name technical skills as both prerequisite for and aim of IBL.

b. Teachers state that IBL can be implemented only very occasionally because of its ineffectiveness and at the same time they declare that IBL would not be effective because of students' unfamiliarity with it, a result of the occasional implementation. They do not realize that IBL must be adjusted to students' prior knowledge and skills (see section 2.2) and that familiarity with IBL needs to be developed gradually (see section 2.1).

Moreover, the teachers' assertions throughout all dimensions indicate that they regard exclusively Level 2 and Level 3 as IBL. Considering all three aspects the students' insufficient skills, their unfamiliarity with IBL and IBL starting only from Level 2, it is hardly surprising that the teachers expect an overextension of their students and assume IBL to be ineffective. As a natural consequence, they see IBL (including its open tasks) as desirable, but not applicable in regular chemistry classes.

Compared with the openness of IBL and students' activities respectively, teachers give only little importance to the aspects which are referred to as "Essential Features of Classroom Inquiry" by the NRC (see section 2). The idea that IBL starts from a question, which finally is answered through findings from an investigation is not present in the teachers' idea of IBL and could be caused by their own view of Nature of Science (see section 2.3). This lack of goal orientation as well as the high level of openness could be the reason, why teachers consider IBL as appropriate for acquiring skills, but not knowledge. This perception is supported also by studies, which show successful content learning especially at lower levels of IBL and in the course of constructivist approaches like investigation cycles (see

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section 2.2). But even if IBL was inappropriate to construct learners' knowledge, it would not be a contradiction to the curriculum, which includes not only scientific content, but also inquiry activities (see section 2.1).

Since the findings of this article refer to data collected in a very special setting and the interviewed teachers can be assumed to be especially committed, the results in this article have to be seen as explorative and casuistic. Nevertheless, the article shows that teachers are sometimes oblivious to didactical principles included in curricula, reform documents or workshops and thus, the underlying concepts might be understood in a different way than originally intended. The article illustrates what teachers think about how IBL takes place and gives detailed reasons why experienced teachers still refrain from implementing it. Moreover, the article shows exemplarily the importance of in-depth analyses to assess the meaningfulness of statements referring to ambiguous terms like IBL. The fact that the data originate from teachers who participated in a PDP regarding IBL emphasizes the persistence of prevalent beliefs as well as the issues unprepared teachers might have when implementing IBL.

7 Conclusions and Implications

The present results suggest that it is hard for teachers to grasp IBL in its complexity and entirety even after attending a workshop which addressed diverse aspects of IBL. In contrast to the multifaceted approach intended in policy and research documents, IBL is reduced to a specific method of teaching which is applied to achieve goals beyond those of the 'regular' chemistry lessons. To support teachers in developing an elaborated concept of chemistry education including IBL as instructional approach, work on various points is required: the teachers' concept of IBL, their interpretation of curricula and their skills regarding the planning, application and reflection of IBL. Only if all points are addressed can teachers realize that IBL and secondary chemistry education are not two irreconcilable concepts. Designing, conducting and evaluating a PDP appropriate for this purpose constitutes the next step of research.

Acknowledgements

We are very thankful for the teachers cooperating in this research project.

Furthermore, we want to thank our colleagues at the University of Vienna, Austria, for their support in analyzing the data and for their comments regarding this article: Brigitte Koliander, Thomas Plotz, Sandra Puddu, Rosina Steininger and Brigitte Wolny.

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DOI: https://doi.org/10.23770/rt1811

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DOI: https://doi.org/10.23770/rt1811

Appendix: Excerpt from the coding manual

Dim.	category	Description	Exemplary quote [quotes translated]
LEARNING ENVIRONMENT	ENV1: engaging setting	The setting awakes students' attention, interest, curiosity or enthusiasm. It is motivating and encourages the students to involve in a subject, theme or problem. The setting includes stimuli like phenomena, observations, experiments, material or questions. It is challenging to design settings which really engage the students.	*[…] because their interest is roused by an unexpected or interesting phenomenon or something they have observed or seen, ahm, starting from this motivation […] (T3-05:40)*
	ENV2: openness	IBL learning environments are more open than traditional learning environments. This refers to the task (topic, structure …) as well as to the activities of students and teachers. However, the openness of IBL in regular lessons is limited.	*[…] that students may introduce their own ideas as regards the conduct of investigations and the findings from these investigations. (T2-04:46)*
	ENV3: practical work	Practical work is an essential feature of IBL, though not strictly necessary.	*[…] through practical work, but also theoretically […] (T1-06:20)*
	ENV4: teamwork	In IBL units, students work in teams.	*[…] team work […] (T3-22:50)*
OBJECTIVES	OBJ1: exploring	IBL aims to get the students exploring: examining intensively the object of investigation by formulating hypotheses, planning and conducting investigations and providing explanations. - Posing questions is not part of this section – it is subject of category OBJ2.	*[…] in IBL units […] the main focus is likely not the handling, this is a side effect – a positive one – but I want them to develop, to think, to consider something […] (T5-16:29)*
	OBJ2: posing questions	IBL aims to encourage students to practice themselves in questioning.	*[…] these questions are the real aim […] (T2-27:07)*
	OBJ3: methodical skills	IBL aims to acquire and strengthen the students' methodical skills like writing reports, distinguishing observation, interpretation and explanation, arguing and reasoning as well as error analysis. - Posing questions is not part of this section – it is subject of category OBJ2.	*[…] acquiring methodical skills […] like writing lab reports, using terms exactly and drawing conclusions. (T3-31:53)*
	OBJ4: applying and transferring	IBL aims to get the students applying and transferring their knowledge, abilities and skills. This involves application and transfer not only within one discipline, but also interdisciplinary as well as beyond the borders of scholastic experiences.	*[…] that they apply all their already existing knowledge and experiences to a problem […] (T5-08:20)*
SCAFFOLD-ING	SCA1: before an IBL unit	Prior to an IBL unit, teachers organize the unit: defining the structure, creating a task and preparing material (instructional sheets, reagents, equipment, …)	*[…] preparing, arranging and I think first and foremost waiting for questions […] (T5-28:16)*
	SCA2: during an IBL unit	During an IBL unit, teachers have the role of a coach. They support the students through answering questions or facilitating. Additionally, they make sure that everything takes place in an orderly manner.	*[…] Coaching. Of course, I must not show the answer to them immediately, I may support them along the way there […] (T5-28:55)*
OBSTACLES	OBS1: students' features	The implementation of IBL is made difficult by students' abilities (knowledge, competencies), their attitude (interest, motivation, conscientiousness, willingness) and a lack of familiarity with IBL.	*The students are not really used to it, somehow it is a slight overextension for them […] usually it does not happen to them. (T2-12:37)*
	OBS2: teachers' features	The implementation of IBL is made difficult by teachers' content knowledge and a lack of methodical knowledge and skills.	*[…] you must have content knowledge to an extent far beyond that required […] (T1-38:27)*
	OBS3: resources	The implementation of IBL is made difficult by a lack of time (preparation, implementation) and material (teaching material, reagents, equipment) as well as by inappropriate organizational and spatial conditions.	*[…] the material is quite effortful and the schools have only a low budget and very often you have to organize it by yourself, and you must go shopping, and generally to look for the stuff and pay for it by yourself […] (T3-39:18)*
	OBS4: effectiveness and efficiency of IBL	Teachers refrain from implementing IBL because of lacking effectiveness and efficiency. The outcome of IBL is relatively poor and the efforts are disproportionate compared with the added value.	*[…] it is quite fruitless. There is only little improvement in enthusiasm and in what they remember, all in all insubstantial. (T4-22:35)*

DOI: https://doi.org/10.23770/rt1811