Chapter 12
Inquiry approaches in Physics Education

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Abstract. Despite EU recommendations over a decade ago that inquiry-based learning is an effective strategy for learning science, this method is still uncommon in European schools. Teachers express doubts about the feasibility and effectiveness of inquiry-based learning and a lack of understanding of how to use inquiry approaches in their classrooms. This chapter presents an overview of inquiry-based learning and discusses how an inquiry approach can be utilised to develop both student and teacher learning in physics. An inquiry approach that involves teachers conducting their own practitioner inquiry in the context of inquiry-based learning in physics is recommended.

1. Introduction

A human being enters the world without any prior knowledge or experience. From that day on, we start to develop our own experiences of the world and everything in it. We continue to explore and develop our understanding of the world around us because we are intrinsically curious [1] and inquisitive. And although for some of us, *inquisition* may carry pejorative connotations, this is what we do to explore and discover the world around us – having a strong intrinsic motivation [2] we constantly make inquiries throughout our lifetimes. We would not survive in this world if we lacked the ability to construct our learning based upon our experiences [3]. Accumulation of experiences, together with constant reflection, creates the process of learning, ultimately leading to the progress of self-development. The lack of curiosity puts humanity at risk and threatens the development of our open-mindedness, independence, self-esteem, and respect for others and overall learning. Despite recent international focus on promoting the development of core competencies, it is still quite common that the focus of 'learning content knowledge to pass tests' prevails [4] and other learning is either treated as a secondary need or moved to specialised courses. Accumulating knowledge without the use of reasoning - learning by heart - appears to originate from the Middle Ages when education was almost inseparable from religion [5]. Nevertheless, it is still one of the most common methods of self-learning.

The challenges regarding student engagement and participation in science disciplines are a matter of international concern. The 2015 report to the European Commission of the expert group on science education [6] highlighted that 'Europe faces a shortfall in science-knowledgeable people at all levels of society and the economy' (p. 6). This challenge was raised in a previous European Commission report in 2007 [7]. The OECD [8] reported that in OECD countries only 6% of new entrants to university choose to study natural sciences. Accepting that it's not essential that all students study science disciplines at third level, it is critically important for society that all students engage in science studies to develop science literacy (EU Key Competences, [9]) and an inquisitive mindset that develops the skills necessary to make informed decisions on societal challenges such as climate change, food, water, and energy shortfalls. While all the science disciplines face challenges engaging students, it is particularly pronounced in the discipline of physics for a multitude of reasons, such as shortages of qualified teachers, perception of being difficult, and gender stereotyping.

The OECD Learning Compass 2030 sets out an aspirational vision for the future of education (OECD, [10]):

> How can we prepare students for jobs that have not yet been created, to tackle societal challenges that we cannot yet imagine, and to use technologies that have not yet been invented? How can we equip them to thrive in an interconnected world where they need to understand and appreciate different perspectives and worldviews, interact respectfully with others, and take responsible action toward sustainability and collective well-being?

The Learning Compass offers a vision of the types of interdependent competencies that students will need to thrive in 2030 and beyond including the development of knowledge, skills, attitudes and values, transformative competencies and a cycle of anticipation, action, and reflection. The insufficient focus on the assessment of such competencies is an issue of global concern. Learning goals are misaligned with XXI-century society demands and patterns of behaviour, thus creating a dissonance between school (education) and learning for life.

Students' intrinsic motivation for learning has been shown to significantly decrease at around 10 years of age [11] and evidenced as a so-called fourth-grade slump that occurs not only in reading comprehension [12, 13] but also in motivation for STEM education [14]. This phenomenon appears to be quite common and needs proper addressing. The sooner that the role of intrinsic motivation is recognized at schools and the longer this innate ability to explore the world is cherished, the better prepared individuals will be for lifelong learning [15].

Thus, the use of engaging and active methodologies is urgently needed to influence learners' attitudes and motivation for STEM, while at the same developing their skills, understanding and knowledge of STEM. This chapter presents an overview of inquiry-based learning and discusses how an inquiry approach can be utilised to develop both student and teacher learning in physics.

2. What is Inquiry?

Inquiry is a natural process of wondering about the world, experiencing it with all senses, and building human being's own attitude towards the miracle of its existence and the beauty of its structure. Inquiry starts any adventure and keeps the pace of any learning endeavour without giving up. Inquiry-based learning (IBL) can be described as a process of constructing knowledge through direct experience in authentic circumstances by the involvement of one's creativity. This instance comprises the ideas and works of the precursors of two pedagogical streams: constructivism and progressivism. Constructivists were confident that learning is an act of students who *construct* knowledge out of their experiences. For them, repeated exercises of building knowledge needed creativity, and at the same time, enhanced it. Progressivists argued that doing is more valuable than the result of doing. For them, the process combining thinking, trying out, reflecting, and redesign - applied to the unknown, triggered motivation and engagement, and resulted in natural learning.

In the early 1960s, Schwab [16] and Bruner [17] independently brought the concept of inquiry-based learning, comparing it to any other act of life that leads to achieving understanding. Just before, Bruner [18] argued:

> What a scientist does at his desk or in his laboratory, what a literary critic does in reading a poem, are of the same order as what anybody else does when he is engaged in like activities – if he is to achieve understanding. The difference is in degree, not in kind. The schoolboy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else. The "something else" usually involves (…) classroom discussions and textbooks that talk about the conclusions in a field of intellectual inquiry rather than centring upon the inquiry itself. Approached this way, high school physics often looks very little like physics, social studies are removed from the issues of life and society as usually discussed, and school mathematics too often has lost contact with what is at the heart of the subject, the idea of order. (p. 14)

Bruner focused his idea of IBL around a concrete image of "acting like a scientist." He also drew attention to the fact that the school curricula did not promote such a learning approach. The idea of reflecting a scientist's way of approaching science problems at school has evolved over the past 40 years. Several educators and researchers in education elaborated Bruner's concept by setting up principles [19]; describing conditions for successful implementation [20, 21] and designing materials for schools, particularly relating to science subjects [20, 22]. A new evaluation format at school, i.e., 'assessment for learning' [23] was proposed to encompass the complexity of the learning outcomes, and on this basis strategies and tools for assessing IBL were designed (e.g., SAILS, [24]).

Following the idea of Bruner, the IBL method is usually associated with a research cycle. To date, a few different versions of inquiry cycles have been proposed [19]. A cycle is complete because it mimics the entire unit of the scientific process of research. However, it is not a rigid structure and should be implemented according to the learning purpose and class circumstances. The IBL method is not uniform, and the IBL process can take place on at least three levels, distinguished as structured, guided, and open inquiry [21].

3. What is Inquiry at the student level?

IBL is more than another didactic method. It is a way of thinking, behaving, and enhancing attitudes and beliefs. It promotes holistic development by activating all three domains of learning: cognitive, psychomotor, and affective – in one inquiry process. Students constantly create, reflect, and design, thus gaining new knowledge and developing the knowledge already acquired (cognitive domain). They act primarily by engaging their hands – manipulating, connecting objects, moving them, matching them, and rearranging; they walk and carefully observe (psychomotor domain). Learning occurs upon personal and collective effort. Students interact with each other since communication and cooperation in groups lie at the heart of the IBL. Dynamics of this interaction with others and emotions involved in the pursuit of understanding constitute reinforcement of the affective domain of learning. For these reasons, IBL approaches have been promoted in many national curricula over the past decades [7, 25].

Sokołowska [21] presents an extended model for an IBL process consisting of nine phases of inquiry cycle, as shown in Table 1.

Table 1. Sequence of steps in the Inquiry-Based Learning cyclic process [21].

1. **Setting the scene and generating ideas** on a specific topic or problem initiates the entire process. A general theme is selected at this phase. Questions arise: Why does this happen? What is the trend? What if? The problem may be launched by students' interests or observation. If a teacher initiates the topic - it may remain not verbalized until students reveal it during the brainstorming. When **Generating ideas** students spontaneously bring their experiences, examples from life, associations and refer to their current knowledge. The teachers' role is to ensure that everybody has a voice and guide the group with minimal intervention. In this phase, teachers learn what their students already know about the chosen topic. Thanks to that, teachers can still adapt the subsequent steps of the process - avoiding elements already known to learners or diversifying experiments due to different levels of students.
2. **Formulating an inquiry question** asks one or a series of qualitative or quantitative questions related to the selected topic to narrow it down. It should be formulated considering the feasibility of doing the investigation to search for the answer, i.e., specific conditions created during classes, i.e., class time, availability of materials, classroom conditions, and student safety.
3. The next step is **putting forward hypotheses/predictions** on the outcomes of the experiment. Students come with their hypothesis, reasoning based on their knowledge and prior experiences. It may occur just after formulating the inquiry question or after establishing an action plan, but always before students proceed to the investigation.
4. **Planning investigation** is an organization of research. Students divide themselves into groups and agree upon the roles they take in each group (conducting experiments, taking notes, ordering collected data, etc.). In this phase, students decide on selecting materials, tools, and instruments necessary to perform the experiment and write an action plan. This plan may not be too detailed since students are very likely to employ a trial-and-error procedure and modify their plan when experimenting.
5. **Carrying out the investigation** starts after making a hypothesis and setting an inquiry plan. Students perform one or more experiments, recording their observations and experimental data.
6. **Data analysis** takes place after completing all stages of the experiment. Students organize their notes on experiments and then analyse experimental data and observations. They transfer the results into visual representations.
7. Based on the obtained results, students **draw conclusions**. They try to answer the inquiry question by verbalizing arguments that support their reasoning. Students return to the hypotheses put forward at the beginning and confront them with the experiment's outcomes.
8. After completing their investigation, the groups **share** and compare **their results**. Students learn how to present their studies clearly and consistently within a given time frame, and ask constructive questions to other research groups.
9. **Developing the problem** is a possible (not always present) closing phase of the IBL cycle and, at the same time, a stage potentially opening the next inquiry cycle (an extension of the same problem, an investigation of a related issue, etc.)

While doing an inquiry, students are constantly challenged by the undiscovered. So, by practicing inquiry, students are likely to develop high-order skills for adaptation to any new situation, not only in a school or any other familiar circumstances, but also in completely unknown environments. Such experiences can build their independence and self-confidence and equip them with the necessary skills for and the attitude of lifelong learning. Inquiry never leads to any win or failure. Whenever one phenomenon or instance is understood, a few new challenging questions open, and the inquiry process continues in another cycle. Whenever anything goes the way the inquirer cannot understand, the result is the same – a new question arises, and the iteration of a trial-and-error procedure continues. Individuals regularly learning by inquiry will constitute a society ready to act creatively, think and reflect logically, form coherent arguments, and address global challenges.

Despite EU recommendations [7] over a decade ago that the IBL is an effective strategy for learning science, this method is still uncommon in European schools. The hesitation of teachers' widespread implementation of IBL is rooted in teachers' doubts about its feasibility and effectiveness. Science curricula overloaded with content knowledge leave little space for a time-consuming method of doing science. Also, the final standardized exams, evaluating a narrow part of learning, solely related to content knowledge [4] do not encourage changing the classroom practice from *knowledge transfer* to *constructing knowledge from experience.* Such a construction of standard curricula and assessment in science education is not only in contradiction to the nature of science, which should be reflected in the way science is delivered at school, but also appear to ignore many findings reporting substantial or at least minor positive effects of IBL approaches on students' attitudes toward science (e.g. [26–28]) and acquisition of the content knowledge [29–32], including medium- or long-term retention of knowledge [33, 34].

It is difficult for teachers to remove the systemic obstacles that impede widespread use of IBL. However, given the enormous benefits of inquiry [19], some teachers would introduce the method if they knew how to. Harlen [20] argues that moving from more traditional to inquiry-based teaching is likely to involve a shift in several aspects of teachers' pedagogy (Table 2).

Table 2. Harlen [20] (p. 22): "Moving from more traditional to Inquiry-Based Learning is likely to involve a shift in which teachers…"

…do more of this	…do less of this
Having students seated so that they can interact with each other in groups.	Having students seated in rows working individually.
Encouraging students to respect each other's views and feelings.	Allowing students to force their own ideas on others, not listening to others.
Asking open questions and ones that invite students to give their ideas.	Asking questions that call for nothing more than a one-word or short, factual response.
Finding out and taking account of students' prior experiences and ideas.	Ignoring students' ideas in favour of ensuring that they have the 'right' answer.
Helping students to develop and use inquiry skills of planning investigations, collecting evidence, analysing, and interpreting evidence and reaching valid conclusions.	Giving students step-by-step instructions for any practical activity or reading about investigations that they could do for themselves.
Arranging for group and whole class discussion of ideas and outcomes of investigations.	Allowing students to respond and report individually only to the teacher.
Giving time for reflection and making reports in various ways appropriate to the type of investigation.	Giving students a set format in which to record what they did, found and concluded.
Providing feedback on oral and written reports that enables students to know how to improve their work.	Giving grades or marks and allowing students to judge themselves against each other in terms of marks or scores.
Providing students with a clear picture of the reason for particular tasks so that they can begin to take responsibility for their work.	Presenting activities without a rationale so that students encounter them as a set of unconnected exercises to be completed.

…do more of this	…do less of this
Using assessment formatively as an ongoing part of teaching and ensuring student progress in developing knowledge, understanding and skills.	Using assessment only to test what has been achieved at various times.

4. What is Inquiry at the teacher level?

The lack of qualified and experienced teachers of physics in second-level schools is an urgent matter of international concern. It is widely recognised that the quality of an education system is highly dependent on 1) getting the right people to become teachers, 2) developing them into effective instructors, and 3) ensuring that the system can deliver the best possible instruction for every child. As a result of significant funding for national and international projects over the past two decades, many excellent IBL resources have been designed and thousands of teachers have been introduced to IBL approaches. However, even with the success of these initiatives, the widespread and effective implementation of IBL, its long-term use in the classroom and the sustainability and scalability of the teacher education offered by such programmes is still an issue of major concern. Additionally, issues of teachers' self-confidence in using an IBL approach exist and further obstacles such as curriculum demands, and the pressure of national assessments are hindering the use of IBL in schools.

To support the sustainable use of IBL in physics classrooms and enhance students' interest, motivation, knowledge, and skills in physics we need to consider what are appropriate strategies and models for teacher professional learning. In 1986, Thomas R. Guskey presented a model of teacher change through staff development programs. He highlighted that the purpose of professional development programmes was to bring about changes in teachers' classroom practices, beliefs and attitudes and the learning outcomes of students [35]. Teachers' motivation to engage in professional development and teachers' process of change are two critical considerations in programme design. This model proposes that teacher change is a process of learning that is "developmental and primarily experientially based" for teachers [35], p. 7. This idea helps us to understand why teachers retain or abandon particular teaching practices. Guskey [35] suggests that change in teachers' attitudes and beliefs depends on collecting evidence of positive influences changes in classroom practice has on student learning.

So, what does effective professional learning look like? Enhanced teacher knowledge and skills is more likely to occur in professional development programs that focus on "hands-on" experiences for teachers that are integrated into daily school life [36]. Penuel et al., [37] advocate that the focus of professional development should be on general and specific forms of content to support teaching practice. Active learning that supports student inquiry and coherence in aligning professional development activities with the learning goals of participants are critical for effective professional learning [37]. The authors propose a framework for professional learning where teachers and colleagues from the school or area work alongside each other. Timperley et al. [38] also advocate teachers' involvement in a professional community of practice with some external expertise preferable and an active school leadership presence. Timperley et al. [38] suggest integrating different aspects of theory and practice and pedagogical content knowledge in professional learning opportunities. Including a variety of activities that are aligned with the intended learning goals where understandings can be discussed and negotiated is important in facilitating effective professional learning [38]. Teacher collaboration in the form of professional learning communities and communities of practice are reported to address physics teacher isolation [39] and raise teacher satisfaction through sharing of practices and participation in learning activities with colleagues [40].

Practitioner inquiry (PI) has been promoted as a model that empowers teachers to make evidence informed professional judgements and changes in classroom practice that influence their student learning [41]. PI or teacher inquiry is a form of professional learning defined as the systematic, intentional study of one's own professional practice [42]. It involves teachers identifying problems, constructing inquiry questions, gathering, and analysing data to make evidence-based conclusions and recommendations with respect to their chosen problem. They engage in systematic reflection and take action for change by asking questions or "inquiries", gathering data to explore their inquiry, analysing the data, making changes in practice based on knowledge constructed, and sharing learning with others as part of professional learning communities [43]. Ownership is maybe one of the most important considerations for a successful PI - the teacher must be willing to change his/her classroom practice!

Adopting a PI approach where the teacher acts as a reflective practitioner to inform their own practice has been shown to lead to more sustainable pedagogical impact. In 1999, Cochran-Smith and Lytle [44], investigated three conceptions of teacher learning (knowledge-for-practice, knowledge-in-practice, and knowledge-of-practice) and used them to guide their theoretical perspective of an inquiry stance. This idea describes the positions that teachers take towards knowledge and is separate from inquiry as a project that comes to the end of a cycle as it highlights the building of knowledge over a professional lifespan.

> Teachers and student teachers who take an inquiry stance work within inquiry communities to generate local knowledge, envision and theorize their practice, and interpret and interrogate the theory and research of others. [43]

Dana [45] interprets inquiry stance as a continuous cycle of questioning, systematically studying and improving practice while becoming a natural part of every-day teaching. She highlights the tensions that exist between inquiry stance (a way of being) and the inquiry process to produce practitioner research. In her illustrations of inquiry as a stance, data collection becomes part of teaching, so that inquirer and teacher roles are integrated [45]. A review of over 200 teacher practitioner inquiries, [46] identified patterns in the types of PI questions raised by teachers and organised them systematically into six "passions":

1. Helping the individual child,
2. Desire to improve the curriculum,
3. Desire to improve or experiment,
4. Beliefs about management, teaching and learning,
5. The intersection of teachers' personal and professional identities and
6. Focus on understanding the teaching and learning context

The authors suggest that framing inquiry questions on one of these six passions can help practitioners to focus on specific questions and potential solutions. Like IBL, the process of PI involves a step-by-step process of asking a question about one's own practice, formulating an inquiry plan (usually following discussion and deliberation with other practitioners), implementing methods, collecting evidence from practice, analysing data to find insights, and changing practice or refining the question based on findings [45, 47].

Dyson [48] reported some of the difficulties that teachers encounter in their engagement in practitioner inquiry. Firstly, practitioners may often have different interpretations of the concept of inquiry - as a systematic or an informal process. Secondly, teachers felt a tension between school leadership supporting them in their professional growth and a focus on student performance [48]. Cochran-Smith and Lytle [49] highlighted that inquiries solely focusing on student learning during the teaching period may in fact reinforce the notion of inquiry as a project rather than an inquiry stance. Dana and Yendol-Hoppey [43] also expressed concerns arising from a focus on high stakes exams over student learning outcomes as a barrier to inquiry stance. In addition, [48] outlined concerns over mandating reflection in the PI process that is contradictory to encouraging and facilitating reflective practice in the everyday work of teaching. Rutten [50] recommends that future inquiries include the term 'practitioner inquiry' as a keyword when describing *systematic, intentional studies of their own practice,* to consolidate research in this area.

5. Practitioner Inquiry in the context of Inquiry Based Learning

Practitioner Inquiry (PI) can tackle various topics and challenges that a teacher is faced with. This kind of inquiry is not limited to an educational setting. It is often used as a kind of action research in organizations where employees (= practitioners) want to improve their professional practice. In the ERASMUS + Project Three Dimensions of Inquiry in Physics Education [51] project, two dimensions of inquiry, IBL & PI, reinforce each other by conducting PI in the context of IBL. Though it is not a necessity, the project partners experienced an added value of bringing the two together. Making PI more specific in the context of IBL, provides teachers with a direction and focus and, at the same time, amplifies their teaching methodology of IBL.

The 3DIPhE project concluded that if teachers want to learn something about their teaching, it is important to make students' learning visible. Collecting data or evidence of that learning is crucial. Teachers must become comfortable with using data and evidence as tools in routinely and critically reflecting their own practice (through the process of Practitioner Inquiry). However, teachers often have a misunderstanding about what is meant by this. Collecting data is an essential part of a teachers' role and involves more than the collation of results at the end of the school year. A teacher should begin by articulating what 'it' means to them, then use the tools to enable them to explore the issue. A variety of quantitative and qualitative strategies for collecting data (evidence) should be used, e.g., student work, test scores, notes, interviews, questionnaires focus groups, pictures, journals. Data must be used in a learning-oriented manner to realize any valuable improvement in the learning, as an ongoing process: collecting, analysing, new learnings, changes in practice. Practice cannot be considered effective unless it is responsive to the participating students and promotes their learning. The worth of the co-constructed criteria in practice, therefore, needs to be judged in terms of how students are responding and learning [52]. Students' involvement in inquiry makes it immediate, relevant, differentiated, active, and engaging, therefore it makes sense to share it with the students they teach [53]. An example of PI in the context of IBL from the 3DIPhE Project [54] is presented in Table 3.

Table 3. Example of Practitioner Inquiry in the context of Inquiry Based Learning [54]

Margaret conducted a PI into how her students perceive IBL in physics
Physics teacher Margaret was teaching a group of 4 boys and 14 girls with a humanistic profile. The course was introductory physics at basic level, only 1 hour per week for one school year. As this was the first time the students got introduced to IBL a guided level of inquiry was adopted. Margaret wanted to find out how her students perceive the IBL method during this physics course. Therefore, she applied inquiry-based learning in two topics: The Moon and centrifugal force. The students were very active in class, engaged in experiments, conducted research, discussed their results, and formulated their own conclusions. After completing the two topics Margaret administered a test and immediately after the test (when students did not know the results yet) students were asked honestly to fill in an anonymous survey to answer the question: 'Did the method of IBL help you in taking the test?' It

seemed that all students disagreed. An exemplary response was that ‘the IBL method did not fully help me prepare for the test, although I like that we could come to some conclusions in physics lessons, and they were not boring.’ Discussing these results with her students, it turned out that they did not believe they would learn something using IBL. When preparing for the test, students resorted to using traditional methods: reading the book or even searching the internet. However, what they had studied was not asked at the test, because the test examined inquiry skills like drawing conclusions, interpreting physics phenomena and laws. In fact, the students perceived they were lost during the test. The method of learning and the test were different from what they were used to. However, when Margaret corrected the test, the results showed that the average student grade was 72% which was higher than the average score of 60% obtained in previous traditional tests based on facts and administered after traditional lessons.

Margaret discussed these results with a group of colleagues from her Professional Learning Community (PLC) formed in the 3DIPhE project. She felt that IBL hadn’t worked in her class. During the discussion, the group managed to convince her to continue using IBL, since it had worked, but somehow the students did not realize it. Indeed, students were very surprised with the test results, they somehow realized (and were convinced) that they had learned more when developing inquiry skills, not only acquiring content knowledge as usual. The IBL method was implemented a second time in a topic about radioactive decay. After completing the topic, Margaret asked the students again to fill in the survey about their perceptions of IBL and what they learned. The change was enormous. Many students now agreed when they were asked if IBL supported their learning. Again, Margaret was very surprised, this time positively. When she discussed this change of perception with her students, they admitted that they needed more time to get used to the method. Exemplary responses included 'learning by playing, better acquisition of content knowledge, teaches how to "be up to", remember the lessons, doing experiments by themselves, cooperation between teacher and students.' A few of the students pointed out weaknesses, such as a slight chaos, there were a few students doing nothing, some problems with remembering part of the content.

Margaret finally concluded that whenever you start with IBL, you should not give up after the first trial. If students are not used to the method, they may be very distrustful and lacking confidence in what they acquire. At first, the method looks like only playing and having fun, and in a traditional school system of teaching with the most common method of learning facts and laws by heart, "playing" is considered a waste of time. Such an opinion is embedded also in students' minds. Only being persistent in using IBL can convince students that they learn more with IBL than in traditional format. The method itself is so engaging and interesting that sooner or later the students realize that they learn a lot.

6. Conclusions and Implications

Physics is often presented in schools as a discipline focused solely on “solving problems”, which is often unappealing to students and results in students exhibiting resistance to learning physics. On the other hand, physical phenomena are common in everyday life and vitally important across many industrial and economic sectors. Thus, understanding physics phenomena is one of the most necessary endeavours for today’s learners and society. Addressing this challenge requires teachers and curricula developers to design and adopt new approaches for learning and teaching physics that embody the true nature of this discipline.

Over the past decade, physics education in schools, colleges, universities, and physics curricula have adopted learning goals towards developing student’s scientific abilities, skills, and competences alongside physics-specific knowledge. It is less common, however, for physics programmes to explicitly consider knowledge and skills associated with the application of physics in interdisciplinary contexts and in the wide variety of career settings in which many graduates find themselves (Phys 21: Preparing Physics Students for 21st-Century Careers, [55]). Crosscutting, interdisciplinary connections are becoming important features of the future generation physics curriculum and defines how physics should be taught collaboratively with other STEM courses [56]. Studies report that an integrated approach to STEM education can be effective in supporting students to develop transversal competences such as problem-solving, innovation and creativity, communication, critical thinking, meta-cognitive skills, collaboration, self-regulation, and disciplinary competences [57].

Inquiry Based Learning (IBL) is an active learning method based on a research cycle employed by real researchers in their laboratories. As argued in this chapter, IBL has been shown not only to be successful in raising student motivation and interest in physics and other STEM subjects, but also has proven to be effective in student acquisition and long-term retention of learning. IBL is recognised as an effective method for developing research skills, collaboration, critical thinking and sustaining natural human curiosity. Indeed, IBL is promoted as an important strategy for the reinforcement of positive attitudes towards cooperation with others and lifelong learning.

Practitioner inquiry (PI) involves teachers carrying out systematic, intentional studies of their own practice. Like IBL, PI involves a step-by-step process of asking a question about one's own practice, formulating an inquiry plan (usually following discussion and deliberation with other practitioners), implementing methods, collecting evidence from practice, analysing data to find insights, and changing practice or refining the question based on findings. PI has been promoted as a professional learning model that empowers teachers to make evidence-informed judgements and changes in their professional practice that influence their student learning. [52] advocates that a PI needs to be judged in terms of how students are responding and learning.

Additional benefits have been reported when teachers adopt an inquiry approach of carrying out a PI in the context of IBL. The findings from the PI example presented in this chapter reminds teachers that persistent use of IBL can serve to convince students that they learn more with IBL than in traditional format. The teacher in this example concludes that "the IBL method is engaging and interesting to students and sooner or later the students realize that they learn a lot". Using this type of inquiry approach can support teachers to develop an inquiry stance - a continuous cycle of questioning, systematically studying and improving practice while becoming a natural part of everyday learning and teaching. Developing teachers' confidence and competence in using inquiry approaches can be supported through their participation in professional learning communities with small groups of teachers sharing and reflecting on their own PIs.

Many models of inquiry exist, so it is important to adopt an approach that achieves learning outcomes in terms of knowledge, skills, attitudes, and value for both teachers and students. Carrying out a PI in the context of IBL in physics education can serve to create an inquiry culture in the classroom, with both teachers and students conducting and reflecting on their own inquiries. Student engagement in IBL activities can develop their conceptual understanding, inquiry skills and sense of belonging in physics while teacher engagement in PI can provide them with evidence and insights to inform the design of future learning experiences tailored to their own student's needs.

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