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Inquiry-Based Learning in a Digital Environment for 21st-Century Skills in Physics Course: a Review of Recent Research

Fuja Novitra[1*], Salman Al Farisi[2], Siska Angreni[3]

[1] *Department of Physics, Universitas Negeri Padang, Padang, Indonesia*
[2] *Physics Education Study Program, UIN Sulthan Thaha Saifuddin Jambi, Jambi, Indonesia*
[3] *Faculty of Teacher Training and Education, Universitas Bung Hatta, Padang, Indonesia*
Corresponding author. Email: fujanovitra@fmipa.unp.ac.id

ABSTRACT

Inquiry-based learning (IBL) and 21st-century skills have received significant attention from educational researchers and practitioners in the field of physics education. With numerous studies affirming the positive effects of IBL, an increasing number of researchers are exploring IBL to foster various competencies within schools. However, little is known about how IBL in digital environments can influence students' 21st-century skills. This paper reviews recent literature on IBL and identifies a substantial body of research targeting enhancements in 21st-century skills resulting from IBL in digital settings. Findings indicate that integrating IBL with digital elements holds considerable potential to enrich learning experiences and develop 21st-century skills. The conceptual framework of such learning is grounded in theories of learning such as constructivism, cognitive theory, experiential learning, and connectivism. The instructional structure should be configured to has a balance between scientific processes and technological integration. This study also offers valuable insights for researchers, instructional designers, and educators in the field of physics education involved in the design and implementation of IBL in digital environments.

Keywords: 21st Century Skills; Digital Learning; ICT; Inquiry; Teaching.

I. INTRODUCTION

The rapid development of Information and Communication Technology (ICT) has profoundly influenced and transformed various aspects of society in the 21st century [1], [2], encompassing economic, social, cultural, health, and educational dimensions [3]. The current generation, characterized as "highly mobile" and "always connected," is notably "visually-literate" and "data-literate" due to their engagement with diverse digital platforms. This phenomenon has spurred various educational trends in the 21st century. The lives of this generation are inseparable from technology and the internet, as evidenced by their ubiquitous smartphone usage [4]–[7]. At least three important trends have emerged due to technology disruption in 21st-century education.

At least three significant trends resulting from technological disruption in 21st-century education can be identified. The first trend demands schools to shift from teacher-centered learning to student-centered learning approaches [8] acilitated through constructivist, collaborative, and IBL methods [9], [10]. The second trend involves the integration (infusing and transforming) of ICT into learning activities [11]–[14]. The inclination of youth towards internet-enabled activities necessitates leveraging digital technology in education. Emphasis on developing 21st-century skills among youth can be achieved by providing access to digital technologies (online) [15]. The third trend mandates schools to offer students experiences and opportunities that intellectually stimulate them to acquire 21st-century skills [11], [16]–[19]. These trends underscore the need for 21st-century education to rapidly adapt to technological changes and the demand for new skills. Integrating IBL in digital environments emerges as a potential solution to address these challenges. Through IBL, students engage in deeper and more meaningful learning processes where they are challenged to question, explore, and discover

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answers on their own. Digital environments provide tools and resources that enrich this process, making learning dynamic and interactive.

IBL has long been a focal point in educational research, particularly in efforts to cultivate 21st-century skills. These skills, encompassing critical thinking, creative thinking, collaboration, and communication, are deemed crucial for students to thrive in the rapidly evolving digital era [20]. As technology becomes more pervasive in education, IBL in digital environments emerges as a promising approach to developing these skills. Previous studies have indicated that IBL can have positive effects on learning outcomes, including enhanced conceptual understanding and student engagement [21].

Despite several studies highlighting the positive impacts of IBL, there remains a need for further research exploring whether IBL in digital environments can be applied across various educational levels, which learning theories are relevant as foundations for effective development of IBL in digital settings, what components of inquiry are pertinent to IBL in digital environments, and what combinations of IBL and digital learning are relevant for the development of students' 21st-century skills. Therefore, this research aims to review recent literature on IBL and identify studies focusing on the enhancement of 21st-century skills through the implementation of IBL in digital environments in the field of physics education. This review seeks to provide insights into how technology can be leveraged to strengthen the IBL process and enhance the skills required by learners in the 21st century. With a better understanding of the interaction between IBL and digital technology, it is expected that more effective and innovative learning strategies can be developed to support education in the digital age.

This article aims to fill these gaps by reviewing recent literature on IBL and identifying research focused on enhancing 21st-century skills through the implementation of IBL in digital environments in the field of physics education. The review not only evaluates the effectiveness of IBL in developing these skills but also discusses various learning theories underpinning this concept. Thus, the article offers valuable insights for researchers, instructional designers, and educators involved in the design and implementation of IBL in digital environments.

Literature Review

a. 21st-Century Skills

The issue of 21st century skills has been the main subject in recent years, both among educational researchers and educational policy-making authorities throughout the world. These skills are not developed through conventional learning, but are shifted through ICT-based learning [11], [14]. This means that 21st century skills must develop simultaneously with digital literacy [22]. Digital literacy is attitudes and skills in using digital technology and communication tools to access, manage, integrate, analyze and evaluate information, build new knowledge, create and communicate with others [19], [23].

Therefore, the core skills of the 21st century (creativity, critical thinking, collaboration and communication) are skills that are integrated with digital literacy. Creativity is the skill to use ICTs to generate new ideas, or treat ideas that are familiar in new ways and turn those ideas into products, services or processes that are recognized in a particular domain [24], [25]. Critical thinking is the skill to use ICTs to make judgments and choices of information about information and communication obtained using reflective reasoning and evidence sufficient to support an opinion [26], [27]. Communication is the skill to use ICTs to send information to others and be able to express it [28], [29]. Collaboration is the skill to use ICTs to develop social networks and work in teams to exchange information, negotiate agreements, and make decisions with mutual respect for each other to achieve common goals [30], [31]. Based on this, it seems that the framework of the 21st century skills this requires learning to support the 21st century skills and utilize ICT fully. This certainly will be a challenge for educators to be able to implement it.

b. Inquiry-based Learning

Inquiry is the ability to think and work scientifically that recommended by experts of science and education around the world [9], [32]. IBL is the scientific phenomenon-based learning, students investigate in scientific and authentic to generate hypotheses, make the plan, doing experiments, and analyzed the data they found [33]–[35]. There are three dimensions of thinking in IBL, namely concept maps, data tables, and reasoning maps. Concept maps include the concepts of subject knowledge that underlie problems and the relationships between concepts. The data table records problem information, reflected as a set of key variables and their changes during the observation period. Reasoning map is a representation of the relationship of evidence between hypothesis and data or subject knowledge, each hypothesis is supported or rejected by evidence from the subject's data or knowledge [36]. IBL is essentially a varied process by providing opportunities for students in activities, such as observing, planning questions or hypothesizing, gathering information through books and other sources of information critically, planning investigations or investigations, elaborating what they already know, carry out experiments or experiments, analyze and interpret data, and communicate the results got.

Relating with this 21st century trend, IBL is very effectively implemented with the help of ICTs [37]–[39]. In the 21st century, the information available online is very accessible and very abundant. Networked-based classroom activities provide opportunities for students to gain knowledge and skills, expanding their opportunities for learning, communication, collaboration, and knowledge creation [40]. Therefore, using ICT in IBL enables a variety of investigation activities (such as data collection, data analysis, and communication and discussion of results) that are more complex and "up to date", and learning can accommodate students in developing 21st century skills that needed by themselves.

c. Digital Learning for Physics Course

The learning behavior of this generation, which is entirely different from previous generations in terms of social practices, learning styles, and even cognition, has given rise to digital learning as a solution [41]. Digital learning is a general term used to define learning that utilizes technology to support the learning process, such as online, blended, and mobile learning [42]. The concept of digital learning encompasses the use of online tools and platforms to deliver curricula, facilitate student discussions, and integrate various media to enhance understanding of concepts [43]. One of the main advantages of digital learning is its broader accessibility [44].

With online learning and educational platforms, students can access learning materials from anywhere and at any time [45]. Additionally, this flexibility not only allows for more structured independent learning but also facilitates distance education for students, which can increase student engagement in learning. Thus, digital learning is a teaching and learning process that uses various types of technology devices, such as smartphones, tablets, computers, and others [46]. In the context of physics education, digital learning presents unique opportunities to revolutionize traditional teaching methods [21]. Educational institutions can create specific courses incorporating activities and procedures for students that include searching for information, watching educational videos, completing assignments, taking online exams, and participating in discussions through forums or learning platforms. The transition to digital learning in physics courses offers numerous opportunities to improve access to and the quality of education. Proper utilization of technology and adequate support can make digital learning an effective solution for modern educational trends [47]. Future advancements in artificial intelligence, virtual reality, and augmented reality are expected to further enhance the digital learning experience, making it more immersive and interactive. Digital learning offers many opportunities to improve access to and the quality of education. With proper use of technology and adequate support, digital learning can be an effective solution for current educational trends..

II. METHOD

This research is a literature review using a systematic literature review approach. The research process is carried out to identify and examine relevant studies to collect and analyze data from the research [48], then the results are used to answer research questions [49] and provide guidelines for further research [50]. The stages we carried out in this study were by designing the review, conducting the review, analyzing and writing up the review [50]. Therefore, in this study, we collected and analyzed data from studies relating to IBL in a digital environment to see the relevance of such learning in improving 21st Century Skills.

A search was conducted to find the latest literature on IBL, and the following keywords were used: ("inquiry") OR ("inquiry learning") OR ("inquiry-based learning") OR ("digital inquiry") OR ("inquiry learning 21st century") OR ("networked learning") AND (" technology inquiry). Articles were obtained from three publishers, namely ERIC, Taylor and Francis, and Sciencedirect. Then the journal article was considered based on the minimum Q4 criteria on Scopus Index. The year range is from 2013 to 2023. Of the 120 studies participated in the IBL and 60 studies that met the criteria.

III. RESULTS AND DISCUSSION

General Findings

We searched papers from reputable journals to identified relevant research in the subject. This search resulted in 120 papers related to IBL and 60 papers met the criteria. The papers identified for review were diverse with respect to the age of the participants, elements of learning, learning theory, and learning outcomes. The majority of papers investigated middle education (45.66 %), followed by high education (26,66%), elementary education (25%) and special education (1.66 %) as shown in Figure 1.

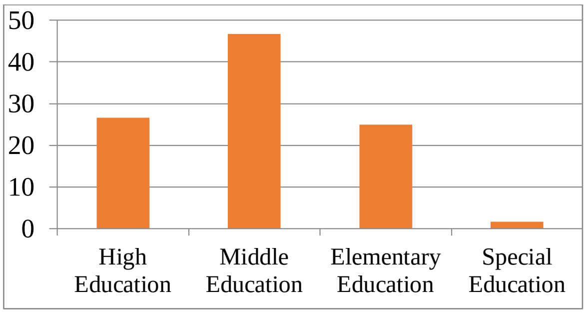

Figure 1. Research objectives at various levels of education

Various types of inquiry were used in the studies. The majority of the papers (42%) used guided inquiry, followed by used open inquiry (30%), and structured inquiry (28%). Thirty-six percent of the studies integrate ICT into IBL and 64% still use traditional IBL. It also examined various kinds of learning outcomes, and each paper presents a variety of learning outcomes. Most research results (64%) reported IBL can improve student competencies in the cognitive and process science domains. Another result (36%) reported IBL can improve 21st century skills.

This research focuses on the IBL in digital environment on the development of 21st century skills. In the initial search, 120 journal articles related to IBL in digital environment and 60 studies fulfilling our criteria. The majority of studies examined secondary education (45.66%), the rest were higher education (26.66%), primary education (25%) and special education (1.66%) as shown in Figure 1. Various types of inquiry were used in studies. Most papers (42%) use guided inquiry, and the rest use open inquiry (30%), and structured inquiry (28%). From this percentage it can be seen that IBL can be applied at all levels by paying attention to 4 levels of inquiry. Open inquiry for higher education, guided inquiry for secondary education, structure and confirmation inquiry for primary and special education [51], [52]. The level is also not absolute. Open inquiry can be used in basic education to improve students 'metacognition skills [53], or guided inquiry is used for basic education to improve students' critical thinking [54], [55], but it is recommended to pay attention to what is the essence of learning to be carried out. If it aims to provide experience in conducting investigations for students with minimal experience, it is necessary to apply confirmation or structured inquiry. If it aims to provide opportunities for conducting structured investigations and interpreting data, it is necessary to apply guided inquiry. If we intend it for students who have experience doing scientific steps, they can use open inquiry.

Inquiry-based Learning for 21st Century Skills

Eighteen papers reported the effect of IBL on 21st century skills development, with the majority focusing on critical thinking skills (Figure 2 and Table 1).

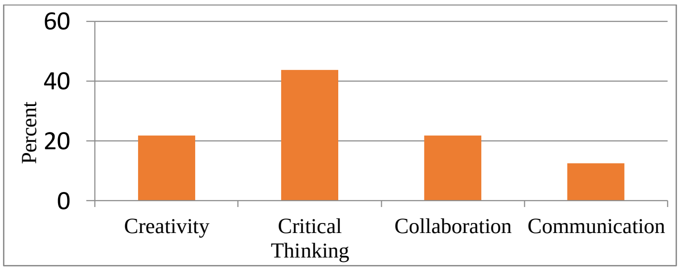

Figure 2. Twenty first century skills targeted as learning outcomes in IBL studies.

Table 1. IBL study for 21st century skills

21st Century Skills	Count of Papers	Study
Creativity	9	[54], [56]–[63]
Critical Thinking	14	[36], [37], [64]–[66], [38], [53], [54], [56], [58], [59], [62], [63]
Collaboration	10	[35]–[37], [51], [57], [62], [63], [67]–[69]
Communication	6	[35]–[37], [51], [57], [63]

Of the 60 papers examined, there are 18 papers that report on the effect of IBL on 21st century skills development. Critical thinking is the most skill that can be improved in the application of IBL, followed by creativity, collaboration, and communication. This is because IBL emphasizes the activity of planning questions that direct students to conduct investigations [36], [37], [70]–[72], [51], [53], [54], [56]–[58], [62], [67]. Therefore, students can really observe the problem as a whole and explain it deeply. Creativity is also a skill that can be developed in IBL. IBL includes the brainstorming process [36], [58] and Make a Plan [51], [53], [54], [56], [71], [72] which is the key to produce original ideas to provide problem solutions, so IBL can be used as a forum for group creativity to produce problem solving ideas. Furthermore, collaboration and communication skills can also be developed through IBL. IBL provides an opportunity for students to do working collaboratively and discussion [36], [62], [67], [68], [70], so students are trained in presenting information clearly and effectively through presentations, demonstrations, and other media, and are trained to help groups solve problems and manage groups. In this context, IBL not only creates academically meaningful learning experiences but also has great potential in equipping students with essential skills needed for success in today's information age. Therefore, the implementation of IBL in the educational curriculum can be an effort to prepare a future generation that is competent and ready to face global challenges.

Learning Theories

Analysis of 18 studies investigated 21st century skills development using IBL, revealed that the majority of studies referred to one or more learning theories. The theory is constructivist, experiential, cognitive, and connectivist as shown in table 2.

Table 2. Learning theories implemented in IBL

Learning Theory	Count of Papers	Study
Constructivist Theory	17	[35], [36], [59], [63], [65]–[69], [37], [38], [51], [53], [54], [56]–[58]
Cognitive Theory	8	[36], [38], [51], [53], [63], [64], [67], [68]
Experiential Theory	18	[36], [37], [62]–[69], [38], [51], [53], [54], [56]–[59]
Connectivism Theory	7	[36], [38], [51], [54], [58], [62], [68]

The next review is about learning theories used in applying IBL for the development of 21st century skills. Based on table 2, Experiential becomes the most dominant learning theory in IBL followed by constructivist, cognitive, and connectivist. Leaning inquiry includes experiential theory, because IBL is experiential learning that gives meaningful learning to students [37], [73]. The constructivist also dominates learning theory in IBL [51], [59], [72], [74], because students are trained to shape their knowledge the construction of observations, observations, and draw conclusions. Cognitive learning theory is very close to IBL [36], [39], [75]. The process of inquiry and problem solving in IBL certainly involves complex cognitive processes, such as finding information and data from various aspects, integrating information with knowledge and producing interconnected solutions. Connectionism learning theory can also support IBL, so that learning is more efficient [38]. Connectionism is a new learning theory that explains how Internet technology can provide opportunities for people to learn and share information on the World Wide Web and among themselves [76]–[80].

Based on these findings, preparing IBL in a digital environment requires a combination of learning theories that support the effective integration of information and communication technology, as well as scientific processes. Integrating learning theories that support the IBL approach in a digital environment can provide students with a more dynamic and relevant learning experience. This also creates opportunities for the holistic development of 21st-century skills.

Inquiry-based Learning Element

Further analysis of 18 studies of IBL for 21st century skills shows that the elements of IBL have their respective characteristics. Table 3 displays the distribution of all elements of IBL. Observation, questioning, collecting data, discussion, and drawing conclusions are the most prominent characteristics of IBL.

Table 3. IBL elements implemented in study.

Element	Count of Papers	Study
Questioning	12	[35], [36], [65], [67], [37], [51], [53], [54], [56]–[58], [62]
Making Hypotheses	11	[35], [36], [67], [53], [54], [58], [60], [63]–[66]
Collecting Data	13	[35], [37], [65], [66], [69], [51], [53], [56], [57], [59]–[61], [63]
Data Analysis	9	[35], [37], [51], [53], [57], [59], [63], [66], [72]
Literature Review	4	[54], [57], [63], [65]
Brainstorming	4	[35], [36], [58], [60]
Make a Plan	7	[35], [51], [53], [54], [56], [60], [69]
Explanations from Evidence	4	[35], [36], [51], [66]
Observation	16	[35], [36], [63], [64], [66]–[68], [70], [38], [51], [53], [56]–[59], [62]
Discussion	13	[35], [36], [65], [67], [68], [38], [51], [53], [54], [57], [59], [62], [63]
Presentation/ Communicate	10	[35], [51], [54], [58], [60], [62]–[65], [68]
Concept Application	5	[35], [36], [62], [67], [68]
Drawing Conclusion	8	[35], [37], [51], [54], [57], [62]–[64]
Reflection	13	[35], [36], [66], [68], [69], [38], [51], [53], [56], [58], [59], [62], [64]

Furthermore, related to the elements of IBL in 18 inquiry studies for 21st century skills, there are several important elements in IBL for 21st century skills: (1) Quesioning, (2) Making Hypotheses, (3) Collecting Data, (4) Data Analysis, (5) Literature Review, (6) Brainstorming, (7) Make a Plan, (8) Explanations from Evidence, (9) Observation, (10) Discussion, (11) Presentation/Communicate, (12) Working Collaboratively, (13) Concept Application, (14) Drawing Conclusion, and (15) Reflection. Each of these elements not only reflects the commonly used practices in IBL but also underscores the importance of integrating these elements in developing critical thinking skills, creative thinking skills, communication, and collaboration necessary in the current information age [81], [82]. By understanding the distribution and role of each of these elements, educators can design more effective and meaningful learning experiences for their students.

Based on these results, these elements can be reduced to several stages: (1) Orientation, consisting of Questioning, Making Hypotheses, and Making a Plan (Open Inquiry); (2) Exploration, consisting of Collecting Data, Data Analysis, Literature Review, Explanations from Evidence, and Observation; (3) Concept Construction, consisting of Discussion, Presentation/Communication, Working Collaboratively, and Concept Application; and (4) Closure, consisting of Drawing Conclusions and Reflection. These stages reflect a structured framework for IBL. In the Orientation stage, students are encouraged to ask questions, formulate hypotheses, and design plans (in the form of open inquiries). This provides a strong foundation for initiating the inquiry process in an organized manner. The Exploration stage involves collecting data, analyzing data, conducting literature reviews, explaining evidence, and making observations. This is the stage where students gather information and begin to develop a deep understanding of the topic they are investigating. Then, the Concept Construction stage leads to discussion, presentation/communication, collaborative teamwork, and the application of concepts. This allows students to develop communication, collaboration, and practical application skills of what they have learned in a broader context. Lastly, the Closure stage includes drawing conclusions from the inquiry results and reflecting on the learning process. This helps students summarize their findings, evaluate their learning experiences, and identify lessons for the future. By using this framework, educators can design comprehensive and in-depth learning experiences, enabling students to develop not only knowledge about specific topics but also essential critical thinking, creative thinking, communication, and collaboration skills necessary in the information era.

The Roles of Digital Learning Aspects in Inquiry-based Learning for Physics Course

There are 16 studies that explain the benefits of digital learning activities in IBL that can be used in physics course to develop students' 21st century learning, as shown in Table 4.

Table 4. The Roles of Digital Learning Aspects in IBL

Element	Count of Papers	Study
Information sharing	7	[55], [57], [62], [63], [67], [76], [83]
Information search	6	[35], [52], [57], [62], [67], [84]
Knowledge construction	8	[36], [52], [55], [57], [63], [65], [67], [75]
Problem-solving experience	9	[35], [36], [52], [57], [63], [65], [67], [75], [83]
Digital collaboration	9	[37], [38], [57], [62], [63], [67], [75], [76], [83]
Digital communication	9	[37], [38], [57], [62], [63], [67], [75], [76], [83]

There are 28 papers that investigate the relevance of IBL in digital environment for 21st Century Skills. From the 28 papers, there are 16 studies that explain the benefits of digital learning aspects in IBL that can be used in 21st century learning, namely information search, knowledge construction, problem-solving experience, digital collaboration, and digital communication. The aspects in digital learning plays an important role in preparing students to face the challenges of 21st century learning [85], [86]. This study proves that digital technology plays a significant role in enhancing IBL experiences. Based on the analysis of the study, digital technology in physics education context facilitates various crucial aspects of modern IBL. It was found that technology supports students in efficiently sharing information, conducting in-depth information searches, and building knowledge through various digital tools and resources. Additionally, technology enriches students' experiences in solving complex problems and facilitates effective collaboration and communication within the learning context [87], [88].

This can be accommodated by leveraging various learning platforms, such as Learning Management Systems (LMS) [89], [90]. This approach not only enhances students' critical and analytical thinking skills but also prepares them to meet the demands of an ever-changing global society. Consequently, the integration of digital technology in education not only expands access to knowledge but also enriches and deepens the learning process, resulting in self-directed learners who are actively engaged in the pursuit of knowledge.

Based on the synthesis of these findings, there is an indication that an IBL concept in a digital environment for physics course offers a structured approach to developing 21st-century skills, balancing scientific processes with the utilization of technology. By leveraging the orientation stage for questioning, hypothesizing, and planning, students initiate the inquiry process in an organized manner. The exploration stage then allows them to collect data, analyze information, and deepen their understanding through literature review and evidence-based explanations. Then, the concept construction stage encourages discussion, presentation, collaboration, and the application of concepts in broader contexts. The closure stage aids students in drawing conclusions from their findings and reflecting on their learning. These stages are facilitated by digital platforms, enabling the integration of technology to enrich and deepen the students' learning experience. Thus, this learning concept is not only relevant in the current educational context but also crucial for developing essential skills needed for the future.

IV. CONCLUSION

In conclusion, IBL in a digital environment for physics course should be developed based on a combination of experiential, constructivist, cognitive, and connectivist learning theories. This approach can provide benefits in information search, knowledge construction, problem-solving experience, digital collaboration, and digital communication. This learning can be carried out in several stages: orientation (questioning, making hypotheses, making a plan (open inquiry)), exploration (collecting data, analyzing data, literature review, explanations from evidence, observation), concept construction (discussion, presentation/communicating, working collaboratively, concept application), and closure (drawing conclusions, reflection). These stages are facilitated by digital platforms, creating complex learning experiences both in digital and face-to-face. Thus, this learning concept is not only relevant in the physics education context but also crucial for developing essential skills needed for the future. This report shows optimism about the potential of IBL in a digital environment for the development of 21st-century skills in the field of physics education. Although this study has its limitations, this learning concept is believed to be a viable answer to the challenges of 21st-century education.

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