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Pogil as a Framework for Developing 21st-Century Skills in Chemistry Education

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ABSTRACT: This article examines Process-Oriented Guided Inquiry Learning (POGIL) as an effective framework for teaching chemistry in upper secondary education within a digital learning environment. The paper outlines the theoretical foundations of POGIL and highlights its distinctions from other instructional approaches, including Problem-Based Learning (PBL), Project-Based Learning (PrBL), and Inquiry-Based Learning (IBL). A structured implementation model is proposed, encompassing group role distribution, worksheet design, and integration of digital tools such as PhET and Google Docs. An illustrative lesson on "Chemical Equilibrium" demonstrates how POGIL fosters the development of 21st-century competencies—critical thinking, creativity, communication, and collaboration (the "4Cs"). The study identifies challenges and prospects for implementation and argues that combining POGIL with digital technologies significantly enhances student motivation and learning outcomes.

KEYWORDS: POGIL, chemistry education, digital learning environment, 21st-century skills, 4Cs, critical thinking, creativity, communication, collaboration, inquiry-based learning.

INTRODUCTION

Modern education requires not only the assimilation of subject knowledge but also the formation of key 21st-century skills. These competencies, often referred to as the "4Cs," include critical thinking, creativity, communication, and collaboration [1]. In the context of the digital transformation of schools, there arises the need for the introduction of pedagogical methods that effectively contribute to the development of these skills. The project-based method gives the learning process a learner-centered and activity-oriented character, and corresponds to modern educational goals [2]. One such technology is Process-Oriented Guided Inquiry Learning (POGIL)—an approach originally developed for the teaching of chemistry in the United States, which has proven its high effectiveness both in upper secondary classes and in university practice. POGIL represents a learner-centered methodology, in which students work in small teams, and the teacher acts in the role of facilitator [3].

LITERATURE REVIEW

Beginning as a process developed by a group of chemistry professors who sought to help their students better understand the concepts of general chemistry, the POGIL project has transformed into a dynamic organization of dedicated educators who assist one another in transforming classrooms and improving student achievement, develop instructional materials to support this process, conduct research expanding knowledge about teaching and learning, and provide professional development and collegiality—from elementary school teachers to college instructors [4].

The analysis of the POGIL methodology and its practical application in teaching high school chemistry showed that in order to achieve this goal, the following tasks were set: (1) to examine the theoretical foundations of POGIL and its place among other modern educational approaches; (2) to propose a structured methodology for its implementation, including the use of digital tools; and (3) to demonstrate how lessons using the POGIL method directly contribute to the development of the 4Cs skills.

POGIL is an inquiry-based approach in which students, working in small groups, actively construct new concepts by analyzing models, data, and simulations [5]. The teacher, from a traditional lecturer, turns into a facilitator, guiding student teams in the learning process without providing direct answers. This transition promotes deeper assimilation of material and significantly increases student engagement [6].

POGIL differs from other popular pedagogical methods in several key aspects. Unlike Project-Based Learning (PBL), POGIL assumes short, structured activities designed for a single lesson rather than a long-term project spanning several weeks. Although POGIL is similar to Problem-Based Learning (PrBL) in its focus on students' independent discoveries, it is more structured: learners follow a clearly defined sequence from model analysis to concept formulation. Finally, although POGIL is a

form of Inquiry-Based Learning (IBL), it is distinguished by the strict distribution of roles among group members and the use of specially designed worksheets [7]. This unique combination of inquiry-based and cooperative learning makes POGIL a powerful tool for the formation of the 4Cs skills.

RESEARCH METHODOLOGY

The effective implementation of POGIL in teaching chemistry relies on two main components: structured group work and carefully designed worksheets, whose effectiveness can be enhanced through a digital learning environment. Creatively organized lessons can also serve as a tool for developing students' scientific literacy [8]. Scientific literacy is understood not only as the knowledge of facts but also as the ability to apply scientific methods in real life, critically analyze information, build arguments based on evidence, and make well-informed decisions [9].

Group Organization and Role Distribution. Student teams, which as a rule consist of four persons, are assigned specific roles to ensure active participation and shared responsibility [10]:

Manager: monitors the progress of the group's work, adherence to the schedule, and manages time.

Recorder: records the group's answers and reasoning on the worksheet.

Presenter: presents the group's conclusions and addresses the instructor for clarification.

Quality Control: checks the team's work for accuracy and logical consistency.

Such a distribution of roles guarantees that each student is an active participant and that the team functions as a cohesive unit.

POGIL Worksheet. A POGIL worksheet guides students through a three-stage learning cycle:

1.Explore: Students analyze a model—this may be a table, graph, or simulation—in order to identify patterns and trends.

2.Concept Invention: Students use the identified patterns to define and formulate new scientific concepts.

3.Application: Students apply the new knowledge to solve problems, make predictions, or justify their reasoning.

Integration of Digital Tools. The effectiveness of POGIL can be significantly enhanced through the integration of digital tools:

Simulations: Platforms such as PhET and ChemCollective can provide interactive models for the Explore stage, allowing students to manipulate variables in real time and observe chemical phenomena.

Collaboration: Google Docs and other collaborative platforms can be used at the Concept Invention stage for joint note-taking and collective reasoning in real time.

Learning Management Systems (LMS): Platforms such as Google Classroom can facilitate the distribution and collection of worksheets as well as serve as a hub for group communication.

Visualization: Tools such as Canva can be used at the Application stage, enabling students to create visual representations of concepts or processes.

RESULTS AND DISCUSSION

Let us consider the application of this methodology in studying the topic "The Periodic Law of D.I. Mendeleev and the Periodic System of Chemical Elements."

The entire content of the topic "The Periodic Law and the Periodic System of Chemical Elements by D. I. Mendeleev" consists of two closely interconnected major blocks of information: data on the periodic change in the properties of chemical elements and substances depending on the increase in atomic masses of the elements, and data on the structure of atoms of the elements.

When studying the periodic system, the analysis begins with the periodic recurrence of the properties of elements arranged in order of increasing atomic mass, leading students to the formulation of the definition of the periodic system given by D. I. Mendeleev. The next stage involves studying the structure of the atom and establishing connections between the acquired knowledge and the phenomenon of periodicity. The topic concludes with a generalization and an examination of the creative work of D. I. Mendeleev.

When studying this topic, the following educational, developmental, and upbringing objectives are set

Educational objective – to provide students with knowledge about the structure of the periodic system, to teach them how to work with the periodic table of elements, to classify chemical elements, and to predict their properties.

Developmental objective – to teach students to identify essential features when characterizing elements, simple substances, and chemical compounds; and, based on knowledge of the periodic system of elements, to determine the type of chemical bond and the characteristic general properties of substances.

Upbringing objective – while studying chemistry, students should understand the significance of the periodic law and the periodic system of elements developed by D.I. Mendeleev for the advancement of science and industry; they should grasp the idea of the material unity of chemical elements and substances, as well as the transition from quantitative changes to qualitative ones

Also, according to the National Curriculum of the Republic of Uzbekistan, developed for the modernization of school education and including updated syllabi and teaching methods, the following competencies are highlighted, which 8th-grade students should acquire when studying this topic.

Scientific competence – the ability to analyze, from a scientific perspective, the periodic system, the periodic law, natural families of elements, electronegativity, and the classification of elements.

Practical competence – the ability to create a model of the periodic system based on the periodic law, as well as models of crystal lattices, taking into account the relationship between the structure of a substance and its properties [11-14].

In accordance with the above-mentioned didactic objectives and methodological recommendations, we will develop a worksheet based on POGIL.

Demonstration of POGIL: The Periodic Law.

To illustrate the methodology, an example of a POGIL lesson on the topic "Periodic Law" is provided.

Explore:

Model: A fragment of the periodic table (e.g., Li–Ne and Na–Ar) including atomic number, atomic radius, and ionization energy values.

Guiding questions:

Describe how the atomic radius changes across a period from left to right.

What happens to the ionization energy in the same direction?

What trends do you observe when moving down a group?

Concept Invention:

Based on your observations:

Formulate a definition of the Periodic Law.

How is the atomic number related to the recurrence of chemical properties?

Why is the atomic number a more consistent organizing principle than atomic mass?

Application:

Task: A blank position appears in the periodic table below aluminum. Predict what properties this unknown element would likely have (e.g., atomic radius, ionization energy, type of oxide).

Use scientific reasoning (*Claim, Evidence, Reasoning*) to justify your prediction, referring to the periodic trends you have just formulated.

Use scientific reasoning (Claim, Evidence, Reasoning) to explain your prediction, referring to the equilibrium principles you have just formulated.

The structured nature of the POGIL methodology directly contributes to the development of the 4Cs of 21st-century skills:

Critical Thinking: Students must analyze models, formulate hypotheses, and evaluate their own reasoning. The role of Quality Control specifically encourages critical analysis of the group's work.

Creativity: Students develop creativity by formulating original hypotheses at the Concept Invention stage and by creating unique visual representations or arguments at the Application stage [15].

Communication: POGIL lessons require constant dialogue and exchange of information within the group. The role of Presenter obliges students to clearly formulate their reasoning and defend their group's conclusions.

Collaboration: Shared responsibility and clearly defined roles guarantee that each participant contributes to the success of the team, promoting effective teamwork and mutual accountability. Enhancing students' collaboration, communication, critical thinking, and creative thinking skills, effectively organizing chemistry lessons in schools, and using modern pedagogical technologies and innovative methods lead to an increased interest in chemistry among students [16].

CONCLUSION

POGIL is an effective methodology for teaching chemistry that harmoniously combines the acquisition of subject knowledge with the development of essential 21st-century skills. The use of a digital learning environment further enhances its impact, providing students with an interactive, collaborative, and engaging experience. Although the implementation of POGIL is associated with certain challenges, such as the need for comprehensive teacher training and the development of high-quality worksheets, research shows that its integration with digital tools significantly increases student motivation and improves learning outcomes]. The expansion of POGIL's application in chemistry teaching will not only raise academic performance but also better prepare students for lifelong learning and professional success in the future.

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