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THE EFFECTIVENESS OF USING VIRTUAL LABORATORIES IN CHEMISTRY EDUCATION FOR DEVELOPING STUDENTS' EXPERIMENTAL SKILLS

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Abstract. The development of experimental skills is a fundamental objective of chemistry education because students need to understand not only theoretical concepts but also how chemical knowledge is applied through observation, measurement, experimentation, and analysis. Traditional laboratory activities provide valuable opportunities for students to develop these skills; however, they can sometimes be limited by factors such as cost, availability of equipment, safety concerns, limited laboratory time, and differences in students' prior experience. Virtual laboratories have emerged as a technological approach that can complement traditional laboratory instruction. They allow students to perform simulated experiments, manipulate variables, observe chemical phenomena, collect data, and repeat procedures in a safe and flexible environment. This article examines the effectiveness of virtual laboratories in developing students' experimental skills in chemistry education.

Keywords: virtual laboratories, chemistry education, experimental skills, science education, laboratory instruction, digital learning, scientific reasoning

Introduction. Chemistry is an experimental science in which theoretical knowledge is closely connected with practical investigation. Students studying chemistry are expected to understand chemical concepts while also developing the ability to conduct experiments, use laboratory equipment, make accurate observations, record measurements, analyze results, and draw scientifically justified conclusions. Therefore, the development of experimental skills is an important component of effective chemistry education.

Traditionally, experimental skills have been developed through hands-on laboratory activities. Students work directly with chemicals and laboratory equipment, follow experimental procedures, observe reactions, collect data, and evaluate their results. Although this approach remains important, traditional laboratories may present several challenges. Schools and universities may have limited access to specialized equipment or chemicals, laboratory activities may be expensive, and some experiments involve substances or procedures that present safety risks. In addition, limited laboratory time can restrict students' opportunities to repeat experiments and correct mistakes.

The development of digital technologies has created new possibilities for laboratory instruction. Virtual laboratories provide simulated environments in which students can conduct experiments using computers or other digital devices. These environments can reproduce many aspects of laboratory work, including selecting equipment, measuring substances, changing experimental conditions, observing reactions, and analyzing experimental data.

The growing use of virtual laboratories raises an important educational question: to what extent can they contribute to the development of students' experimental skills? This article explores this question by examining the educational benefits, limitations, and appropriate applications of virtual laboratories in chemistry education.

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Virtual laboratories in chemistry education. A virtual laboratory is a computer-based learning environment that simulates laboratory experiments. Depending on the platform, students may be able to manipulate virtual chemicals, operate laboratory instruments, change experimental variables, record observations, and obtain experimental results.

Virtual laboratories can be used before, during, or after traditional laboratory instruction. For example, students can complete a virtual experiment before entering a physical laboratory. This can familiarize them with the experimental procedure and equipment and reduce uncertainty during the actual experiment. Alternatively, a virtual laboratory can be used after a practical session to allow students to repeat an experiment or investigate variables that were not explored during the physical laboratory.

One of the major advantages of virtual laboratories is their flexibility. Students can often access simulations outside scheduled laboratory hours and repeat experiments several times. This provides opportunities for individual learning and allows students to learn from unsuccessful attempts without consuming additional physical resources.

Development of experimental skills. Effective experimentation begins with appropriate planning. Students need to identify the purpose of an experiment, select appropriate equipment and materials, determine relevant variables, and establish a logical sequence of procedures.

Virtual laboratories can support these skills by allowing students to plan experiments in an interactive environment. Some simulations require students to select appropriate equipment or determine which substances and quantities should be used. Students can therefore practice making experimental decisions before working in a physical laboratory.

Virtual environments can also make the consequences of poor experimental planning immediately visible. For example, students may select an inappropriate concentration or fail to control an important variable and then observe how this affects the experimental outcome. Such experiences can encourage students to understand the relationship between experimental design and results.

Experimental work requires students to follow procedures accurately. In chemistry, this can involve measuring liquids, preparing solutions, using indicators, controlling temperature, operating instruments, and following safety procedures.

Virtual laboratories can provide repeated practice with experimental procedures. Students can perform the same simulated procedure several times without using additional chemicals or equipment. This repetition may help students become more familiar with the logical sequence of experimental operations.

However, virtual practice differs from physical practice. A simulation cannot completely reproduce the physical coordination required to hold laboratory glassware, manipulate a pipette, operate a burner, or handle chemicals. Therefore, virtual laboratories are better understood as a complement to, rather than a complete replacement for, hands-on procedural training.

Observation and measurement. Observation is a central component of experimental science. Chemistry students must learn to recognize changes such as color variation, precipitate formation, gas production, temperature changes, or changes in other measurable properties.

Virtual laboratories can provide students with controlled opportunities to observe chemical phenomena. Because simulations can display results consistently, they may also help students focus on identifying relevant observations and distinguishing significant experimental changes from irrelevant information.

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In addition, virtual laboratories can provide numerical measurements and allow students to practice recording and organizing experimental data. Students can learn to construct tables, identify patterns, and compare measurements obtained under different experimental conditions.

Collecting data is only one part of experimental work. Students must also analyze their results and determine what the evidence means.

Virtual laboratories can support data-analysis skills by allowing students to repeat experiments and generate multiple sets of results. Students can compare data obtained under different conditions and use graphs, calculations, or statistical methods to interpret their findings. For example, in a virtual titration experiment, students may change the concentration of a solution and observe how the volume required to reach the endpoint changes. They can then analyze the relationship between the variables and use the results to test chemical principles.

Repeated experimentation can be particularly useful because students have opportunities to identify errors and investigate why different experimental conditions produce different results.

Problem-solving and scientific reasoning. Experimental chemistry involves more than following instructions. Students should be able to identify problems, formulate hypotheses, modify experimental conditions, and evaluate evidence.

Virtual laboratories can create opportunities for inquiry-based learning. Instead of simply following a fixed procedure, students can be asked to determine which variables should be changed to answer a particular research question.

For example, students could investigate how temperature affects reaction rate by conducting a series of virtual experiments at different temperatures. They can formulate a hypothesis, conduct the experiments, collect data, and determine whether the evidence supports their hypothesis.

This type of learning can encourage students to view experimentation as a process of investigation rather than simply as a sequence of instructions.

Advantages of virtual laboratories. Several characteristics make virtual laboratories useful in chemistry education.

First, safety is an important advantage. Students can investigate potentially dangerous reactions without being exposed to hazardous chemicals or equipment. This is particularly useful when introducing experiments that would otherwise require specialized safety precautions.

Second, virtual laboratories provide repeatability. Students can repeat experiments multiple times, change variables, and compare results. In a physical laboratory, repeating an experiment may require additional chemicals, equipment, time, and supervision.

Third, virtual laboratories can improve accessibility. Students who cannot regularly access a physical laboratory can participate in simulated experiments using digital devices. This can be particularly valuable in educational settings with limited laboratory infrastructure.

Fourth, simulations can provide immediate feedback. Students can often observe the consequences of their decisions quickly, helping them recognize procedural errors and understand relationships between variables.

Finally, virtual laboratories can promote student-centered learning. Rather than relying exclusively on teacher demonstrations, students can actively manipulate experimental conditions and explore chemical concepts at their own pace.

Despite their potential benefits, virtual laboratories have important limitations. The most significant limitation is that simulations cannot fully reproduce the physical experience of laboratory

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work. Students may understand how a pipette or burette works in a virtual environment but still require physical practice to develop the motor skills needed to use the equipment correctly.

Another limitation is that virtual experiments may simplify the uncertainty and complexity of real laboratory work. Physical experiments involve measurement errors, equipment limitations, contamination, unexpected reactions, and other sources of variability. Simulations may not always represent these factors accurately.

There can also be technological barriers. Students and institutions need appropriate computers, software, internet access, and technical support. In addition, the quality of virtual laboratories varies considerably between platforms.

Finally, virtual laboratories should not be regarded as automatically effective simply because they use digital technology. Their educational value depends on how they are designed and integrated into the curriculum. A simulation that merely asks students to click through predetermined steps may provide less educational value than an interactive simulation that requires students to make decisions, interpret evidence, and solve experimental problems.

Integrating virtual and traditional laboratories. The most productive approach may be to combine virtual and hands-on laboratory experiences. These approaches can serve complementary purposes.

A virtual laboratory can be used as a pre-laboratory activity to introduce students to equipment, procedures, safety considerations, and experimental objectives. Students can then enter the physical laboratory with greater familiarity and confidence.

During or after the physical laboratory, students can use simulations to explore additional variables or repeat experiments that were difficult to perform in the classroom. This combination provides students with both conceptual and practical experience.

For example, students could first complete a virtual acid-base titration, where they learn how to select equipment, add a solution gradually, identify an endpoint, and record measurements. They could then perform the titration using real laboratory equipment. Finally, they could return to the virtual environment to investigate how changes in concentration affect the titration curve.

Such an approach connects digital simulation with physical experimentation and allows each learning environment to contribute different aspects of experimental competence.

The role of the teacher. The effectiveness of virtual laboratories also depends on the role of the teacher. Teachers should provide clear learning objectives and guide students in interpreting their experimental experiences.

Instead of treating a virtual laboratory as an independent activity, teachers can use questions that encourage students to explain their decisions and evaluate their results. For example:

- Why did you select this experimental procedure?
- Which variable should be controlled?
- What would happen if the concentration were increased?
- What evidence supports your conclusion?
- What sources of error could affect the result?
- How would the experiment differ in a physical laboratory?

These questions encourage students to move beyond simply completing a simulation and toward developing scientific reasoning.

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Assessment is also important. Students' virtual laboratory activities can be evaluated through laboratory reports, data-analysis tasks, reflective questions, experimental-design assignments, or practical assessments. Combining different forms of assessment can provide a broader picture of students' developing experimental competence.

Research discussion. Virtual laboratories have considerable potential to support the development of experimental skills in chemistry education. They provide students with opportunities to practice experimental procedures, manipulate variables, collect data, analyze results, and engage in scientific problem-solving. Their flexibility, safety, repeatability, and accessibility make them particularly useful as complementary tools.

At the same time, the distinction between virtual and physical experimental skills should be recognized. A student may develop strong conceptual understanding and experimental reasoning through simulations without developing all of the physical skills required to work safely and accurately in a laboratory. Consequently, replacing all hands-on experiences with virtual simulations may leave important aspects of practical competence underdeveloped.

The educational value of virtual laboratories is therefore likely to depend on the learning objectives and the way the technology is implemented. Virtual laboratories are particularly useful when students need repeated opportunities to explore variables, analyze data, or understand complex processes. Physical laboratories remain essential when students need to develop hands-on skills involving real equipment, materials, measurements, and laboratory safety.

A blended approach can combine the strengths of both environments. Virtual laboratories can prepare students for practical work and provide additional opportunities for experimentation, while physical laboratories can provide authentic experience with equipment and materials.

Ultimately, effective chemistry education requires a balance between theoretical understanding, digital experimentation, and authentic hands-on laboratory experience. The combination of these approaches can provide students with broader opportunities to develop the practical, analytical, and scientific skills required for successful engagement with chemistry.

Conclusion. Virtual laboratories represent an important technological development in chemistry education and can contribute significantly to the development of students' experimental skills. They provide safe and flexible environments in which students can practice experimental procedures, investigate variables, collect and analyze data, and develop scientific reasoning.

However, virtual laboratories should not be viewed as a complete substitute for hands-on experimentation. Their main educational value lies in complementing traditional laboratory instruction. When carefully integrated into the curriculum and supported by appropriate teacher guidance, virtual laboratories can provide additional opportunities for students to practice and reflect on experimental processes.

References

1. de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. Science, 340(6130), 305–308.
2. Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. Science Education, 96(1), 21–47.

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http://houghtonstreetreview.com/index.php/hsr

3. Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. Learning and Instruction, 21(3), 317–331.
4. Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers & Education, 87, 218–237.
5. Tatli, Z., & Ayas, A. (2013). Effect of a virtual chemistry laboratory on students' achievement. Educational Technology & Society, 16(1), 159–170.
6. Makransky, G., Thisgaard, M. W., & Gadegaard, H. (2016). Virtual simulations as preparation for lab exercises: Assessing learning of key laboratory skills in microbiology and improvement of essential learning outcomes. PLOS ONE, 11(6), e0155895.