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# Physics virtual laboratory: an innovative media in 21st century learning

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# Physics virtual laboratory: an innovative media in 21st century learning

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**Abstract.** Despite Virtual Laboratory (VL) in 21st century Physics learning is commonly used, but its development which is appropriate with theories and concepts is still a lacking. VL is a media to explain abstract concepts and minimize misconceptions. If VL is applied in Physics instruction, a better understanding of Physics theories and concepts is needed. This development study aims to 1) map important components for creating Physics Virtual Laboratory (PVL), 2) create PVL innovation which is appropriate with theories and concepts of Physics, and 3) design the PVL sketch and animation. This study uses an instructional design of Morrison, Ross, and Kemp to create the PVL. Isobaric process in Thermodynamics is provided as the topic. The findings of the study are 1) PVL consists of some components, i.e. basic competence and indicator, video, experiment goals, virtual experiment, and problems, 2) Thermodynamics is applied for developing the PVL, and 3) the final sketch is designed using Corel Draw and Adobe Illustrator, while the animation is created by Adobe Flash. Further study is recommended to implement the PVL to other Thermodynamics processes, such as isothermal, isochoric, or adiabatic.

## 1. Introduction

Innovation is absolutely needed to improve the quality of education, particularly integrating technology in 21st century Physics learning. Abstract topics, such as Kinetic Theory of Gases and Thermodynamics, can be modelled using computer software to get better understanding and minimize misconceptions [1]. Virtual Laboratory (VL) is one example [2–6]. Many of these VLs have been developed to assist learning process. But some of them are lacking in theories and concepts. This is because the VLs are not real or created with a software, so they are prone to some misconceptions. The media that is expected to reduce misconceptions is actually vulnerable to the misconceptions itself. However, the VL still needs to be developed as an alternative learning media. So, the development of the VL should be done carefully in accordance with appropriate theories and concepts, as well as reviewed supporting components to create better quality of the VL.

Based on previous studies, there are several advantages of applying the VL, such as creates active learning, can be used many times, replaces unavailable experiment tools in laboratory, and applies preliminary experiment before the real one [1,2,7–9]. Time management is properly needed to apply it in leaning process [2]. The VL can be supported by several components, such as video, animation, texts, audio, and problems [1,7–10]. Several buttons, such as home, forward and backward options, can be added in each screen [3]. Thus, this study aims to create VL innovation which is appropriate with Physics theories and concepts (PVL). Meanwhile, isobaric process in Thermodynamics is chosen as the focus topic.

## 2. Method

Instructional design of Morrison, Ross, and Kemp is implemented to create the PVL. It consists of instructional problems, learner characteristics, task analysis, instructional objectives, content sequencing, instructional strategies, designing the message, development of instruction, and evaluation instruments [11]. These steps can be used simultaneously or individually and may start from any step [12]. Although not all of the steps must be applied [13], this study uses all of the nine steps.

## 3. Result and discussion

The PVL in this study is produced via nine steps of Morrison, Ross, and Kemp. These specific steps structurally lead to a better PVL. In this part we layout the results of this study and also discuss them based on the nine steps by Morrison, Ross, and Kemp.

### *3.1. Instructional problems*

Kinetic Theory of Gases and Thermodynamics are usually taught by lecturing without any demonstrations or experiments involved. This is because these topics describe gases as a large number of particles. However, no one can actually see particles and that is the problem. Previous studies show that the best way to learn science is by doing the science [14,15]. But in these topics, if students should do an experiment, they have to do it by virtual experiment. The experiment is designed by animation and illustration to describe the intended concepts. But not all the experiments have been created with the appropriate theories and concepts. Even some of them are lacking. Books actually facilitate all theories and concepts, but not animation, even with virtual experiments. Students may use digital media such as PVL to get better understanding of these topics.

### *3.2. Learner characteristics*

Kinetic Theory of Gases and Thermodynamics are included in $11^{th}$ grade senior high school Physics in Indonesia. So, the target audience is students aged 16 to 18 years old. This ages are expected to have enough skills for mastering and applying technology to support their learning. However, an online survey on April 2018 using Google Forms of (https://goo.gl/forms/grVEhWHTQ0r7xPe92) to 319 students shows that only 15% of the respondents use digital media to support their Physics learning, and the rest of them still use printed books. Therefore, students' awareness to use digital media is still low. To familiarize the students with digital media and Thermodynamics process, this study creates a VL innovation consisting of virtual experiment and several supported components. Appropriate theories and concepts are implemented in this development.

### *3.3. Task analysis*

This study is focused on isobaric process. Task analysis is described from basic competence of Gases Kinetic Theory. This is because all the Thermodynamics process involving particles' movement is included in this topic. The basic competence of this study is presenting tasks related with Kinetic Theory of Gases and its physical meaning. The indicator, i.e. doing isobaric process experiment, is derived from it. The task analysis is placed in PVL menu called Basic Competence and Indicator. It is used to explain to students and users about what will be learned from the PVL.

### *3.4. Instructional objectives*

Instructional objectives are derived from the indicator. These objectives are involved in explaining and analysing correctly the quantities and units of isobaric process. These allow students to understand isobaric process through the virtual experiment. Moreover, students can identify the quantities and units. These consist of pressure (atm and $N/m^2$), volume (litres and $m^3$), and temperature (kelvin), while $R$ and $N_A$ are constants in this process. $R$ is the gas constant and $N_A$ is Avogadro's number ($6.02\times10^{23}$) [16].

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**Table 1.** Basic competence, indicator, and objectives of isobaric process experiment.

| Basic Competence | Indicator | Objectives |
|---|---|---|
| presenting tasks related with Kinetic Theory of Gases and its physical meaning | doing isobaric process experiment | explaining isobaric process correctly |
| | | analysing the quantities and units of isobaric process correctly |

*3.5. Concept sequencing*

In order to provide students with the concepts of isobaric process, the PVL menus are sequenced as follows:

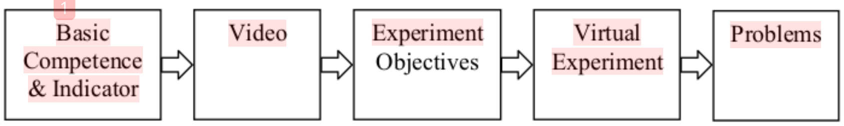


**Figure 1.** The sequence menus of PVL.

Video. Video can be used to attract students' attention, give information concerning specific concepts, apply as an alternative reading, and provoke students for asking questions [3,10,17]. The video should be presented in short duration and involves attractive demonstration [3]. In this study, the purpose of the video is to show students about isobaric process phenomena before they do the experiment. The video is downloaded from The Sci Guys-Science at Home (*https://www.youtube.com/watch?v=NplVuTrr59U*) with the topic of Charles' Law of the Ideal Gases. It explains about an expanding balloon placed on boiling water, while leaving an inflated balloon in a freezer will make the size of the balloon smaller. The video is chosen because the phenomena and explanation are separated, so it may be cut easily. Students have to arrange a hypothesis before they obtain the correct explanation. Hypothesis is part of integrated science process skills. This skill allows students to state their tentative explanation about the phenomena [18]. The real duration of video is 5:12, but it is cut from 00:58 to 02:12. So the duration time is 1:14.

Virtual experiment. The experiment is inspired from PhET Colorado (*https://phet.colorado.edu*) with topics of Balloons and Buoyancy, Gas Properties, State of Matter, and State of Matter Basics. Experiment tools, both in PVL and PhET, are almost the same. The tools consist of floor pump, piston pipe, piston cover, tripod, digital thermometer and barometer. Calculation with the appropriate theories and concepts are needed to complete the procedures. When the particles with N number of particles are pumped into the piston, the ideal gas equation is applied. To make the temperature not too big or the pressure not too small, the particles pumped have to be proportional to the power Avogadro's number ($10^{23}$). The pressure in isobaric process remains constant [16]. If the piston's volume is varied, the temperature is obtained as

$$PV = nRT, \tag{1}$$

$$PV = \frac{N}{N_A}RT, \tag{2}$$

$$T = \frac{PN_A}{RN}V. \tag{3}$$

The unit of pressure used is atm in each condition. If there is no particle or the piston is empty, both the temperature and pressure are zero. The piston's volume is set to be (in litres) 500, 400, 300, 200, and 100. The number of particles pumped into the piston are 100 x $10^{23}$, 200 x $10^{23}$, and 300 x $10^{23}$. Figure 2 shows the sketch of PVL's experiment.

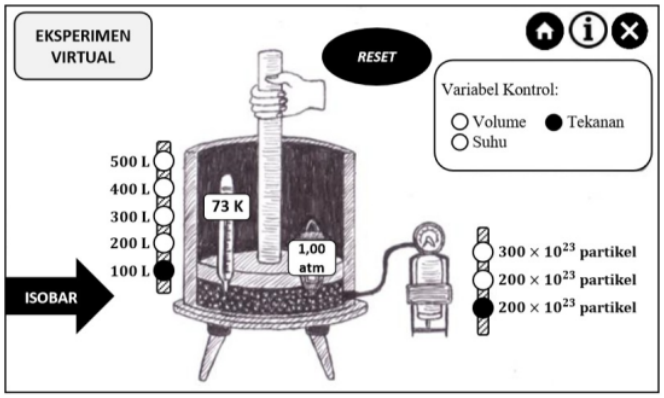


**Figure 2.** PVL's experiment sketch (eksperimen virtual: virtual experiment; variabel kontrol: control variable; suhu: temperature; tekanan: pressure; and partikel: particles)

The procedures in the PVL experiment are 1) pumping monoatomic particles into the piston [$N$ = 100 x $10^{23}$], 2) measuring the temperature and pressure [initial volume is 500 litres], 3) reducing the volume to 400 litres by pushing the piston cover, 4) measuring the temperature and pressure again, 5) repeating the measurement for 300, 200, and 100 litres, 6) adding the number of particle to 200 x $10^{23}$ or 300 x $10^{23}$ by pumping the floor pump, and 7) repeating the experiment. The next problem is how to make the animation of the particles moves and whether variation of volume affects the motion of the particles. Based on previous studies [16,19], the motion of the particles depends only on the temperature. When the volume is varied, the temperature changes, and so does the motion. The analysis is derived from the particles' average kinetic energy and the ideal gas equation, that is

$$\overline{E_k} = \frac{3}{2}PV, \tag{4}$$

$$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}PV, \tag{5}$$

$$\bar{v} = \left(\frac{3PV}{m}\right)^{1/2}. \tag{6}$$

Inserting the ideal gas equation (1) into equation (6), produces

$$\bar{v} = \left(\frac{3nRT}{m}\right)^{1/2}, \tag{7}$$

$$\bar{v} = \left(\frac{3NRT}{mN_A}\right)^{1/2}, \tag{8}$$

$$\bar{v} = \left(\frac{3RT}{M}\right)^{1/2}, \tag{9}$$

where M is the atomic mass of the gas. Hydrogen is the gas pumped into piston, so the atomic mass is 1.008 u or 1.008 x $10^{-3}$ kg. After doing the experiment, students have to make the analysis and calculations. The PVL unit for pressure is atm and volume is litres. Students have to change the units into International Units before doing the analysis and calculations. The results will be compared with the experiment.

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Problems. PVL's problems are created to test students understanding of the concepts inside the experiment. These problems are developed based on indicator of the real time thinking literacy (processing and presenting information quickly in real time) [20,21]. Students are given 2.5 minutes to solve each problem before the time is finish and they cannot answer it again. The limited time aims to test whether students can process and present the isobaric concepts in real time or not.

### *3.6. Instructional strategies*
PVL is accompanied with music along the activities. The sound of the music can be adjusted (reduced or turned off) to suit the students such that they enjoy and eager to learn. The experiment sketch is designed using Corel Draw and Adobe Illustrator, while the animation is developed using Adobe Flash. These strategies are expected to make PVL more attractive for students and users.

### *3.7. Designing the message*
Before pumping the particles into the piston, students have to choose the control variable of the isobaric process (only the correct choice will activate the experiment). If the hypothesis in the previous video is correct, the students should be able to choose the correct control variable. However, if the hypothesis is wrong, they will learn through this step. Designing the message inside PVL's activities is the ideal gas equation applied in isobaric process. The pressure remains constant in each condition. This is stated in the video, virtual experiment, and problems. In the experiment, the pressure always shows in 1.00 atm although the volume and number of particles are varied. Nevertheless, when there is no particle or the piston is empty, both the temperature and pressure are zero. The experiment is completed using four buttons, i.e.: reset, home, information, and close. Reset button is to return the experiment to the initial condition, home button is used to go back into the homepage, information button is used to explain what should be done, and close button is used to exit the PVL. There are also two symbols, viz.: a hand and an arrow. The hand symbol is utilized to push and pull the piston cover, and the arrow is used to pump the floor pump.

### *3.8. Development of instruction*
PVL will be applied in cooperative learning activities. These activities enable students to learn in small group discussion [22–24]. Each group consists of three to four students. A previous study [25] reveals that a small group discussion make Physics learning more effective than a larger one. Students discuss and conduct the experiment together. They can also discuss the given problems. These activities use scientific approach to introduce the theories and concepts of isobaric process. Through all the activities (hypothesis, virtual experiment, and problems), students' understanding of isobaric concepts is expected to improve.

### *3.9. Evaluation of instruments*
Before designing the PVL using Corel Draw, Adobe Illustrator, and Adobe Flash, the sketch and data are given to experts. There are four experts who review the PVL. They consist of a Physics teacher and three lecturers. Table 2 shows several suggestions of them.

**Table 2.** Experts' suggestions

| Expert Review | Suggestions | Actions |
|---|---|---|
| E-1 | If there is no particle in the piston, the temperature and pressure are zero. | Some suggestions applied in PVL are:<br>1. If there is no particle or the piston is empty, the temperature and pressure are zero (based on ideal gas equation when $N = 0$). |
| | It is better to set the number of particles pumped into the piston proportional to the power of Avogadro's number ($10^{23}$). | |
| E-2 | If there is no particle in the piston, the temperature | |

| | | |
|---|---|---|
| | remains at room condition (27 $^0$C or 300 K). | 2. The number of particles pumped into piston is proportional to the power of Avogadro's number ($10^{23}$), so that the temperature is not too big and the pressure is not too small. |
| | The illustration of the particles can be made by comparison (1:2:3), not in real number. | |
| E-3 | If there is no particle or the piston is empty, the temperature is zero. It comes from ideal gas equation. | |
| | Comparison is needed to illustrate the number of particles (1:2:3). | 3. Comparison is applied to illustrate the number of particles in the piston. |
| E-4 | The motion of the particles must be thought again depending on the quantity. It only depends on the temperature or other quantity that may impact the motion. | 4. Particles' motion depends on the temperature (based on the equation of particles' average kinetic energy). |
| | The experiment is created with animation, so the video for the hypothesis should be the real phenomena rather than animation. | 5. The video is chosen based on the real phenomena of Charles' Law. |

Based on the experts' suggestions, the sketch and data are revised. Table 3 shows the fixed condition of PVL's experiment. In the initial condition, the temperature and pressure are set zero and there is no motion of the particles at all.

**Table 3.** Condition in PVL's experiment

| $N$ | $P$ (N/m$^2$) | $V$ (m$^3$) | $T$ (K) | $v$ (m/s) | Motion Comparisons |
|---|---|---|---|---|---|
| 0 | 0 | 0.5 | 0 | - | - |
| $100\times10^{23}$ | $1.013\times10^5$ | 0.5 | 367 | 2776 | 12 |
| $100\times10^{23}$ | $1.013\times10^5$ | 0.4 | 293 | 2480 | 11 |
| $100\times10^{23}$ | $1.013\times10^5$ | 0.3 | 220 | 2149 | 10 |
| $100\times10^{23}$ | $1.013\times10^5$ | 0.2 | 147 | 1757 | 8 |
| $100\times10^{23}$ | $1.013\times10^5$ | 0.1 | 73 | 1238 | 4 |
| $200\times10^{23}$ | $1.013\times10^5$ | 0.5 | 183 | 1960 | 9 |
| $200\times10^{23}$ | $1.013\times10^5$ | 0.4 | 147 | 1757 | 8 |
| $200\times10^{23}$ | $1.013\times10^5$ | 0.3 | 110 | 1520 | 6 |
| $200\times10^{23}$ | $1.013\times10^5$ | 0.2 | 73 | 1238 | 4 |
| $200\times10^{23}$ | $1.013\times10^5$ | 0.1 | 37 | 881 | 2 |
| $300\times10^{23}$ | $1.013\times10^5$ | 0.5 | 122 | 1601 | 7 |
| $300\times10^{23}$ | $1.013\times10^5$ | 0.4 | 98 | 1435 | 5 |
| $300\times10^{23}$ | $1.013\times10^5$ | 0.3 | 73 | 1238 | 4 |
| $300\times10^{23}$ | $1.013\times10^5$ | 0.2 | 49 | 1014 | 3 |
| $300\times10^{23}$ | $1.013\times10^5$ | 0.1 | 24 | 710 | 1 |

Motion comparison values are used to compare the particles' motion in each condition. The higher the temperature, the greater the values, and the faster the motion. To illustrate the actual number of particles, a ratio of 15:30:45 particles is used. Figure 3 shows the fixed sketch of the PVL experiment after using Corel Draw, Adobe Illustrator, and Adobe Flash. Further study is needed to implement the PVL to other Thermodynamics processes, such as isothermal, isochoric, or adiabatic.

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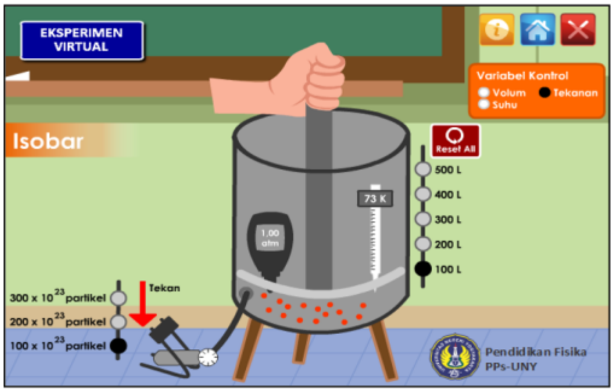


**Figure 3.** Fixed sketch of the PVL experiment (eksperimen virtual: virtual experiment; variabel kontrol: control variable; suhu: temperature; tekanan: pressure; partikel: particles; and tekan: push).

## 4. Conclusion

It may be concluded from the study that 1) PVL can be developed from several components, i.e. basic competence and indicator, video, experiment goals, virtual experiment, and problems, 2) Thermodynamics is applied for developing the PVL, and 3) final sketch is designed using Corel Draw and Adobe Illustrator, while the animation is created using Adobe Flash.

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