

PVT Simulation: An Innovative Approach to the Traditional Laboratory Experience

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Abstract

Petroleum engineering is based on the complex relationship between fluids and reservoirs, so understanding the behavior of reservoir fluids is fundamental for every petroleum engineer. Pressure-volume-temperature (PVT) measurements on hydrocarbon mixtures provide crucial information that aids engineers in evaluating reservoirs and designing oil recovery programs. Unfortunately, PVT experiments are not suited to the laboratory environment for undergraduate students because of the safety risks associated with the elevated pressure and temperature conditions and the explosive substances being studied. In addition, the extensive equipment requirements and associated maintenance costs can also be prohibitive.

To address the need for students to understand PVT measurements, several professors (most recently Dr. Steven Bryant) at the University of Texas at Austin had used a PVT simulation program developed in the mid-1980s in the laboratory section of a fluid behavior course. While the old simulation was powerful and conceptually attractive, the user interface was dated. Students had difficulty using the application and had to manually record data. Some hard-wired features severely limited its instructional effectiveness. Dr. Bryant partnered with the Faculty Innovation Center (FIC) to develop a new PVT Simulation with the goal of improving the user experience so learning would be less arduous and more efficient for students. This paper discusses critical decisions made during the design process to create an optimal learning environment for undergraduates. Survey results illustrate the impact on student perceptions of the virtual laboratory experience and concept development. In November 2004, the PVT Simulation won a silver award in the Teaching with Technology category of UT's Innovative Instructional Technology Awards Program (IITAP).

Introduction

Measurements of pressure-volume-temperature relationships of reservoir fluids find application in nearly every branch of petroleum engineering. Understanding how the measurements are taken and interpreting pressure-volume-temperature data are fundamental skills for petroleum engineers. Although PVT laboratory measurements are routine, they are not easy to obtain because they are taken at elevated pressures and temperatures. Consequently, undergraduate petroleum engineering students at the University of Texas at Austin (UT) do not have the opportunity to do real PVT laboratory experiments due to the effort involved, the limited availability of laboratory equipment, and, above all, safety.

In UT's College of Engineering, several professors had used a software package developed in the mid-1980s to familiarize students in an undergraduate fluid behavior course with PVT measurements. While the old simulation (see Figure 1) was powerful and filled a vital curriculum need, the user interface was dated and very difficult to use. All actions were accomplished using function keys, and students had to manually record the data collected.

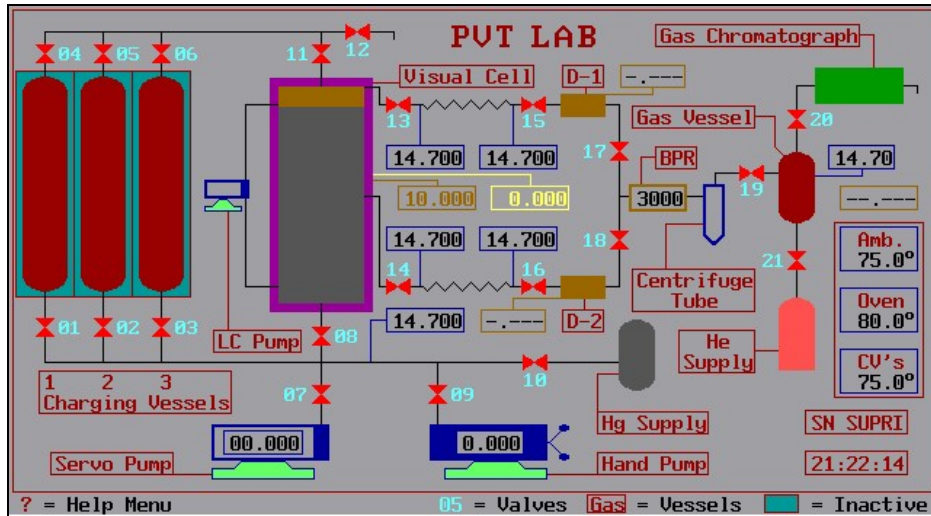


Figure 1: Old PVT Simulation

Although the old simulation's effectiveness was questionable, research and emerging trends in computer-enhanced learning supported the simulation approach. Roger Schank is a leading researcher in the fields of artificial intelligence, cognitive science, and the design of virtual learning environments. Schank advocates computer-based simulations because they "can vastly broaden the range of things students can learn by doing."¹ According to Schank, computer-based simulations can create realistic conditions for learning at little risk to either the organization or the individual.² Clark Aldrich, one of today's leading proponents using simulations for learning, describes other advantages. "A single simulation can teach someone in a variety of ways all at once, and for this reason the medium is actually much closer to how people often learn from real-life experiences....By allowing for user interaction and feedback, they can be used to show how complex systems work in different circumstances."³

Project Initiation and Timeline

Dr. Bryant of UT's Petroleum and Geosystems Engineering department approached the Faculty Innovation Center (FIC) to discuss options for updating the old simulation. The FIC serves UT's College of Engineering by providing media, instructional, and faculty development services.⁴ With staff skilled in instructional design, computer graphics, web design, and programming, the FIC was well equipped to take on the task of developing a new PVT simulation to replace the old one.

The development project was officially launched in the summer of 2003 when Dr. Bryant assigned a graduate teaching assistant (Emee Ermel) to serve as a laboratory content consultant and the FIC assigned an instructional designer (Mary Crawford) to design a new simulation. With the schedule calling for implementation in the spring of 2004, the plan was to initiate the design stage of the simulation during the summer and build it in the fall of 2003.

Project Design Decisions

The goals of the project were to update the visual interface, improve user experience, and ultimately, enhance student learning. During simulation design, the development team faced many critical decision points that determined the resulting user experience and learning environment provided by the software. This section describes the most pertinent decisions.

Overall Laboratory Assignment

The new PVT simulation was not intended to be an independent phase behavior simulator; rather it was designed as a specific learning tool to aid students in their overall virtual laboratory experience. Like a real PVT laboratory, PVT Simulation is a place to collect data that can be used outside the lab. This includes applying the phase behavior concepts taught from classroom lectures to analyze the data gathered from the improved simulation and present them in a coherent, written laboratory report. Although the old simulator was designed to be used with minimal input restrictions, the students found it intimidating and confusing to use and it ultimately inhibited them from understanding the key concepts. Thus, the design decision was made to modify existing laboratory examples and use those as representative models for illustrating the major phase behavior concepts. As a result, PVT Simulation includes constant temperature expansion experiments of three fluids: a pure component (carbon dioxide), a binary system (n-butane and carbon dioxide), and a reservoir fluid (11 components).

Development and Delivery Environments

The development team agreed that the simulation would be developed with Macromedia Flash, which is an ideal tool for producing graphic-rich, highly interactive learning experiences. Flash applications can run within a web browser or independently.

Even though Flash is typically used for creating web-based applications, the development team decided that PVT Simulation would be locally installed on computers in a learning lab. This ensured that students would have the support of graduate teaching assistants while using the simulation should questions arise.

Because PVT Simulation is primarily a data collection tool, the Flash application had to access large files of stored pressure, volume, and temperature data. However, the data exchange model used by Flash is based on web server access. Although PVT Simulation is installed locally on learning lab computers, a live internet connection is still required to access data stored on a web server.

The ability to download and upload measurement data would greatly enhance the student experience. The data import and export functions were among the most challenging aspects of simulation development. Flash does not allow writing to local storage devices. SWFKit, a third party tool that extends the capabilities of Flash, was used so the simulation can save and import student data files.

Initial Orientation and Navigation

The old simulation that was being replaced was difficult to use and provided little built-in support. The development team felt it was important for students to become quickly oriented with the new simulation and easily navigate through each section. The main simulation screen provides an introduction as well as options to see information on learning objectives, the lab environment, laboratory apparatus, lab descriptions, and background on the PVT simulation. Students may download or print a PDF version of this information. See Figure 2.



Figure 2: Main PVT Simulation Screen

Visual Design and User Experience

The old simulation had outdated graphics and a confusing display of unlabeled components. Students had to invest significant time in simply understanding what each object was supposed to represent instead of completing the virtual experiments. Students were frustrated by the interface,

which required using functions keys for all actions rather than the point and click interfaces that are common today. Furthermore, the old simulation was very unforgiving. If the wrong button was hit, the simulation had to be started over from the beginning.

An important aspect of the PVT Simulation is to support student understanding of real laboratory equipment and how it operates. In order to accurately depict real laboratory apparatus, the FIC's graphic artist first digitally photographed each piece of equipment. These photos served as the foundation for 3-D models, which could be easily scaled and manipulated to produce the new simulation's visual interface. The resulting image provides a very realistic representation of the actual lab equipment, allowing students to easily recognize the various components. The layout provides a simplified, but accurate depiction of the configuration of connections between the pieces. See Figure 3. Students simply point with their mouse and click to accomplish actions, such as opening a valve, turning on the mixing pump, or looking inside the visual cell.

**Realistic Representation
of Lab Equipment**

**Downloadable PDF
of Lab Procedure**

UNIVERSITY OF TEXAS AT AUSTIN DEPARTMENT OF PETROLEUM AND GEOSYSTEMS ENGINEERING

P V T Simulation

Pressure Volume Temperature

Lab A

To begin the lab, select the Lab Data tab.

Settings Lab Data

Lab Procedures PDF

Lab A:
Constant Temperature Expansion of a Pure Component

Description:
The purpose of this lab is to generate a pressure-volume diagram of CO₂ showing isotherms at three temperatures. You will perform a constant temperature expansion of pure CO₂ at 60, 80 and 120 degrees Fahrenheit by withdrawing Hg incrementally from the visual cell. Each withdrawal will allow you to record the changes in phase volumes and pressure. Initially, you should observe one phase in the visual cell. As you decrease the pressure in the visual cell by withdrawing Hg, you should be looking for critical PVT properties such as the dew point. Continue taking data until the original phase volume is zero. Save the data for each temperature.

Settings:

Number of charging vessels	0
Contents of the visual cell	10 mL of CO ₂
Initial pressure for visual cell	2000 psia
Ambient Temperatures	75° F

Note: You can save your data at any time using the Save Data button. If you cannot complete the procedure all at once, you can resume later by using the Load Data button to upload a saved data file.

**Hint: If you never observe a phase change, that does not mean there is a flaw in the program.

Procedural Prompt

Lab Description

Figure 3: Lab Interface Screen and Lab Procedure

Procedural Support

In designing the simulation, finding the right balance between procedural support and open-ended exploration was crucial. The procedures used in a real lab are very specific; deviations have dangerous and expensive consequences. On the other hand, an advantage of running simulations is the ability to manipulate a system and see the consequences of those actions. To help students follow appropriate procedures, the simulation includes downloadable lab documents and prompts at the bottom of the screen reminding students what to do. See Figure 3.

Easing the Burden of Data Collection

With the older simulation, students had to record all data manually. One of the goals for the new simulation was to ease the burden of data collection so students could focus more on interpreting the data as it was generated. To achieve this goal, the simulation displays data in a table as the measurements are taken. See Figure 4.

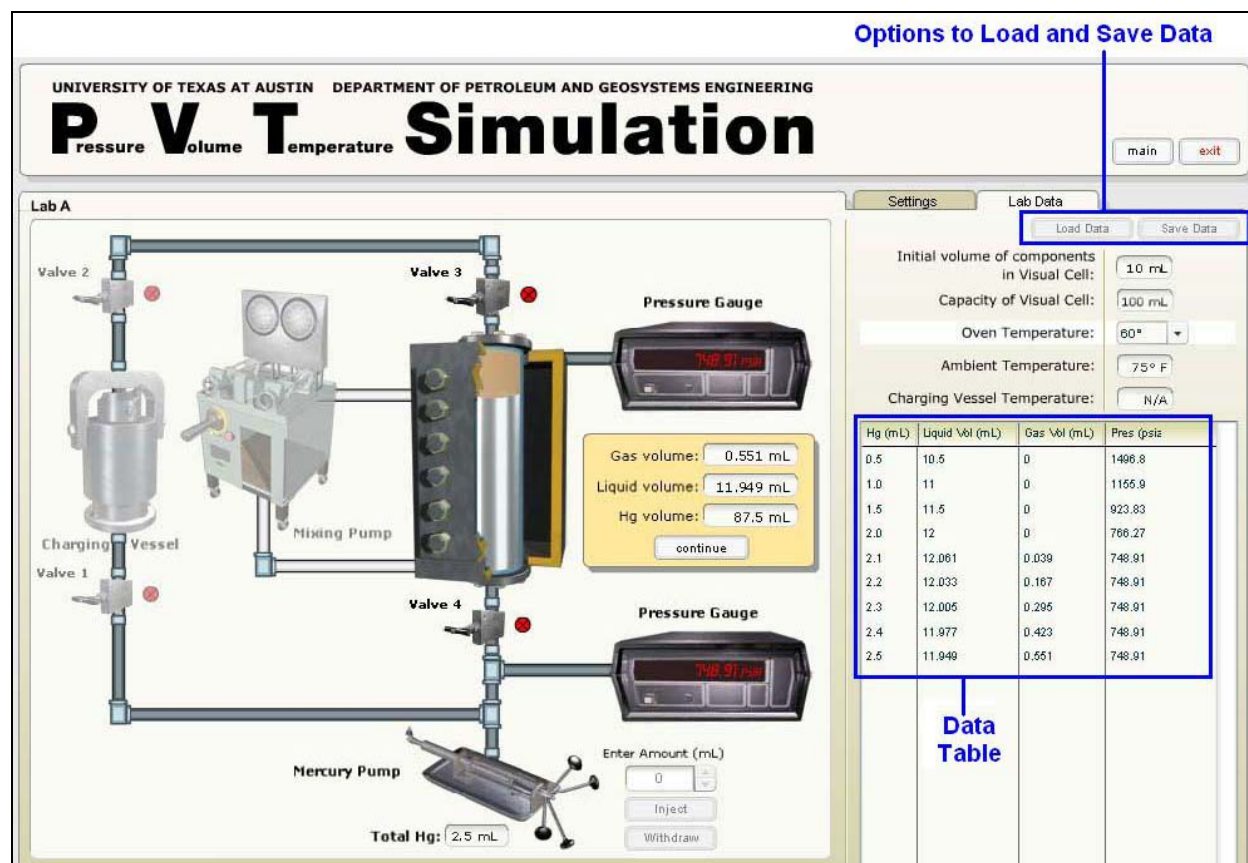


Figure 4: Lab Data

Additionally, it is important for today's students to be able to manage and manipulate data with standard spreadsheet applications. To facilitate data manipulation, the development team designed PVT Simulation to allow students to save and load spreadsheet-compatible data files. An additional consideration was that students would have limited access to PVT Simulation

during scheduled laboratory hours in the computer learning lab. They might not have time to complete a full set of data in one session. By saving and reloading data they can continue collecting data for a partially complete lab at a later time. Allowing students the options of saving, downloading, and uploading data encourages them to actually evaluate their data and correct any mistakes they may have made. Eliminating the time constraints also allows students to focus on understanding the data they have collected and critically analyze each experiment.

No Graphing within the Simulation

Graphing PVT data is one of the goals of the overall PVT assignment. Graphs of the PVT data are vital to support student understanding of some of the basic concepts the assignment addresses, including isotherms and bubble points. While it is certainly feasible to develop software that automatically graphs data, the development team intentionally excluded a graphing feature from PVT Simulation. There were several reasons behind this decision. First, the ability to save and load spreadsheet-compatible data files provided an opportunity for students to do the graphing within a spreadsheet, an important skill for them to develop. Second, without an automatic graphing function, students would be forced to pay attention to the tabular data and decide when they had taken enough measurements. With a graph, it would be very obvious. Third, the development team anticipated that some students may not be completely systematic in their data collection. They may take measurements in unreasonably large increments and have to repeat the measurements in finer increments. In such cases, the graphs would be confusing or meaningless. With saved data files, students have the opportunity to correct their mistakes before graphing. Without an automatic graphing feature, they must take a proactive role in interpreting and understanding the experiments they have completed and compare their phase behavior graphs to previous ones obtained from class lectures.

Consequences of Incorrect Actions

After completing all of the labs in PVT Simulation, students should be able to describe the risks involved in using PVT equipment. Students are allowed to take inappropriate actions and suffer simulated consequences – a message indicates the system has been contaminated or has exploded, all data is lost, and the student must start the procedure again. See Figure 5.

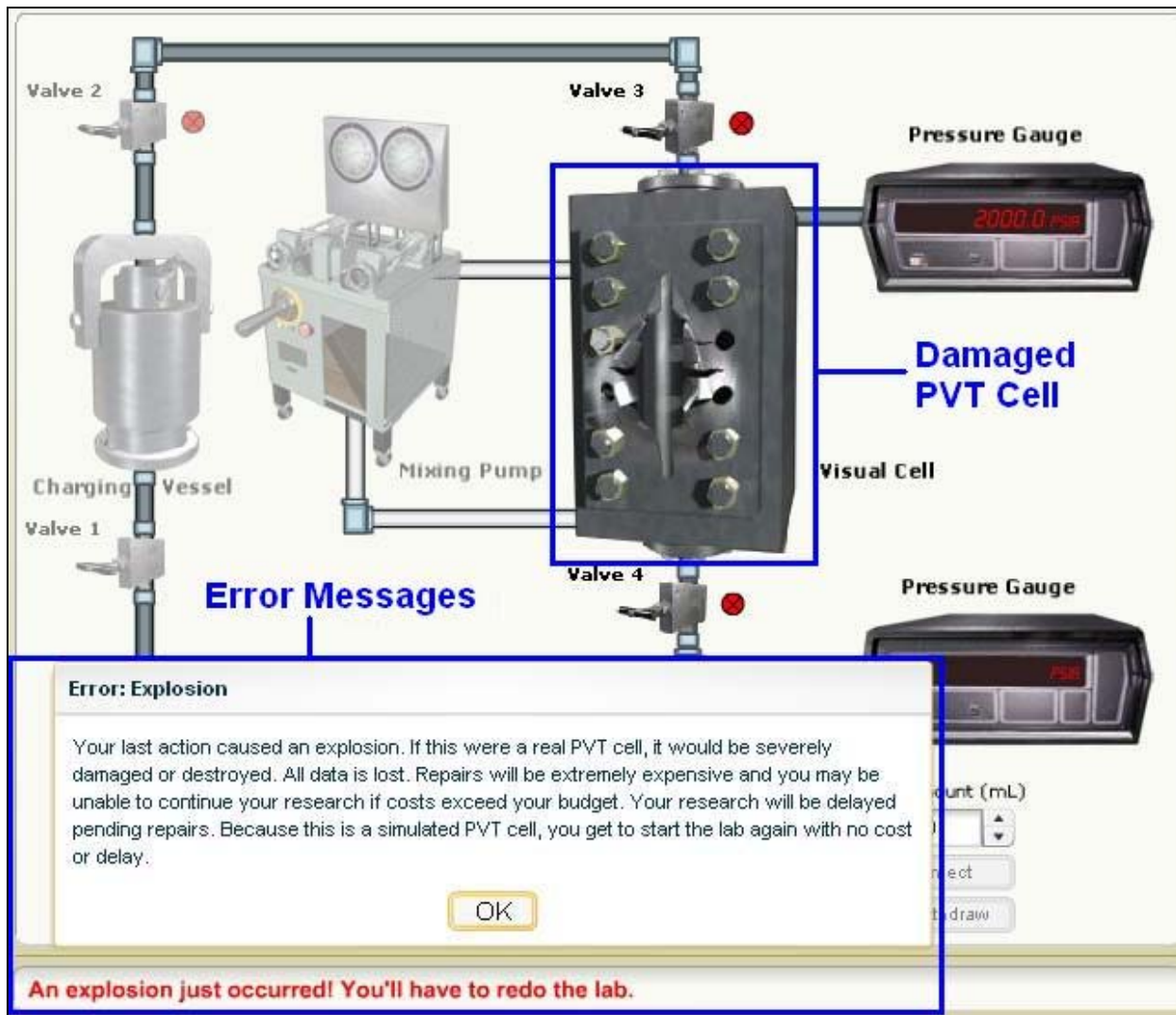


Figure 5: Error Message after Simulated Explosion

Evaluation

In April 2004, students who had used both the old and new simulation were asked to complete an online survey. More than 60 students enrolled in PGE 421K responded. Students were asked to rate how well the old and new simulations helped them achieve specific learning objectives. They were also asked to rate the ease of use, time required to learn to use the program, and whether they would recommend the program for future students. Complete survey results are available in the appendix of this paper.

The new simulation received dramatically higher marks than the old simulation for every item on the survey. Survey results indicate that students viewed the new simulation as a more conducive learning tool for each lab objective. For example, 40.3% of the students agreed or strongly agreed that the old simulation helped them understand the definition of dew point, compared to 85.1% for the new simulation. Only 56.1% of students agreed or strongly agreed that, after using

the old simulation, “I can interpret phase behaviors of fluids at varying temperatures.” After using the new simulation, 95.5% agreed or strongly agreed with this statement.

Students also indicated that they thought the new simulation was easier to use than the old simulation and required a more reasonable amount of time to learn how to use. Only 32.8% agreed that they would recommend the old simulation for future students, but 92.5% agreed that they would recommend the new simulation.

Recognition and Future Direction

In November 2004, PVT Simulation was recognized by the Innovative Use of Instructional Technology Awards Program (IITAP), a university-wide competition that celebrates and rewards faculty efforts to incorporate technology in their teaching. The PVT Simulation team received the Silver award in the Teaching with Technology category, which recognizes “practices, processes, implementations, and successes in teaching through the innovative and effective use of digital technologies.”⁵

Plans are underway to use the simulation again with approximately 60 students this semester. Physical and Chemical Behavior of Fluids II will not be taught by Dr. Bryant this semester. Another professor will be taking over the course and is enthusiastic about using the new simulation because he has experience with the old simulation. Fortunately, the same teaching assistant, Ms. Ermel, is available to provide some continuity in using the simulation.

Bibliography

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5. Innovative Use of Instructional Technology Awards Program web site: <http://www.utexas.edu/academic/cit/services/incentive/iitap/2004/call.html>.

EMEE ERMEL

Emee Ermel is a graduate student at the University of Texas at Austin. She is currently a research assistant and teaching assistant for the Petroleum and Geosystems Engineering Department. Emee has previously earned a Bachelor's degree in mathematics from the University of Texas at Austin.

MARY CRAWFORD

Mary Crawford has been designing innovative interactive instruction for more than 18 years. As an instructional designer at the Faculty Innovation Center of UT Austin's College of Engineering, she works with faculty to support their use of technology to enhance teaching and learning. Mary holds an MA in instructional technology from the University of Texas at Austin.

Appendix

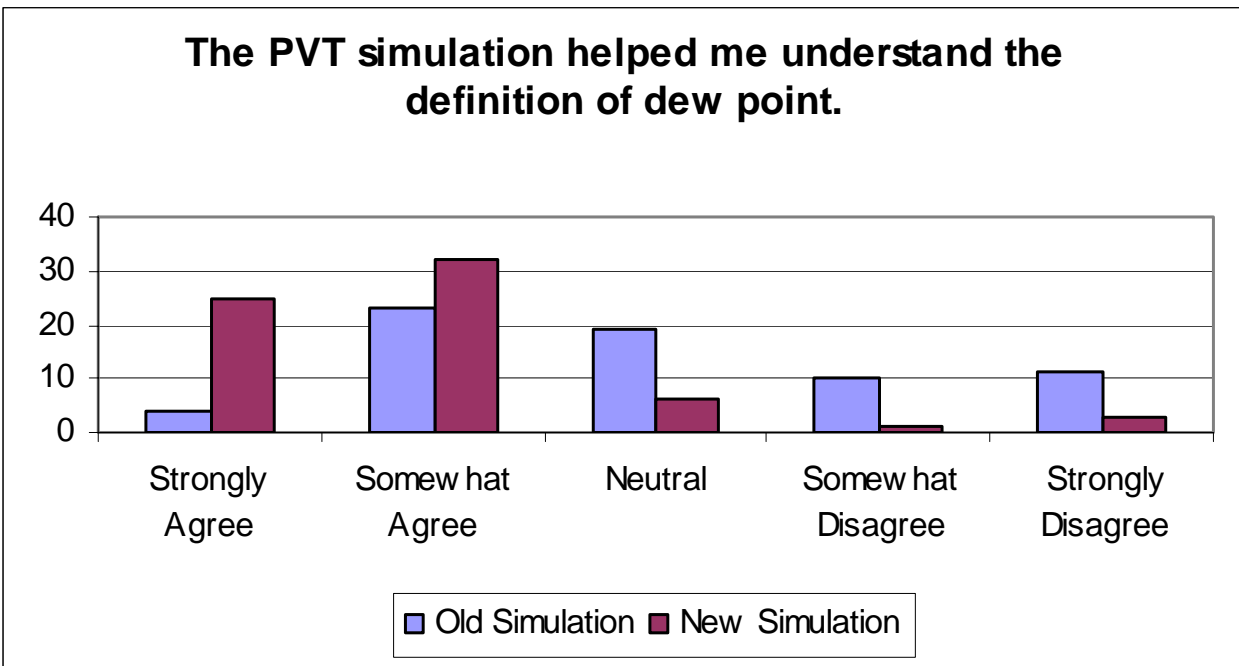


Figure 1: Dew Point

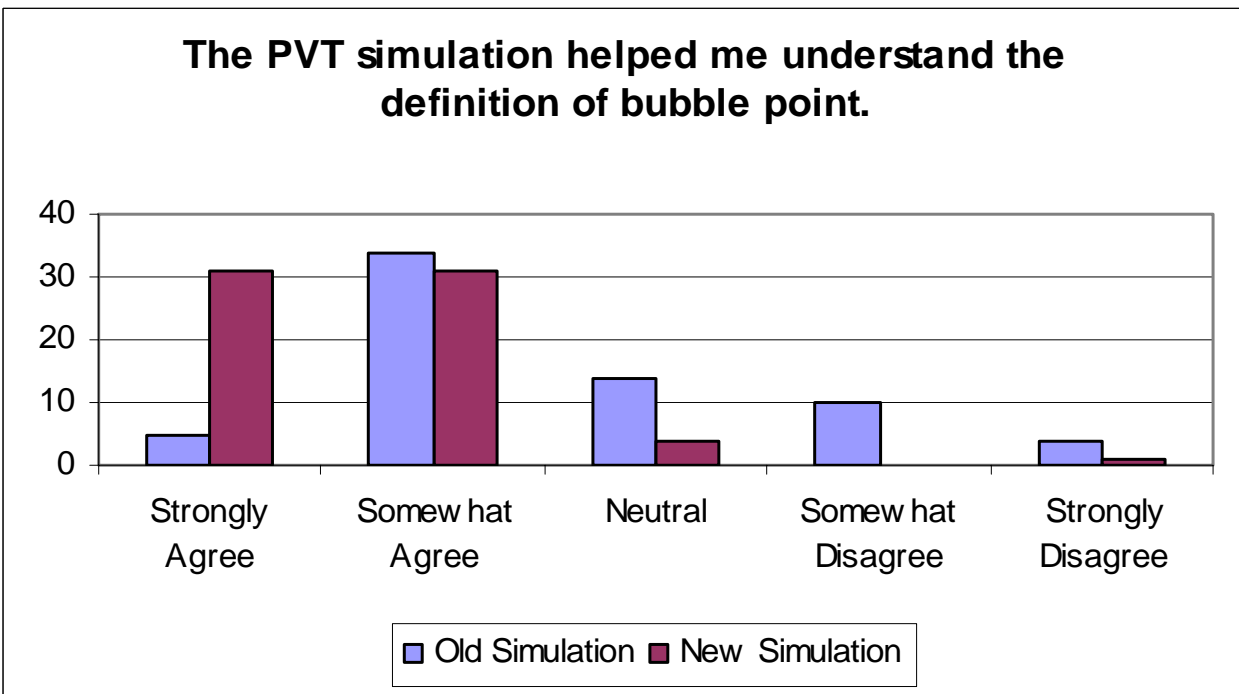


Figure 2: Bubble point

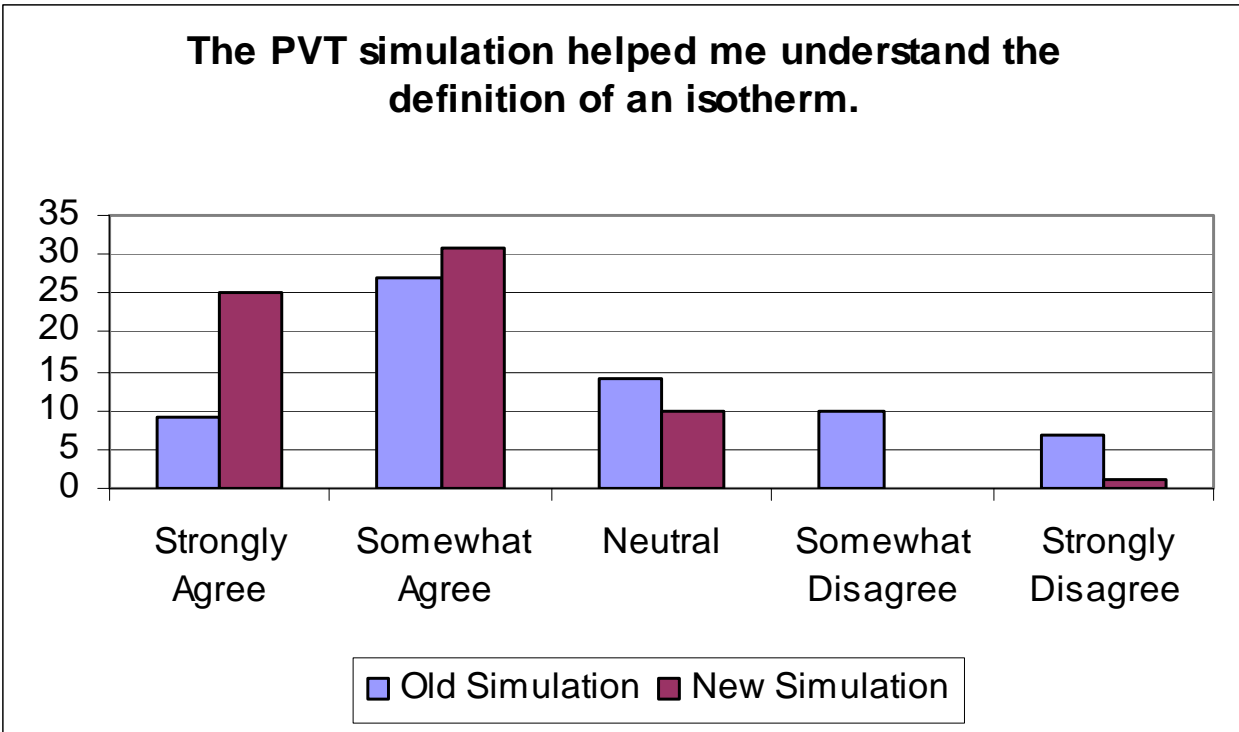


Figure 3: Isotherm

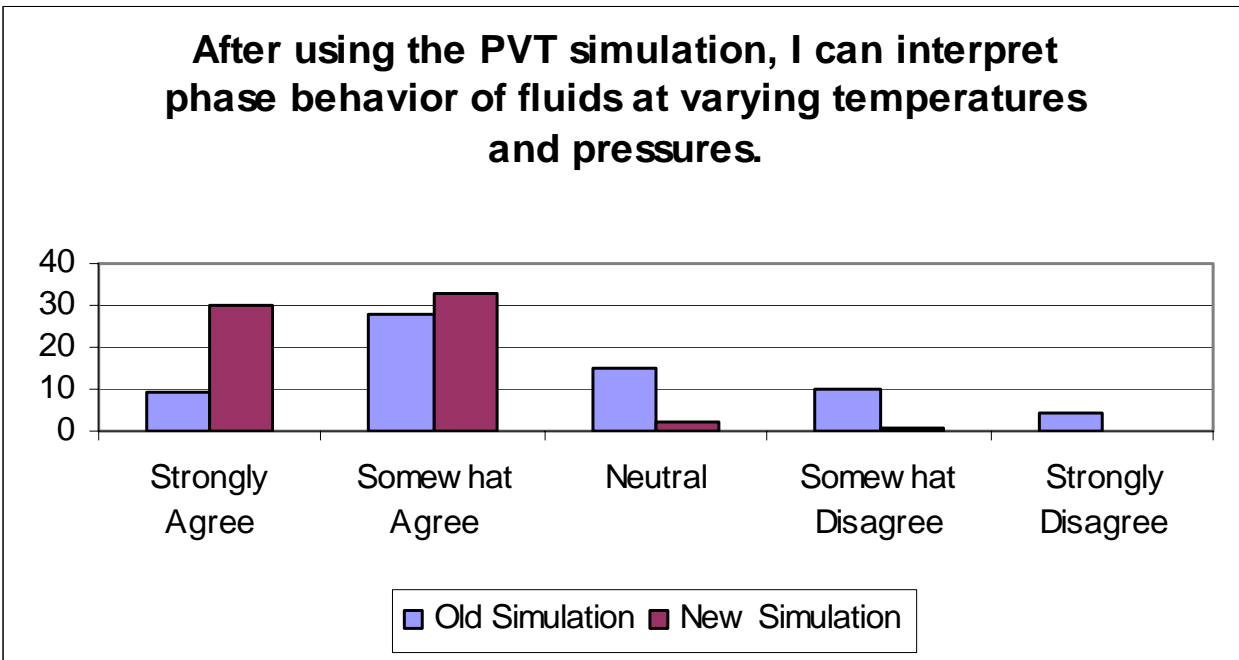


Figure 4: Phase Behavior

After using the PVT simulation, I can explain how the oil formation volume factor (B_o) and solution gas-oil ratio (R_s) are derived.

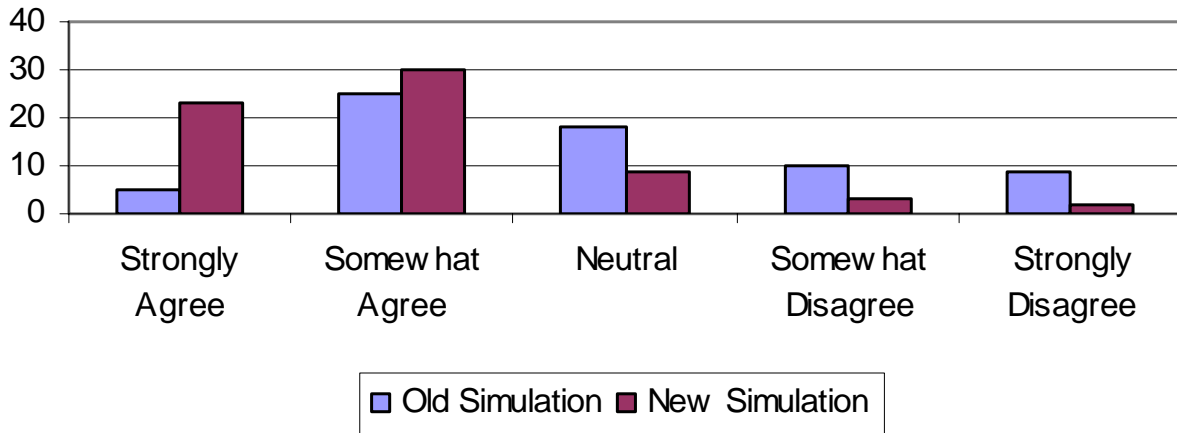


Figure 5: B_o and R_s

After using the PVT simulation, I can describe how PVT data is generated using actual PVT laboratory apparatus.

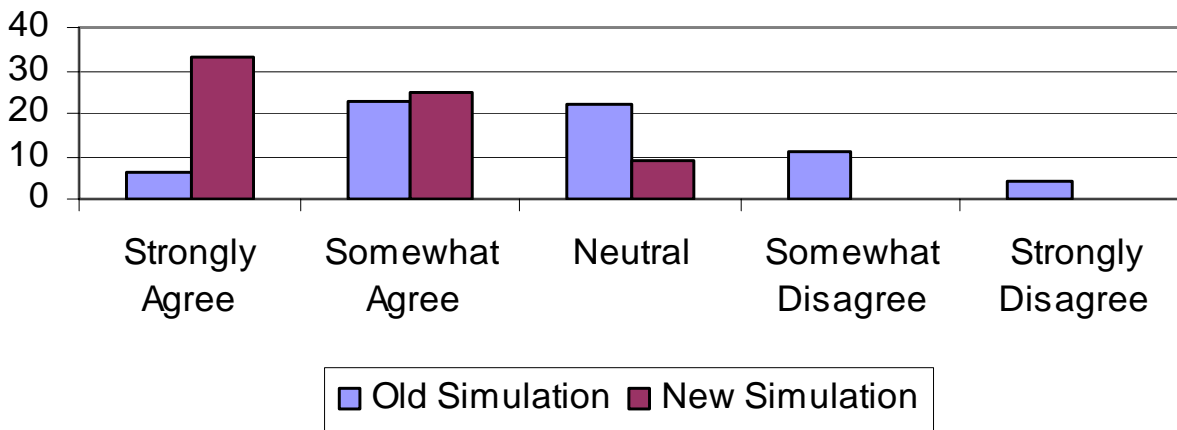


Figure 6: Laboratory Apparatus

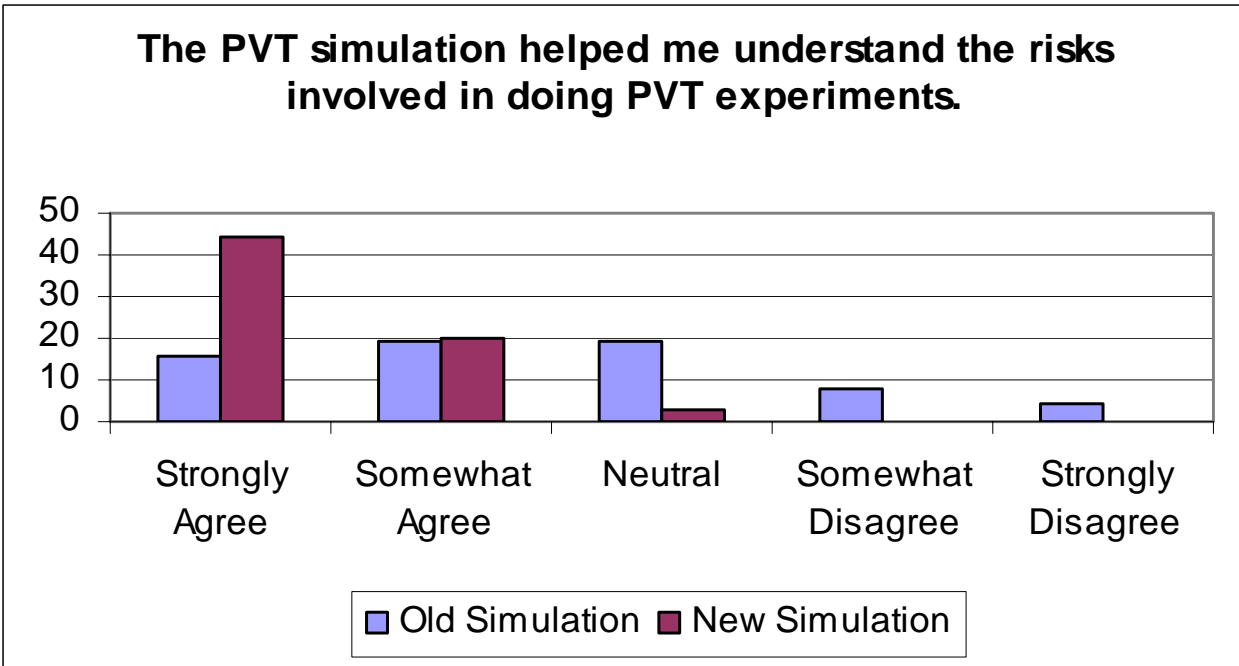


Figure 7: Risks

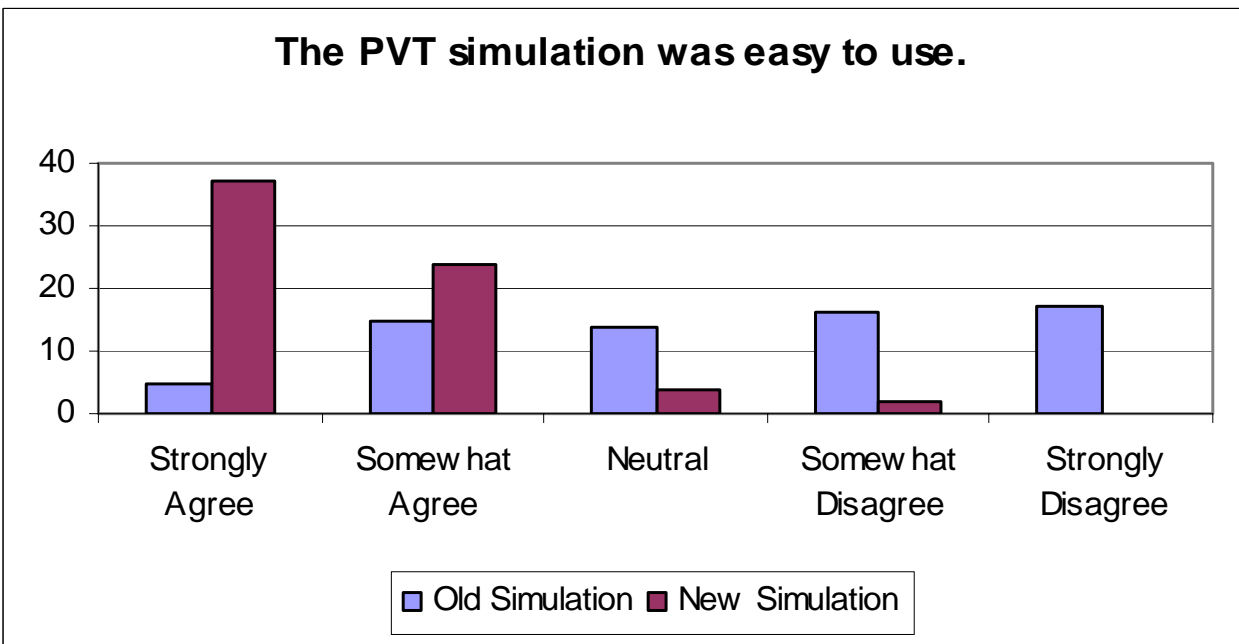


Figure 8: Ease of Use

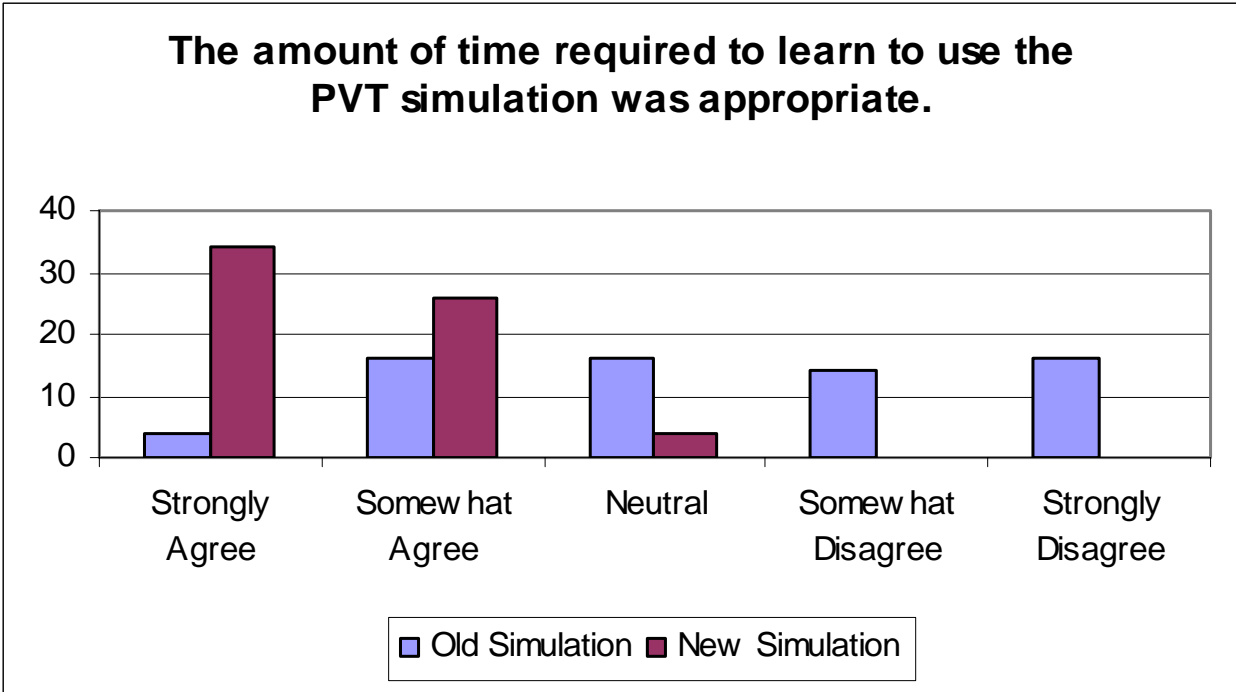


Figure 9: Learning Time

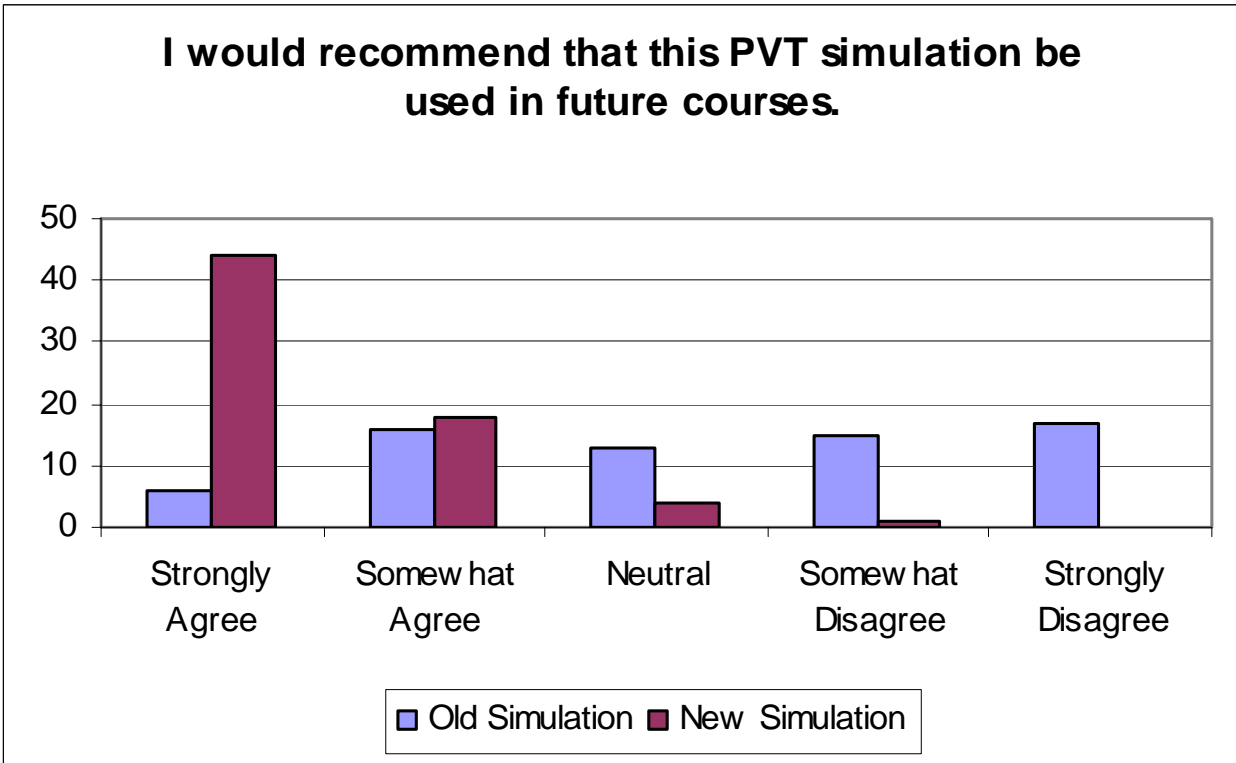


Figure 10: Recommendations