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BYOE: Advancing Petroleum Engineering Undergraduate Education Using Visualization Labs

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Abstract

The world needs young engineers who are skillful and enthusiastic about science and who view engineering as their future career field. Historically, engineering educators have adopted traditional verbal learning while interest in visual learning has lagged behind. As a result, recently, more visualization models and high-performance computing labs have been used in teaching future young engineers. This paper presents five visualization models, incorporated into the petroleum engineering department curriculum, used to advance students' understanding of petroleum engineering-related topics. Furthermore, it shows how these lab-scale models are being used in teaching petroleum courses. In the end, the paper shows the impact of these lab scale models on student engagement and learning by presenting students' feedback on the use of these visualization labs in teaching petroleum engineering courses.

1. Background

At Bob L. Herd Department of petroleum engineering, there are many undergraduate Labs used in teaching petroleum engineering classes (Heinze and Gamadi 2019). Here is a list of these Labs.

1. The Oilfield Technology Center (OTC) offers students the opportunity to do hands-on work with equipment used for artificial lift, oil treating, gas processing, drilling, and completions. OTC has three test wells, including the deepest test well on university property in the United States - Red Raider No. 1. An on-site shop and classroom building combined with the full-scale equipment and wells provide a unique facility for teaching, research, and workforce development.
2. **Visualization Labs-**These labs provide students with a first look at scaled-down typical oilfield equipment and its function before working with full-scale equipment at the Oilfield Technology Center.
3. Mud Lab: Students gain knowledge about the chemistry, rheology, and properties of drilling mud. They conduct experiments measuring drilling mud properties and evaluating the performance of the drilling mud.
4. Core Lab: Students practice most of the fundamental experiments related to cores, such as measurements of porosity, permeability, interfacial tension, contact angles, resistivity, etc. Students gain knowledge about rock-fluid interactions.

- **The Theory Behind Using Visualization Models**

Historically, educational research has stressed verbal learning while interest in visual learning has lagged behind. Visual literacy has been used as an interdisciplinary concept that includes theoretical perspectives, visual language perspectives, presentation perspectives, and technological development, including digitalization (Abersek, 2008). As the quantity of information learned through visual tools multiplies, the ability to understand, evaluate, and produce visual representations has become progressively significant in education. Visual thinking is essential to comprehending visual information and transforming it into concepts (Bilbokaite, 2010). Some authors (Ferreira & Arroio, 2009; Gilbert, 2005; Rapp & Kurby, 2008; Arroio & Honório, 2008) discuss several factors related to visualization in science education, such as understanding how the visual representation is transformed into knowledge, the importance of training mental models, skills in interpreting and processing of an image. Science seeks to provide explanations for natural phenomena: to describe the causes that lead to those particular effects in which scientists are interested. In conclusion, a visualization teaching base would be the solution to improving engineering education for these reasons,

- Reasoning: One form of reasoning involves the generation of new images by recombining elements of existing images. This is the basis of visual analogy. For example, the perception of waves on water led historically first to the development of the wave model of light and later to the wave model of sound.
- Learning a physical skill: In learning a skill, a person first produces a visual perception that defines the nature of the physical movement entailed in the exercise of the skill. This is done by observing an expert demonstrating the skill. This model is used by the learner to guide the personal development of the physical movement until, when perfected (an ideal situation!), the original visual perception is matched by the visual image that has evolved. For example, this is done by learning to use a pipette, dissect a carcass, to tune a radio circuit.
- Comprehending verbal descriptions: Visual memory is distinct from linguistic memory (Haber, 1970). However, visualizations can be generated from a series of propositional statements, a process that, for many, makes an understanding of the relationships between the latter easier to acquire. For example, the structure of a crystalline substance can be understood by producing a mental image after reading a description of it.
- Creativity: This can take place either by the reinterpretation of the meaning of an existing image or by a change in the frame of reference within which an image is set (Reisberg, 1997). The literature on the history of science is replete with examples of how major scientific advances have been made in these ways e.g., by Faraday, Maxwell, Tesla, Feynman, and, as has already been said, Kekule (Shepard, 1988).

2. Used Lab Scaled Visualization Models in Teaching Petroleum Engineering (PE) Classes

In petroleum engineering teaching, for a long time, there were no attempts to visualize the behavior of an oil or gas flow in reservoirs(rocks) and pipes using lab-scale models due to the cost associated with building these models. This lasted until the 1980s when reservoir engineers learned how to simulate numerically hydrocarbon reservoirs and show the behavior of fluid flow in rock and pipes in 2D and 3D computer models. However, few classes were using numerical simulation models in teaching at that time. PE faculty members continued using traditional teaching methods, such as backboard and PowerPoint presentations including graphs and sketches. In 21 century, tremendous changes have been made in teaching PE classes. Almost every petroleum engineering program started developing and using laboratories to conduct experiments that help students' attainment of course objectives, such as core, fluid, and drilling labs. Since 2014, Bob L. Held department of petroleum engineering has adopted the use of visualization models in teaching. More than seven lab-scale models were built and used in multiple PE classes. In this section of the paper, only five lab-scale models are shown. These models are used in teaching reservoir and production courses, however, a lot more are being used in other courses. The other models are presented in The Oilfield Technology Center (OTC).

2.1. Fluid flow in pipes and friction factor Model

The energy balance required for the calculation of fluid flow behavior involves the calculation of lost work, the total irreversible energy loss to the pipe wall that is unavailable to move the fluid or perform any other action. Figure 1 shows a model, built to mimic fluid flow in pipes and help in estimating lost work when a fluid flows through this loop. Students can visualize the flow in the pipe at different flow regimes (Laminar and turbulent) and see the effect of that pressure loss due to friction.

Figure 1 shows the flow loop

- **<u>Gas-liquid two-phase flow Model</u>**

Co-current gas-liquid flow in horizontal pipes displays similar patterns to those for vertical flow; however, asymmetry is caused by the effect of gravity, which is most significant at low flow rates. The sequence of flow regimes identified by Alves (1954) is shown in Figure 2. In the bubbly regime, the bubbles are confined to a region near the top of the pipe. On increasing the gas flow rate, the bubbles become larger and coalesce to form long bubbles giving what is known as the plug flow regime.

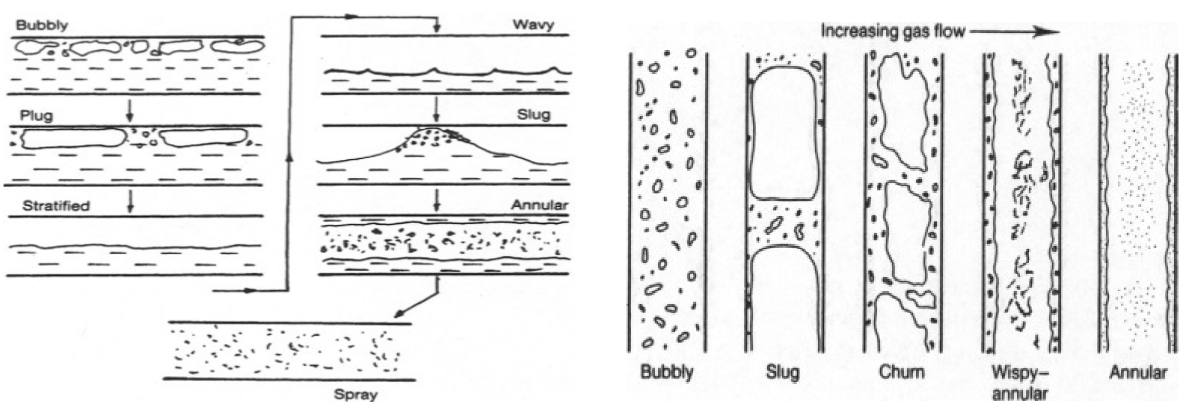


Figure 2 shows flow regimes in vertical and horizontal pipes

A model was built to visualize the change of flow regime inside horizontal and vertical sections of oil and gas wells when the flow rate increases and decreases. The model shown in figure 3 can be used to visualize flow regimes shown in figure 2.

Figure 3 shows a model representing fluid flow in two horizontal and vertical sections.

2.2. <u>Fluid flow in porous media (rock) model</u>

Darcy's law is a phenomenologically derived constitutive equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand. It also forms the scientific basis of fluid permeability used in the earth sciences, particularly in hydrogeology. Figure 4 shows two models to visualize gas, water, and oil flow in porous media, and see the effect of formation permeability on fluid flow. How oil and gas flow rates can be increased or decreased by changing pressure drop can also be visualized in this model.

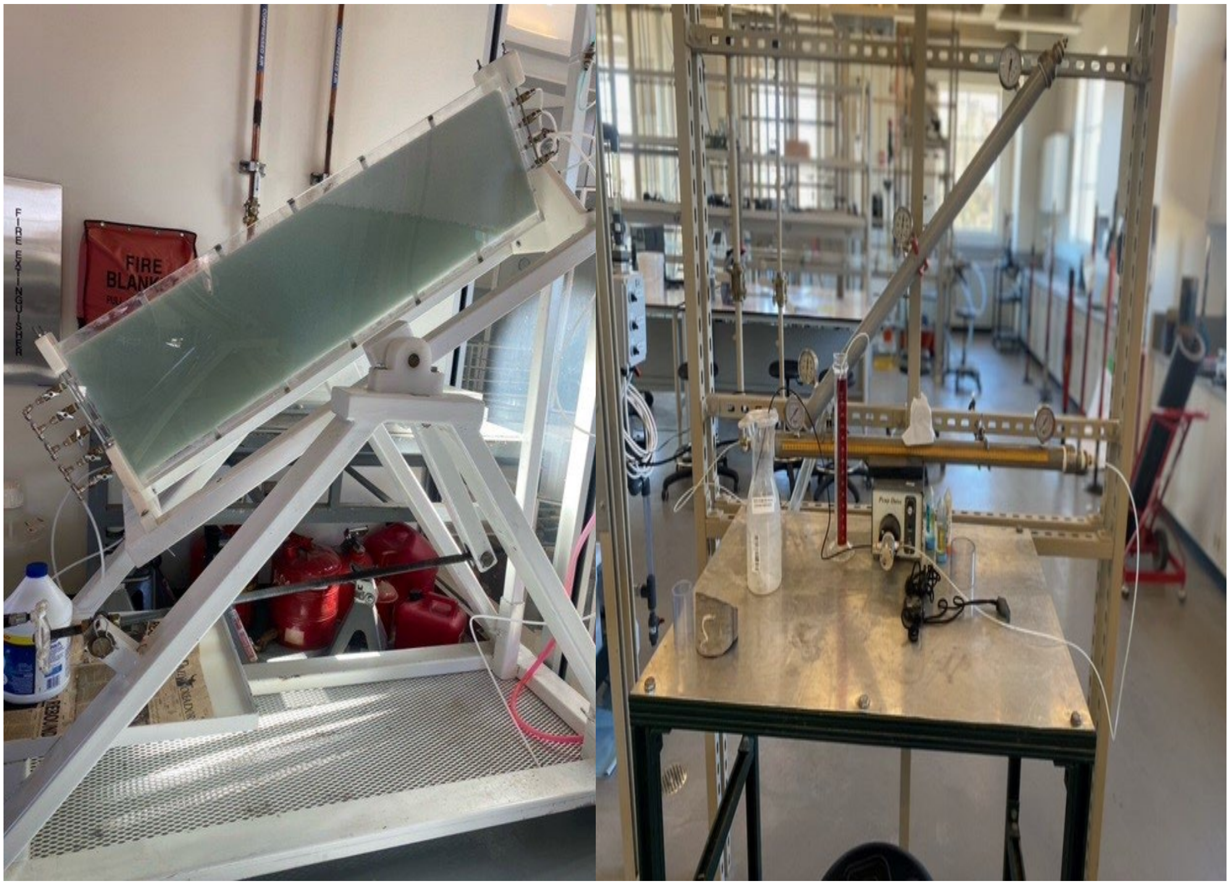


Figure 4 shows two models that represent fluid flow in rocks

- **Artificial life models**

Because formation lack sufficient reservoir pressure to produce fluids to the surface, most of the world's oil and gas wells are unable to produce at economic rates without assistance. This condition may be the result of pressure depletion over time or be caused by low original reservoir pressure. To compensate for the lack of natural energy in these formations, operators equip the wells with artificial lift (AL) systems. Artificial lift well candidates are those completed in formations that have economically viable reserves and sufficient permeability for the fluids to move to the wellbore but do not have sufficient reservoir drive to lift those fluids to the surface.

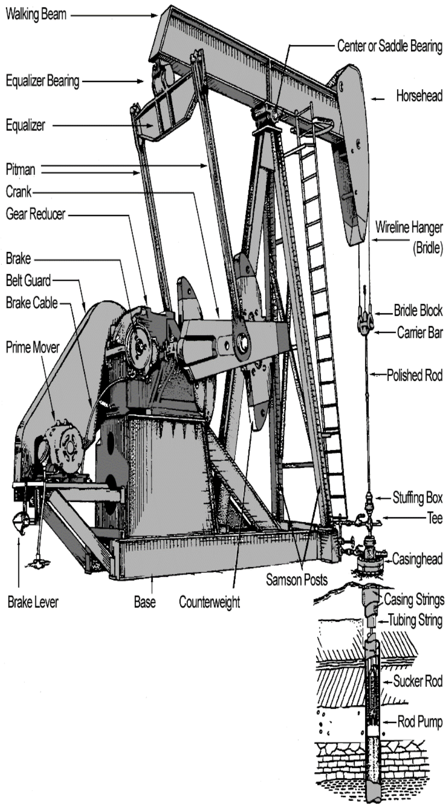
2.3. Gas Lift model

Gas lift is a method of artificial lift that uses an external source of high-pressure gas for supplementing formation gas to lift the well`s fluids. The principle of gas lift is that gas injected into the tubing reduces the density of the fluids in the tubing, and the bubbles have a "scrubbing" action on the liquids. Both factors act to lower the flowing bottom-hole pressure (BHP) at the bottom of the tubing. There are two basic types of a gas lift today: continuous and intermittent flow. Figure 5 shows a model that represents a fully functional lab-scale gas lift system. Students can visualize how gas is being injected into production tubing and how oil is being lifted by the injected gas.

Figure 5 shows a model represents the gas lift technique

2.4. <u>Beam Rod pump model</u>

Beam pumping, or the sucker-rod lift method, is the oldest and most widely used type of artificial lift for most oil wells. A sucker-rod pumping system is made up of several components, some of which operate aboveground and other parts of which operate underground, down in the well. The surface-pumping unit, which drives the underground pump, consists of a prime mover (usually an electric motor) and, normally, a beam fixed to a pivotal post. The post is called a Sampson post, and the beam is normally called a walking beam. Figure 6 presents a detailed schematic of a typical beam-pump installation. Figure 7 represents a fully functional lab-scale model of beam pump. Students can see the downhome section of the beam pump, and how it works. Students can visualize moving and fixed parts of the pump.



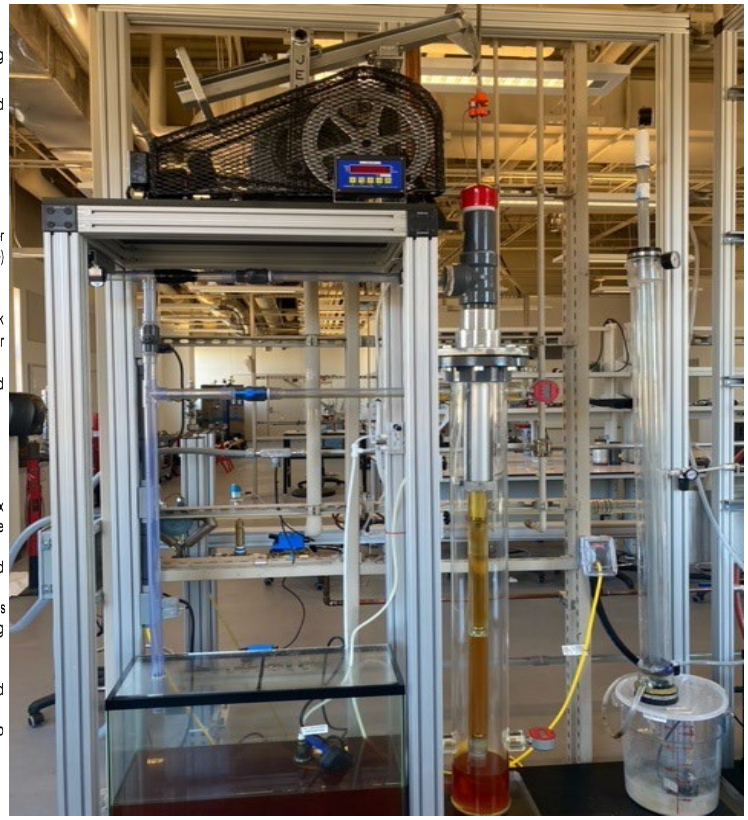


Figure 6 shows a typical beam pump

Figure 7 represents a fully functional lab-scale model of beam pump

- **Oil, water, and gas separator process**

2.5. Horizontal separator model

An oil/gas separator is a pressure vessel used for separating a well stream into gaseous and liquid components. They are installed either in an onshore processing station or on an offshore platform. Based on the vessel configurations, the oil/gas separators can be divided into horizontal, vertical, or spherical separators. In teams of fluids to be separated, the oil/gas separators can be grouped into gas/liquid two-phase separator or oil/gas/water three-phase separators. To meet process requirements, the oil/gas separators are normally designed in stages, in which the first stage separator is used for **preliminary** phase separation, while the second and third stage separator is applied for further treatment of each phase (gas, oil, and water). Figure 8 presents a detailed schematic of a typical horizontal separator. Figure 9 represents a fully functional lab-scale model of the horizontal separator. Students can see how oil and water are being separator when they enter the horizontal separator. Students can see the inter-component of the separator and the function of each part inside the separator.

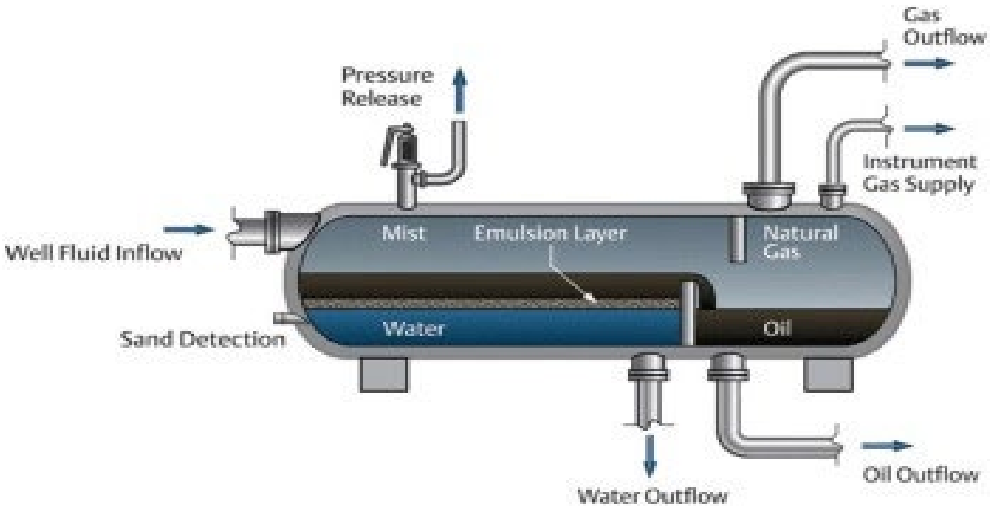
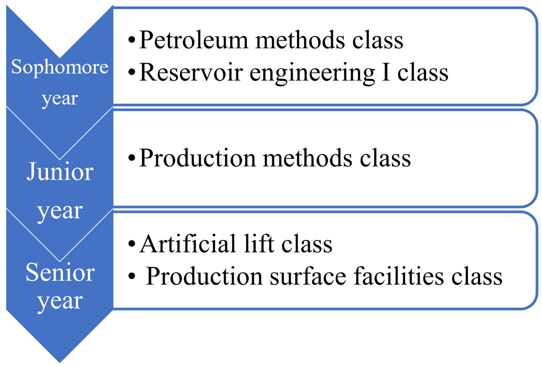


Figure 8 presents a detailed schematic of a typical horizontal separator


Figure 9 represent a fully functional lab-scale model of a horizontal separator

3. How These Labs Are Being Used in Teaching Petroleum Engineering Courses.

Students are exposed to our visualization labs in all academic levels, sophomore, junior, and senior years, as shown in the chart below.



In one class, a faculty member goes through the theoretical, principles, and calculations of a certain topic, such as the beam rod pump model (model 2.4), and in the next class, students are being divided into small groups and taken in the labs. While the model is operating, the faculty and his TA explain to students; how does the pump works, highlight design elements, and try to connect what was mentioned in the previous lecture to the running model.

4. Students' Feedback About Using Visualization Labs in Teaching Petroleum Engineering Students.

Research suggests hands-on teaching experiences; allow for a realistic environment and promote active learning, enhance critical thinking and decision making, and improve students' performance and attainment of the course's objectives. For example, a diver is more likely to recall specific instruction when it is learned and practiced in water rather than on land (Baddeley, 1993). In this section, students were asked to give their feedback on the utilization of visualization models in teaching petroleum engineering classes. The authors used qualitative method to study the efficacy of visualization labs in:

➢ Improving students' performance and attainment of courses objectives.
➢ Enhancing critical thinking and decision making, and
➢ allowing for a realistic environment and promoting active learning.

- **Study sample**

The junior and senior students of the academic year of 2020-2021 at the petroleum engineering department were the populations of the study. There are 34 senior and 35 junior targeted students. All students were taken the same survey questions; however, each group was sent a different survey link. This was done to differentiate junior and senior responses from each other.

- **Survey questions**

a) Did visualization labs create a realistic environment and promote active learning?
b) Did visualization labs enhance your critical thinking for example when you are designing a production technique?
c) Overall, did visualization labs help in attaining the course`s objectives and make complex subjects easy to understand?

5. Survey Results

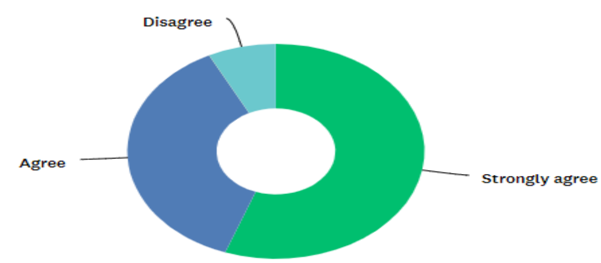
The total responses that have been collected are 51(27 seniors and 24 juniors) out of 69 junior and senior students. The rate of responses is about 74% of the targeted number of students.

5.1. <u>Senior students' responses to the three survey questions</u>

Q1 Customize Save as

Did PE visualization labs& OTC create a realistic environment and promote active learning?

Answered: 27 Skipped: 0

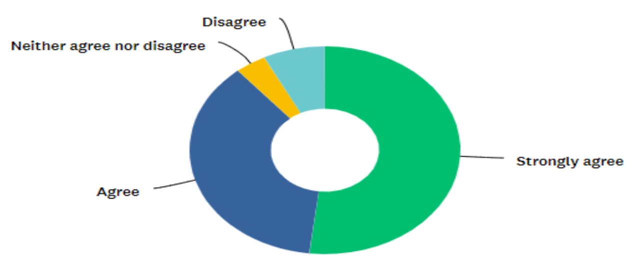


ANSWER CHOICES	RESPONSES	
Strongly agree	55.56%	15
Agree	37.04%	10
Neither agree nor disagree	0.00%	0
Disagree	7.41%	2
TOTAL		27

Q2 Customize Save as

Did visualization labs and OTC enhance your critical thinking for example when you are designing something related to oil and gas production?

Answered: 27 Skipped: 0



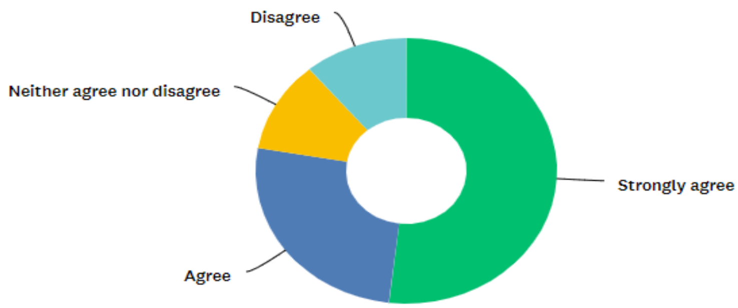
ANSWER CHOICES	RESPONSES	
Strongly agree	51.85%	14
Agree	37.04%	10
Neither agree nor disagree	3.70%	1
Disagree	7.41%	2
TOTAL		27

Q3

Customize Save as

Overall, Did visualization labs & OTC help in attaining the course`s objectives and make complex subjects easy to understand?

Answered: 27 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	51.85%	14
Agree	25.93%	7
Neither agree nor disagree	11.11%	3
Disagree	11.11%	3
TOTAL		27

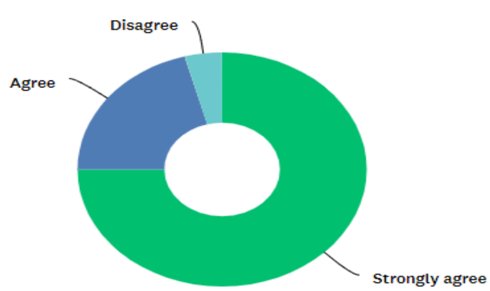
5.2. Junior students' responses to the three survey questions

Q1

Customize Save as

Did PE visualization labs& OTC create a realistic environment and promote active learning?

Answered: 24 Skipped: 0



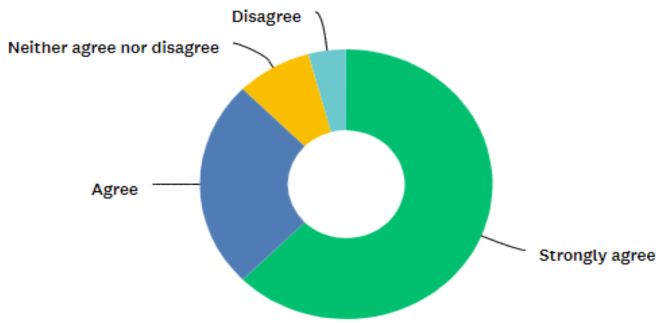
ANSWER CHOICES	RESPONSES	
Strongly agree	75.00%	18
Agree	20.83%	5
Neither agree nor disagree	0.00%	0
Disagree	4.17%	1
TOTAL		24

Q2

Customize Save as

Did visualization labs and OTC enhance your critical thinking for example when you are designing something related to oil and gas production?

Answered: 24 Skipped: 0



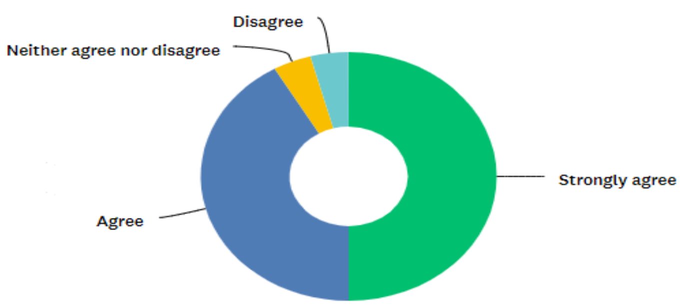
ANSWER CHOICES	RESPONSES	
Strongly agree	62.50%	15
Agree	25.00%	6
Neither agree nor disagree	8.33%	2
Disagree	4.17%	1
TOTAL		24

Q3

Customize Save as

Overall, Did visualization labs & OTC help in attaining the course`s objectives and make complex subjects easy to understand?

Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	50.00%	12
Agree	41.67%	10
Neither agree nor disagree	4.17%	1
Disagree	4.17%	1
TOTAL		24

6. Conclusions

- Visualization models can be used as a pre-experience to give students some idea of what they will encounter in actual equipment. This can improve laboratory safety by familiarizing students with the equipment before using it.
- Visualization models are useful for experimental studies of systems that are too large, too expensive, or too dangerous for physical measurements by undergraduate students.
- Based on the survey results, there is a consensus among Junior and Senior students about the efficacy of using visualization labs in teaching petroleum engineering classes.
- Visualization labs did create a realistic learning environment for students.
- The ABET first student outcome is 'an ability to identify, formulate, and solve complex engineering problems by applying engineering, science, and mathematics principles. It is clear from student responses that visualization labs help them make complex topics easy to understand so visualization labs help in attaining ABET outcome 1.
- The ABET second student outcome is 'an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. It is clear from student responses that visualization labs help students in designing components, hence visualization labs help in attaining ABET outcome2.
- Overall, the department ABET student outcomes 1-7 assessment methods, developed for ABET evaluation, showed that visualization labs can be an extremely effective method in petroleum engineering education in general and more particularly in complex topics related to reservoir and production engineering.

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