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ENGAGING STUDENTS THROUGH A FUN GAS LAWS EXPERIMENT

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Abstract

Hands on practical experiments are a vital element in illuminating engineering concepts which are complicated or hard to grasp. Two topics which come under this are Archimedes' principle and the gas laws.

The authors have created a laboratory experiment that is simple to set up and quick for students to do where they weigh balloons filled with different gases and determine their contents using Archimedes' principle and the gas laws.

The laboratory has been made more fun as it is presented as a puzzle to solve; which gas is in which coloured balloon? By providing fewer balloons than there are groups, students have to share, making the lab more kinaesthetic. Through thinking about lift, displacement, and the gas laws, students develop a good understanding of the principles required while enjoying the learning experience.

Keywords: Practical Education. Gas laws, Fun, Thermodynamics, Experimental Methods.

2. Introduction

Laboratories form a key part of engineering courses. There are various purposes for them, but one aim is to get students to understand the physical relationships that they need in order to function as effective engineers. Most students will start many Engineering courses with some familiarity of the gas laws, but these will need to be revised to ensure a good grounding for thermodynamics. Undergraduate students will have already been introduced to Archimedes' principle but often they do not recognise it as being relevant to their studies. Lab equipment on the gas laws can be quite expensive, and generally only shows the relationship between pressure, volume and temperature [1]:

$$\frac{PV}{T} = \text{constant}. \quad (1)$$

Research has shown that there are numerous ways of making labs more interesting, gamification being one of them. The authors have taken a similar approach to try to make the laboratory which supports teaching of the gas laws more fun, interesting, memorable and engaging for students. Even the name is slightly whimsical, being derived from Jasper Fforde's fictional game show, 'Name that fruit!' [2].

So the idea of using coloured balloons to teach the gas laws was therefore conceived. The concept is simple, weigh a series of empty balloons and write the measured weight on them. Then fill them with different gases and let students weigh them again. By applying the gas laws and Archimedes' principle it *should* be relatively straightforward to determine what gas the balloon is filled with.

Literature review

Making labs more attractive to students should be a key element in their design and delivery. Recently the idea of 'Gamification' [3, 4] has been introduced to help student engagement through the accumulation of points to incentivise their progress. This can be conducted in both actual and virtual laboratories [5] and can encourage students to attend and engage with activities. There is a far smaller corpus of work on labs being 'fun', and most of them cross over into gamification. In their book, Petrich, Wilkinson and Bevan [6] look at the relationship between fun and learning for school children and show that 'tinkering' can be very valuable to student's learning and are a form of intrinsic motivation. Conscious lab design for 'enjoyment' is rare, but does exist and is reported as a powerful enabler to student engagement [7].

Slightly surprisingly, there are a number of papers on the value of balloons for learning, though generally for young children. Two examples provide a history of gamification and the use of balloons as a useful carrier for the learning about colours and numbers; these were by Taylor, Gummer and Welland [8] (in a piece of work sponsored by The European Balloon and Party Council) and Oyshi, Saifuzzaman and Tumpa [9]. The concepts of gamification and fun are clearly shown as a thread through the conceptualisation and actualisation of the activity. As university level use of balloons in practical teaching, Bartholomew and Zürcher [10] use measurements on a balloon to compare the volume and nonlinear elastic properties of the balloon to those in the aorta. This again uses simple equipment and principles to excite the students through the ideas of science.

Teaching the gas laws is important for engineers and scientists. Lin, Cheng and Lawrenz [11] demonstrated that both teachers and 11th grade students (US) have misconceptions on the gas laws. They conducted the research by asking teachers

and students to explain 4 scenarios involving volumes and pressures. They point out the value of verbalising concepts to aid understanding as important. They also point out the move from Aristotelian understanding to that of the scientific method is one that should be promulgated from early experiences. The fact that they found that staff and student understandings and misunderstandings of the concepts are similar shows the importance of assimilating concepts before teaching them.

Most of the papers on teaching the gas laws use variations of Boyle's and Gay-Lussac's laws and they are generally designed for pre university students. For example, Liew and Kalbus use buoyant balloons to find the molar mass of lighter than air gasses [12] and Zabel [13] Uses a scale and Archimedes' principle to estimate the molar mass of a known gas in a balloon. Clarkson, Mills, Sweeney and Marino [14] used the gas laws as an exemplar for teaching various topics using a problem based learning approach. They used two experiments (both on closed systems) to look at static and dynamic response of gases. Here, they were looking at the response rather than measuring the mass of gas or number of moles. McPherson [15] used the gas laws to get high school students to think about the gas laws in a Problem Based Learning (PBL) context. They used balloons and syringes under vacuum to find the weight of air. This has some interesting health and safety issues which would be difficult to get around due to the use of nails to hold the syringes open under vacuum. This experiment did however, allow students to measure the moles of gas and molar mass of gas. Hammar [16] looked at the teaching of the gas laws to high school students. They also apply a PBL approach to test Charles' and Boyles' laws. This approach helped student understanding of the gas laws. It can be seen that none of these approaches to balloons and the gas laws are for University level students or include the key 'fun' enquiry of what balloon contains which gas. There is also little student feedback in these papers which could add evidence to the effectiveness of these as learning experiences.

Limpanuparb et al [17] describe an experiment in which they get students to use a syringe to measure volume, with easily obtained equipment. Also they employ a hot plate and water bath to alter the temperature. As in many of the previous pieces of work, this is designed for pre university level students. University student need to develop higher level inquiry, experimental and analytical skills, so a less didactic approach should be used. A recent paper on the teaching of the gas laws [18] for university level chemistry students again uses syringes. The students are provided with pre and post lab questionnaires which adds to the value of this paper, but it is still very didactic and formal. None of these papers address whether the labs are, fun or have a kinaesthetic element which help student engagement and retention.

For experimental work, all the published and commercial gas law experiments that the authors have found examine the impact of changing temperature, pressure or volume. They mostly involve pistons (which demonstrates Boyle's Law) or heating up gases (demonstrating Gay-Lussac's Law). Neither involve calculating the quantity of gas in the system. For example, a commercial device requires the pushing of a syringe which increases the pressure and temperature of a gas which then cools down allowing the temperature change to be measured. This will include heat transfer to the walls of the syringe [19] which may overly complicate the experiment. Other equipment on sale includes larger scale cylinders with a volume of oil to keep the temperature constant [20] which demonstrates that pressure is inversely proportional to volume. Similar equipment can be produced with a screw controlled piston with a dial gauge as in the 3BScientific Boyle-Mariotte Apparatus [21]. These all look like routine scientific apparatus with little to distinguish

between them. It is unlikely that students would recall the lab at a later date, as good labs are memorable. It can also be seen that these same experiments would be suitable for students at pre university level as there is little quantitative reasoning required which means that the learning would be more superficial Phunsa and Pawala [22] do not apply this to labs, but show that games produce greater retention due to 'Their interactive nature, immediate feedback, and motivational component'. So creating labs which move away from the conventional equipment and routine data acquisition could aid engagement.

The most recent available literature shows a dearth of new gas laws experiments [10 ,18] and the unengaging nature of many of the commercially available experiments shows that a new student centred approach to this should be developed. Almost all of the published ones are for pre university students, very explicit and work mostly as demonstrations. Few of the published papers use student feedback to examine their effectiveness which are an important element of the present work. The sector movements towards gamification [5] and more efficient use of laboratories [23] also offer routes forward to engaging and effective student lab experiences.

It can be seen that a more effective way of getting students to understand the gas laws using cheap equipment would be a useful addition to the arsenal of teaching methods. The use of balloons and scales is a possible way of doing this.

Research question

Will a novel, cheap and fun experiment using balloons to teach the gas laws be an effective educational experience for University students?

Objectives

1. Using different gases, scales and balloons, devise and deliver an experiment to teach students the gas laws and get their feedback
2. Use this feedback to refine the experiment so it is fun and effective.
3. See how the use of this experiment can aid student understanding of the gas laws and Archimedes' principle.

3. Method

Sets of five different colour balloons are selected and each colour of balloon is filled with a different gas. They are then weighed in order to determine their contents. The sequence to setting up the experiment prior to the students arriving is described below for each five groups, who each get one balloon, the full set of balloons being obtained by swapping with other groups.

To prepare the experiment, in a suitably equipped space, select one uniform (see error analysis) balloon of each colour and weigh them empty. Write each weight in large characters on the unfilled balloons using a permanent felt pen. For the one(s) to be filled with helium, the recorded (empty) weight must include a length of string and a weight to stop it floating away.

Then the balloons must each be filled to the same diameter. To make this easier, a template should be used. This can be a sheet of material with a suitable sized hole in it, or some wooden or cardboard callipers. The balloons are knotted and the weight and string are attached to the helium filled one (figure 2 (right)). The lab gas supply which dictated the selection of gases, but bottled gases could equally

well be used. It is important that the air filled balloon is not blown up by mouth. A pump or lab air supply is needed to ensure that the air is dry.

In the experiment the students simply weigh each of the balloons. They can then calculate the molar mass and hence decide what gas each is filled with. For this, lab quality scales are needed that can measure to 1 mg though these were set to 10mg resolution for this experiment. We used the KERN PFB 120-3 balance [24]. The balloons were originally held on the scales using clear adhesive tape (Sellotape or Scotch tape). The tape should not be too adhesive or the balloons may ‘pop’ when removed from the scales. More recently, we have used trays to stop them rolling off the scales.

The balloon that was filled with carbon dioxide was found to deflate over the course of the lab. It turns out that CO₂ actually dissolves in the rubber and the volume of the balloon decreases [25], though not its weight, so it displaces less air. Thus it is necessary to replace these balloons every hour or so to ensure that the results for the CO₂ filled balloons are still valid.

The cheap balloons that are used leak hydrogen rapidly as the small molecules can escape through the rubber, but it is easy to buy sealants designed for party balloons which stop these going down [26] for several days.

There are no major hazards associated with the lab. In the faculty of Engineering at Sheffield [23], all of the laboratory experiments have prelab as described by Garrard & Nichols [27] which includes a section on H&S.

3.1. Calculations

The Universal gas law¹ states that for an ideal gas

$$pV = nR_uT \quad (2)$$

For a gas, we can say that the mass of this volume of gas is

$$m = nM \quad (3)$$

The aim of our experiment will be to find M , the molar mass for a gas; which can be used to find out what gas it is using a table. M Substituting equation (3) into equation (2) and rearranging gives equation (4).

$$M = \frac{mR_uT}{pV} \quad (4)$$

This would be very straightforward were it not for Archimedes’ principle [28]. So, we must account for the mass of displaced air when the balloons are placed on the scales. The measured weight of the filled balloon, m_f , is made up of the weight of the empty balloon, m_e , plus the weight of the gas in the balloon, m_i , minus the weight of the air displaced, m_o . This is shown in equation (5) and figure 1.

$$m_f = m_i + m_e - m_o \quad (5)$$

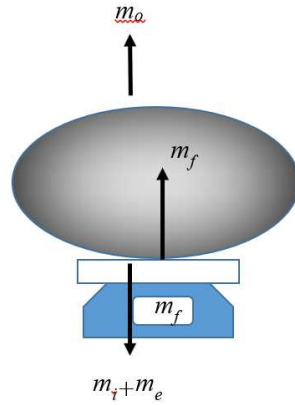


Fig 1. Free body diagram of gas filled balloon

The volume of the balloon can be calculated, assuming that it is round in one axis and elliptical in the other (a prolate spheroid). This can be derived in a number of ways, but it means that the calculated volume V is approximately.

$$V = \frac{\pi D^2 L}{6} \quad (6)$$

Where L is the length of the balloon and D is its diameter, both in metres. Modelling a balloon from its actual profile gave a volume that was within 1% of the prolate spheroid approximation.

When developing the experiment, it was noted (with surprise) that the air filled balloon weighed more full than empty. It was ultimately ascertained that this was because the gases within the balloons are slightly pressurised as a result of the elastic tension of the balloon material. This was included in the analysis. This issue has been tackled in two ways: by calculation and measurement.

The calculation approach uses equation (4), the mass of air displaced by the balloon is:

$$m_o = \frac{p_o V M_{air}}{R_u T} \quad (7)$$

Where m_o and p_o are the mass and pressure outside a balloon filled with air. It is fine to assume that the lab air is at 1 bar and 293 K. By rearranging equation (4), the mass of air inside the balloon, m_i , is the difference in weights between the full and empty balloons, plus the mass of air displaced by the balloon, all of which are now known.

$$m_i = m_f - m_e + m_o \quad (8)$$

Measurements for m_e and m_f are shown in figure 2. Note that m_e must be measured and recorded before the balloon is filled.

Now m_i is known, equation (9) gives the balloon's internal pressure, p_i .

$$p_i = p_o + \frac{(m_i - m_o) R_u T}{V M_{air}} \quad (9)$$

It is important to ensure that students use appropriate units, which in this case are metres (m), Pascal (Pa) and Kelvin (K). As all pressures are in Pa, it is important to use R_u as $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$.

Then, to find to find the molar mass M_i for each of the gases, we use equation (10) which is derived from substituting a rearranged version of equation (4), into equation (8).

$$M_i = \frac{R_u T}{p_i V} (m_f - m_e + m_o) \text{ (g mol}^{-1}\text{)} \quad (10)$$

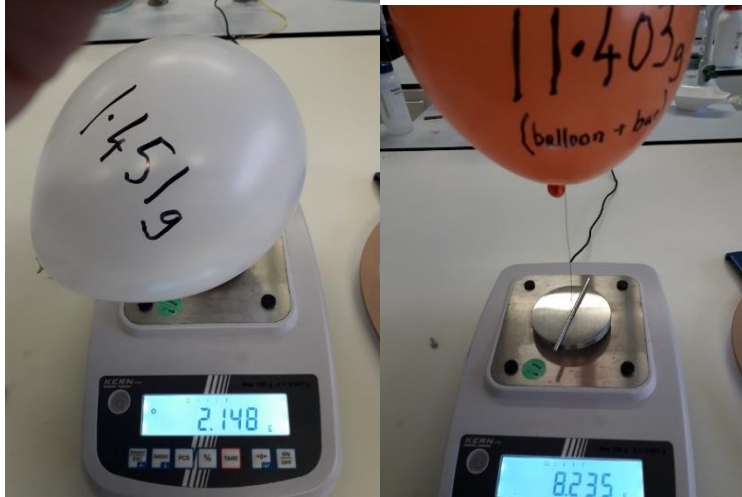


Fig 2. Left, air filled balloon with 0.697g weight increase due to balloon pressure. Right, Helium filled balloon with net negative weight of 3.168g.

As V , p_i and m_o have already been calculated for the air filled balloon, we either know, can look up, or can measure, everything except M_i which we can therefore calculate.

$$M_i = k(m_f - m_e + m_o) \quad (11)$$

Where

$$k = \frac{R_u T}{p_i V} (\text{mol}^{-1}) \quad (12)$$

Students must engage with other groups to negotiate a full set of balloons to experiment on.

A table is provided in the lab so the students can associate their value of molar mass, M_i with an actual gas. On Table 1 (below), the gases actually used are shaded in the balloon colour and the colours of the balloons included.

Gas	Molar Mass g mol ⁻¹	Colour of Balloon
Air	28.97	Yellow
Ammonia	17.03	
Argon	39.95	Green
Carbon Dioxide	44.01	Blue
Helium	4.003	Red
Hydrogen	2.016	
Methane	16.04	
Isobutane	58.12	
Nitrogen	28.01	Orange
Oxygen	32.00	
Propane	44.10	
Steam	18.02	

Table 1. Molar mass of some gases. The gases used are in shaded boxes.

4. Results

To provide some indicative results, the following data were acquired by the authors. The balloons were measured as 25.5cm long and a diameter of 21 cm. To calculate

the interior pressure from the weight, the empty and full balloon was weighed as 2.38 g and 2.623 g respectively (figure 3). Using the equation (10) above, this gave a gauge pressure of 3423 Pa.

This was compared to a U tube water manometer attached to a balloon of the same diameter. This pressure can be calculated from the water rise in the manometer using equation (13).

$$p_i = p_o + \rho g \Delta z \quad (13)$$

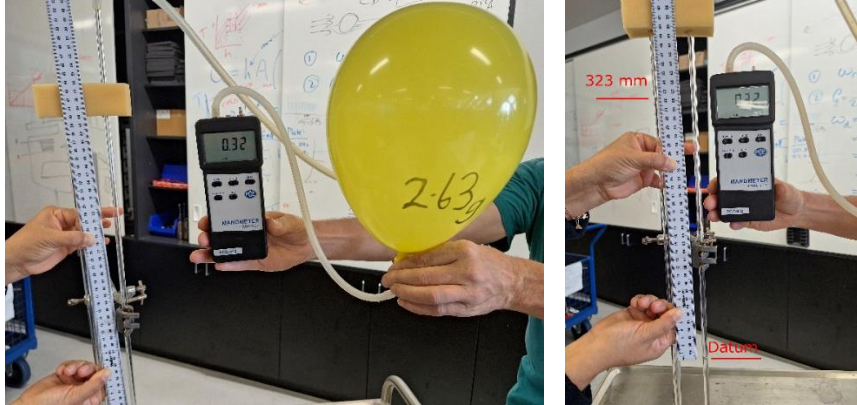


Fig 3. Air filled balloon showing (left) the manometer and (right) a close up of the manometer showing the interior gauge pressure as 323 mm H₂O.

This gave an interior gauge pressure of $p_i = 1000 \times 9.81 \times 0.323 = 3169$ Pa. Which is very close to the pressure calculated from the weight (3423 Pa). This additional experimental measure of the internal pressure can be supplied for students as an additional element in the experiment.

The mass of air displaced, m_o , was calculated from equation (8) as 7.01 g. This was used in all of the calculations which then supports the students' understanding of Archimedes' principle. Example results for the molar mass, based on experimental results are shown below in table 2.

Gas	Balloon colour	Empty weight (g)	Filled weight (g)	Measured M g mol ⁻¹	M g mol ⁻¹
Air	Yellow	2.38	2.62	29	29
N ₂	Orange	2.28	2.37	28.4	28.01
CO ₂	Blue	2.33	6.06	43.0	44
Ar	Green	2.34	5.51	40.7	40
He	Red	12.55	6.47	3.7	4

Table 2. Experimental results and calculated and published Molar masses.

The experimental results are close enough to the actual ones to allow students to identify what gas they are from the table.

Errors and uncertainties

There are quite a number of errors and uncertainties in this experiment, so this experiment will either lend itself to ignoring them or looking the error more deeply. The latter is probably not a good use of students' time as they very soon become very complicated to analyse and there will be better experiments for looking at

experimental error. As we are generally looking for the difference between two similar (in some cases) numbers, the authors have propagated through some errors and will report on the results. The errors will come about for three main reasons

1. Scales readings. This is not really an issue as they read to 2 decimal places in over 2 grams. This is less than a 1% error and a 0.02 g error in reading gives a maximum error in molar mass (for the Helium) of 2%, which will not affect the identification of the gas.
2. Difference in balloons If the tested balloon is (say) twice as thick as the air filled one, its difference internal pressure to external pressure will be double. So there will be more air in it than predicted.. This gives a 2% maximum error in molar mass for all of the gases except for Helium where there is an 18% discrepancy (from 4 to 4.9 kg kmol⁻¹). This will not stop students identifying the Helium, but shows that it is important to try to get similar balloons for the different gases.
3. Balloon diameter and length. If the tested balloon is 1 cm smaller in all dimensions than the air filled one, then there will be a 15% error in molar mass, which renders the experiment invalid for many of the gases. The diameter of the balloons should be within 3mm of each other for the error in Molar mass to be less than 5% which will allow identification. This shows the importance of using either callipers or a template when filling the balloons.

It can therefore be seen that accurate filling and measuring of the balloons is crucial, particularly for gases close to the molar mass of air.

5. Student feedback to examine the effectiveness of the Lab

A questionnaire was created to get student feedback on the effectiveness of the experiment. This was used on our first year Aerospace Engineering students. Though this experiment is suitable for many engineering disciplines. 48 responses out of about 240 students were obtained. The questionnaire's aim was to find out whether the students improved their understanding of: the main learning outcomes of the laboratory, the gas laws and Archimedes' principle, and also to ascertain whether the students found it an engaging and effective way of learning. Based on the authors' previous interests in lab group size and duration [29], questions were asked about these too. Free text responses were also solicited to see what students liked or disliked about the lab. A the questionnaire is included in Appendix A.

Desired lab group size	Number of responses
1	1
2	11
3	17
4	19
5	0

Table 3: Students' desired lab group size

The lab group size for this experiment was generally four students. When asked about desired group size, the most common answer, as shown in table 3 was four, the same. However groups of two and three were also popular. This generally agrees with the results from the survey reported in Beck, Lazari and Di Benedetti

[29] where smaller lab groups were generally desired, but Mechanical Engineering students liked groups of four best of all.

When students were asked about lab duration, Table 4 shows that they liked the one hour duration of the lab. Once again this demonstrates that there is no need to extend labs beyond a natural point and that shorter is often better, but they must be sufficient duration for the students to achieve the learning outcomes without rushing.

Relative lab duration	Number of responses
Shorter	5
The same	39
Longer	4

Table 4. Students' desired lab length.

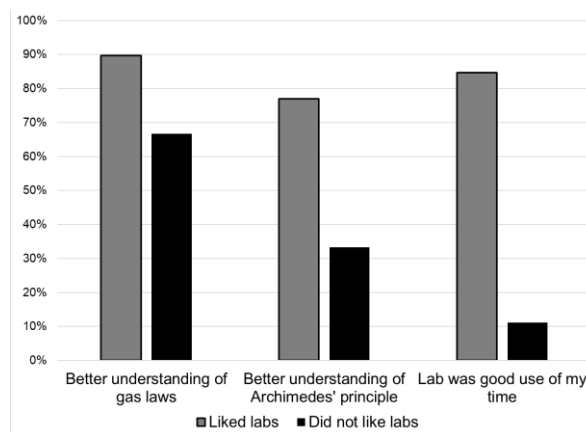


Fig 4. Students' response to questionnaires (% agree) divided by whether they liked the lab (n=39) or did not (n=9).

Figure 4 shows the normalised results for all of these questions. Here the differences between students who liked and disliked labs is visible, but a statistical analysis was conducted to see the validity of this hypothesis.

5.1. Statistical analysis of questionnaires

The authors examined whether students who liked the labs differed in their perceived understanding and enjoyment from those who did not. For three of the questions, we applied a χ^2 test [30] to the data to see if students who liked and disliked the lab learned about the learning outcomes or thought that the lab was a good way to learn [31]. In all cases, the null hypothesis assumed that there was no significant difference in learning outcomes between students who enjoyed the lab and those who did not. If this is rejected by the χ^2 test then we can infer that they feel similarly about the questions, whether they like labs or not.

We can thus examine if the lab was effective even for those who did not enjoy it. When we look at the data, shown in Table 5, The null hypothesis was rejected. This shows that there was unlikely to be a relationship between liking the lab and understanding the gas laws. Students believed that they improved their understanding of the gas laws whether they liked the lab or not. This indicates that the lab achieved its main aim of teaching students about the gas laws.

	Liked lab	Did not like lab	Marginal row totals
Better understanding of gas laws	35	6	41
Not better understanding of gas laws	4	3	7
Marginal column totals	39	9	48 (Grand total)

Table 5: Results for students liking lab and understanding the gas laws. The χ^2 statistic is 3.126. The p -value is 0.0770. Not significant at $p < .05$.

It should be noted that the sample size for those who did not like the lab was small and even a single response could alter the statistics notably. However, two thirds of the students who did not like the lab reported that it gave them a better understanding of the gas laws, compared to five sixths of those who did. A number of students who like the labs, however, said that it did not improve their understanding of the gas laws. So we can deduce that the social, practical or balloons aspect meant that it was engaging, if not universally instructive.

	Liked lab	Did not like lab	Marginal row totals
Better understanding of Archimedes' principle	30	3	33
Not better understanding of Archimedes' principle	9	6	15
Marginal column totals	39	9	48 (Grand total)

Table 6: Results for students liking lab and understanding Archimedes' principle. The χ^2 statistic is 6.46. The p -value is 0.0110. Significant at $p < .05$.

As shown in Table 6, we see that the improved understanding of Archimedes' principle was generally lower than that for the gas laws. This was markedly so for those who did not like the lab compared to those who did. Here the χ^2 test indicates that the students who liked and disliked the lab formed different groups in their improved understanding for this aspect. After these results were obtained and analysed, it was clear that the lab sheet did not clearly identify the element of displaced air and showed that this was needed which would more clearly show the importance of Archimedes' principle. The improved lab sheet, shown in Appendix B, gets the students to explicitly calculate the mass of the displaced air and then uses this in all the subsequent calculations.

	Liked Lab	Did not like lab	Marginal Row Totals
Good use of time	33	1	34
Not good use of time	6	8	14
Marginal column totals	39	9	48 (Grand Total)

Table 7: Results for students liking lab and believing it to be a good use of time. The χ^2 statistic is 19.12. The p -value is .000012. Significant at $p < .05$.

Table 7 shows that student who enjoyed the lab thought it a good use of their time, whereas those who did not would rather learn these concepts in a different way (or possibly not at all).

It is worth noting that the lab was only one hour's duration and 80% of the students who responded to the survey did enjoy the lab.

6. Discussion

It is difficult to find out how well the understanding of the students is affected by the lab, given that there are also tutorials and quizzes on the topic. However, when questions were asked on the gas laws in the exam, 80% of the class answered correctly. This was comparable to the other questions in the test. The balloon buoyancy theme can be further explored in tutorial by asking the students how many helium balloons (of a certain size) it takes to lift a teddy bear off the ground, a parallel to the Winnie the Pooh story by A.A. Milne [32]. All of these elements add to the 'Fun' aspects of the lab and the topics. Repetition of concepts helps to reinforce them in the learner's mind. If this can be done in an engaging way, then that supports learning too. The delivery of practical teaching at the University of Sheffield has been implemented using very large laboratories that are shared between the entire Faculty of Engineering [23]. Thus, in this one hour laboratory, delivered to 80 students at a time, up to 320 can do the laboratory in half a day. This allows the lab to be timed to coincide with the teaching for the entire cohort.

Movement also supports learning. As Kuczala, Lengel and Kuczala [33] point out "Learning does not begin from the neck up. It happens from the feet up". This is reinforced by McGlynn and Kozlowski [34] who show that for middle school students, movement and indeed laboratories themselves, aid learning above stationary activities. Having to exchange balloons with other groups adds to the 'fun' and collaborative nature of the experiment. The different coloured balloons also add to the atmosphere in the lab with students needing to complete a full set to complete that lab.

It was also clear that most students enjoyed the lab. There are a number of reasons why this is more enjoyable than many lab experiences, particularly ones with a very defined outcome and equipment that is designed to be easy to read. In this experiment, the students only read the size and weight of the balloons and have to infer that the weight of the gas comes from the various masses and displacements. It will be noted that the lab sheet is quite directive and that a student could get to the end of it without fully engaging with the concepts behind the lab, however, as pointed out above there are other opportunities to ensure that students to show that they have engaged with the concepts.

Questions that we get when running the lab include "Does the floating balloon's tare weight include the weight attached to it?". This allows us to show the generality of the approach and gets students to think about weights, displacements and Archimedes' principle. It came as a surprise to the authors that the air filled balloon weighed more than an empty one. This clear example of Archimedes' principle will help students appreciate its importance.

Another issue that students often need assistance with is that of units. Two confusions arise here, firstly that of moles, kmol, kPa, Pa, Joules and kJ. It is important that students know that if they use R in $\text{J g}^{-1} \text{K}^{-1}$ in $pV = mRT$, then the pressure, p is in kPa. From tutorials and exams, it is clear that this can cause confusion. There can be also confusions if students use R instead of R_u to calculate

$pV = mRT$. This experiment should instil the idea that the molar mass, M , is important when calculating the mass of a gas.

7. Concluding remarks

The laboratory experiment is a novel, cheap, simple method of teaching of the gas laws. The authors feel that this is an important topic, but that a lot of the equipment that is sold to teach this is both obvious (half the volume, double the pressure...) and misses out on the mass of the gas.

It is both interesting and gratifying that even students who did not enjoy the lab reported that they had an improved understanding of the gas laws. This could be due to them taking a more utilitarian approach and keeping their attention on the key output (molar masses). Students who did not enjoy the lab overwhelmingly thought that it was not a good use of their time. This is possibly due to them having a different (less kinaesthetic) learning style.

The question about an improved understanding of Archimedes' principle had a lower positive response for students who both liked or disliked the lab, and particularly lower for those who did not. This showed that this element of the experiment needed to be strengthened, which has now been done in updated the lab sheet.

Some care is needed when setting up the balloons because the sizes need to be the same. Also, some packets of mixed coloured balloons are of different thickness which will affect the internal pressure. This can be useful to discuss if there are discrepancies in the results!

Also, when discussing the results with students, it can be useful to clarify a couple of points about Avogadro's number. Firstly, that the calculated molar mass of air is exactly the same as that used in the calculations. This is due to the fact that the molar mass calculation is the opposite of the air displaced calculation, so the molar mass propagates through. This can be further elucidated by stating that the early gas laws (Dalton, Gay-Lussac, Charles) used ratios between atomic weights, so the relative molar masses could be created even without a constant (later supplied by Avogadro, with hydrogen atoms weighing $1.00784 \text{ g mol}^{-1}$). These concepts can stretch the brighter students who can look beyond the problem in hand, to debate the issues faced by the early Chemists.

The idea of fun rather than formal investigation adds a degree of whimsicality and play to the lab which makes it more memorable. This approach can be deployed in other contexts such as 'Name that metal!' where an examination of the properties of a painted sample can lead the students to working out from what material a torsion sample is constructed [35].

It would be good to use gases with larger molar masses than CO_2 (44 g mol^{-1}). Hydrocarbons such as Butane (58 g mol^{-1}) would be ideal, if they were safe, and refrigerants (R134a has a molar mass of 102 g mol^{-1}) which would actually feel heavy in a balloon would be a suitable gas. This could also lead on to looking at non-ideal gases and the use of tables and virial equations.

Future work should include larger samples of student feedback and should also doing a longitudinal study of students' understanding of the gas laws before and after this experiment.

The introduction of a fun element, using balloons, movement and needing to share makes the laboratory enjoyable. The equipment is cheap, simple and safe. That the identity of the gases in the balloons can be ascertained by the use of scales and an understanding of the gas laws is interesting for the students. This is thought

to be far more engaging than the conventional experiments using pistons and pressures. It could also be used to look at instrumentation in terms of sensing. Using direct (digital meter and manometer) and indirect (scales) techniques for obtaining the pressure inside balloons of different sizes would be interesting and would lead to further studies on experimental errors.

An understanding of the gas laws is important to engineering students. While the theory is simple, it is useful to get a feeling for what they mean; this also needs to be combined with an understanding of buoyancy. This simple, fun, memorable experiment helps students engage with these concepts.

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Nomenclatures

D	Diameter, m
g	Gravitational acceleration, ms^{-2}
h	Height of manometer column, m
k	A constant, mol^{-1}
L	Length, m
m	Mass, g
M	Molar mass, gmol^{-1}
n	Number of moles
p	Pressure, pa
R	Gas constant, $\text{J g}^{-1} \text{K}^{-1}$
R_U	Molar gas constant, $8.314 \text{ J mol}^{-1} \text{K}^{-1}$
T	Temperature, K
V	Volume, m^3
z	Height of manometer rise, m

Subscripts

air	Displaced air
e	Empty
f	Full
i	Inside
o	Outside

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Appendix A

Student feedback form

12/04/2025, 18:50

Feedback Form

Feedback Form

* Indicates required question

- Please read the [information sheet](#) provided. *
Once you have read it please answer the following question so that we can use (or not use) your data.
I consent to the use of my data set out in the above documentation.
Mark only one oval.

☐ Yes

☐ No
- After completing the lab, I had a better understanding of the gas laws. *
Mark only one oval.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree
- After completing the lab, I had a better understanding of Archimedes' principle. *
Mark only one oval.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree

<https://docs.google.com/forms/d/11YJDWESXy8PthABICfpI-v4n3HjrCM40X14QPT4h/edit>

1/3

12/04/2025, 18:50

Feedback Form

4. I found the lab engaging and enjoyable. *

Mark only one oval.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree

5. I found that the lab was a good use of my time. *

Mark only one oval.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree

6. Compared to lectures, the lab was a good way to learn about the gas laws. *

Mark only one oval.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree

7. I would prefer the length of the lab to be... *

Mark only one oval.

☐ Shorter

☐ The same

☐ Longer

<https://docs.google.com/forms/d/11YjDWESXy8PHABICfp1-v4ns3HjpwCM4tX14QPT4ls/edit>

2/3

12/04/2025, 18:50 Feedback Form

8. I think the best group size for the lab is... *

Mark only one oval.

☐ 1

☐ 2

☐ 3

☐ 4

☐ >4

9. We would love to hear any other thoughts that you had on the lab

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Google Forms

<https://docs.google.com/forms/d/11YjDWESXy8PHABICfp1-v4ns3HjraCM4tX14QPT4ls/edit> 3/3

Appendix B

Latest Lab sheet

School of MAC Engineering Lab Sheet

NAME THAT GAS!

1) Volume of balloon

Length, L = m, diameter, D = m

$$V = \frac{\pi D^2 L}{6} = \frac{\pi \times \text{}^2 \times \text{}}{6} = \text{} \text{ m}^3$$

2) Mass of air displaced by the balloon (Archimedes)

$$m_o = \frac{PV}{RT} = \frac{100,000 \times V}{0.287 \times 293} = \frac{100,000 \times \text{}}{0.287 \times 293} = \text{} \text{ g}$$

3) Pressure inside air filled balloon

 R is $\frac{R_u}{M} = 0.287 \text{ J g}^{-1} \text{ K}^{-1}$, P is 100 kPa, T is $20^\circ\text{C} = 293 \text{ K}$

$$\Delta p = \frac{(m_f - m_e)RT}{V} = \frac{(m_f - m_e) \times 0.287 \times 293}{V} \text{ (Pa)}$$

$$\Delta p = \frac{(\text{} - \text{}) \times 0.287 \times 293}{\text{}} = \text{} \text{ Pa}$$

So the absolute pressure inside all the balloons is

$$p_i = p_o + \Delta p = 100,000 + \text{} = \text{} \text{ Pa}$$

Or, from the manometer, the absolute pressure inside the balloon is

Water head, Δz = m

$$p_i = p_o + \rho g \Delta z = 100,000 + 1000 \times 9.81 \times \text{} = \text{} \text{ Pa}$$

4) Name that gas!

We can work out the molar mass, M for each balloon. Work in grammes and moles to get g mol^{-1} (which is the same number as kg kmol^{-1}).

$$M = \frac{R_u T}{p_i V} (m_f - m_e + m_o) = k (m_f - m_e + m_o) \text{ (g mol}^{-1} \text{ or kg kmol}^{-1}\text{)}$$

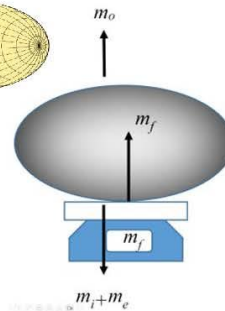
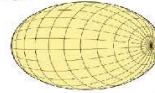
$$\text{Where } k = \frac{R_u T}{p_i V} = \frac{8.314 \times 293}{\text{} \times \text{}} = \text{} \text{ mol}^{-1}$$

Fill in the table

Balloon Colour	m_f (g)	m_e (g)	m_o (g)	M (kg kmol ⁻¹)	Gas



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	M kg kmol ⁻¹	R kJ kg ⁻¹ K ⁻¹
Air	28.97	0.2870
Ammonia	17.03	0.4882
Argon	39.95	0.2081
CO ₂	44.01	0.1889
Helium	4.003	2.077
Hydrogen	2.016	4.124
Methane	16.04	0.5183
Isobutane	58.12	0.1430
Nitrogen	28.01	0.2968
Oxygen	32.00	0.2598
Propane	44.10	0.1885
Steam	18.02	0.4614

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