Indirect Assessment of Deflategate, a High School Chemistry Experiment Simultaneously Measuring Pressure & Temperature Inside a Football

Shuaicheng Tong[1], Sharon L Karackattu[1], Matthew J. Traum[2]
[1]Oak Hall School, Gainesville, FL / [2]Engineer Inc., Gainesville, FL

Abstract

On January 18, 2015 the New England Patriots defeated the Indianapolis Colts 45 to 7 in the American Football Conference Championship Game. Accusations were levied against the Patriots that their game footballs were intentionally deflated to make them easier to handle. These allegations earned the moniker "Deflategate". This controversy in professional sports provides foundation for a hands-on high school chemistry laboratory experiment that challenges students to determine whether observed football deflation was intentional or could have arisen by thermophysical phenomenon. This open-ended question was posed to classes of sophomore and junior high school students in Chemistry, Honors Chemistry, and Advanced Placement (AP) Chemistry at Oak Hall School in Gainesville, FL. A post-activity survey was used for indirect assessment of students' perceived enjoyment, engagement, learning, and understanding from the Deflategate activity.

To answer the question "Could Patriot footballs have been deflated by cold environment exposure?", a special instrument was developed with unique capability to simultaneously measure pressure and temperature inside a football while the ball is exposed to environments at temperatures different than where it was inflated. Students carried out the experiment, simulated football play in an environment different than the ball's inflation temperature, collected relevant data, analyzed the results, and reported their conclusions.

A post-activity survey with n = 63 responders gauged student participant enjoyment, engagement, learning, and understanding arising from the lesson on a four-level Likert scale. Results were strongly positive with the highest average scores (3.66 ± 0.50, 3.57 ± 0.56, and 3.54 ± 0.59) reported for the project being interesting, helpful for learning material, and enjoyable respectively.

Keywords

Deflategate, Ideal Gas Law, Gay-Lussac's Law, K-12 Engineering Education, Energy Engineering Learning Module, EELM™

Introduction

On Sunday, January 18, 2015 the New England Patriots defeated the Indianapolis Colts 45 to 7 in the American Football Conference (AFC) Championship Game. Accusations were quickly levied against the Patriots that game footballs had been intentionally deflated by about 13.8 kPa (2 PSI) below the 86.2 to 93.1 kPa (12.5 to 13.5 PSIG) gauge pressure range stated in National Football League (NFL) rules. Deflation ostensibly made the game balls easier for Patriots players to catch, hold, and carry. This alleged rule violation led to an NFL investigation that found it was "more probable than not" that Patriots equipment managers deliberately tampered with the game balls. As a result, the Patriots were fined $1 million and lost their first- and fourth-round draft picks. Patriots Quarterback Tom Brady was suspended for four games[1]. The incident became widely reported national news and was dubbed by the media as "Deflategate", its now infamous moniker. Although the Patriots were censured, the team never admitted guilt.

Despite the NFL investigation findings of game ball tampering, another explanation for the observed ball deflation is also possible. If the footballs were inflated in a warm locker room (e.g., 296 K [about 73.1 °F]) and then taken out to a much colder field of play, thermophysical processes alone might explain the observed pressure drop. Indeed, the ambient temperature during the infamous January 18, 2015 AFC Championship game was approximately 283 K (about 49.7 °F). Assuming 1) air in the game ball behaved as an ideal gas and 2) thermal equilibrium with ambient temperature had been achieved inside the game ball, Gay-Lussac's law of pressure–temperature proportionality for a closed system of fixed volume[2] predicts a 4.4% pressure drop, which corresponds to 4.1 kPa (0.59 PSI) pressure drop below full ball inflation. Combined with non-idealities such as air leakage from the valve during play, could thermophysical processes alone have been the cause of the reduced game ball pressures underpinning the Deflategate controversy?

This open-ended question was posed to classes of sophomore and junior students in Chemistry, Honors Chemistry, and Advanced Placement (AP) Chemistry at Oak Hall School in Gainesville, FL to motivate their interest in and excitement for engineering thermodynamics. To answer the question, a hands-on group laboratory experiment was created, and a special instrument was developed with the unique capability to simultaneously measure the pressure and temperature inside a football while it is exposed to environments at temperatures different than where it was inflated. Students carried out the experiment, simulated football play in an environment different than the ball's inflation temperature, collected relevant data, analyzed the results, and reported their conclusions.

As early as high school, making connections in the classroom between familiar applications and their relevance to engineering is important to stimulate student interest, promote knowledge of the profession, and drive future engineering students toward appropriate college majors. For example, our own past work incorporates hands-on systems-level engineering design into high school classrooms[3,4] using toys familiar to many students. At the high school level, the work of Widmark using model rocketry is also an exceptional example of this approach[5].

Deflategate is relevant to and useful for teaching engineering at the high school level for multiple reasons. First, it connects engineering to professional sports competitions, which makes it interesting to students who might not have considered the engineering profession as a career prior to this activity. Second, it focuses on a controversial situation made famous by ongoing media coverage to highlight how thermodynamic processes are relevant to familiar real-world events. Third, it presents a hands-on, open-ended experimental activity any high school educator can adopt, insert into a science course, and carry out to introduce students to topics relevant to engineering thermodynamics. The Deflategate activity described here is encompassed within the underlying pedagogy narrative of New Learning developed by Kalantzis and Cope[6] It also follows the Energy Engineering Learning Module (EELM™) pedagogy that places value on experiences which are hands-on, accessible, student-centered, economical, and "turn-key"[7]. Needed hardware must be affordable for an institution with limited resources and be buildable and operable by a handy course instructor or technician without situated knowledge or access to specialized tools or equipment. Recently, EELM™ was demonstrated successfully at the high school level by taking a college-level thermodynamics laboratory and re-casting it for an AP Physics II class[8], demonstrating the viability of EELM™ as a pedagogical framework for inserting engineering content into high school science courses.

Background

Using events widely covered in the media to teach high school chemistry has been advocated for and successfully implemented by several educators. For example, Glaser and Carson developed the *Chemistry Is in the News* project and created a taxonomy to rate activities that comingle current events with chemistry instruction. The activities ranged from reading news articles for class to producing portfolios and then peer-evaluating the portfolios of other students[9]. Demonstrating student engagement effectiveness of using news for technical instruction, Hume et al. surveyed 37 student groups taught with *Chemistry Is in the News* pedagogy finding 75% reported a positive overall experience while only 8% had an overall negative experience[10]. Allchin et al argued that teaching science in the context of contemporary cases is useful to developing students' functional scientific literacy, especially when the underpinning scientific claims are contentious and mingle with discourse on values[11]. According to Latour, a key feature of contemporary cases is that they are unresolved, and the science is still "in-the-making"[12].

The Patriots' Deflategate controversy addresses four critical elements for effective use of news in the science classroom: 1) the story was contentious [Did the Patriots cheat?], 2) the ethical values of Patriots Quarterback Tom Brady were in question [Were rules intentionally broken to gain unfair advantage?], 3) the underpinning science remains unresolved [the Patriots were censured but never admitted guilt; scientific findings from NFLs investigation were disputed by outside scientists], and 4) the events were recent [today's high school chemistry students were in middle school in 2015, old enough to remember Deflategate].

A fifth beneficial feature of the Deflategate activity is that discussion, experiment, and results analysis occur within the context of a single 50-minute class meeting. The literature shows that timeliness of feedback to initial inquiry is important for improved student learning in the sciences. Huang et al reported a study in which students engaged in either asynchronous or synchronous online discussion over social media analyzing science news stories[13]. They found that while all participating students improved their science content knowledge students in synchronous groups acquired better understanding than those in asynchronous groups. This result reinforces a small earlier study by Davidson-Shivers et al that found the ability to give and receive quick feedback in synchronous discussion benefits student learning[14].

Theory & Experimental Methods

For high school chemistry classroom instruction, application of the Ideal Gas Law to the air inside the football provides a surprisingly accurate prediction of the internal pressure change as a function of measured temperature in the time scale of a single 50-minute class session.

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

Under the assumption that the air volume inside the ball remains unchanged despite its level of inflation, Eq. 1 can be reduced to Gay-Lussac's law of pressure–temperature proportionality for a closed system of fixed volume. For purposes of the experiment, it can be rewritten to relate the pressures and temperatures of two end states in a thermodynamic process:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \tag{2}$$

Equation 2 was used during the in-class experiment to estimate the final pressure of the football, P_2, given initial internal pressure and temperature measurements and a final internal temperature measurement.

The unique capability enabling this experiment is ability to simultaneously measure pressure and temperature at a known depth inside the football in real time as the ball warms up and progresses between thermodynamic states. This capability is realized by threading a 40 AWG bare thermocouple bead through the port of a Vevo Sports USA Ballspike Inflation Needle. Figure 1 (A) shows a student and instructor inflating a football with this instrument. Footballs inflated at room temperature were then stored for 20 minutes in a school freezer while the temperature and pressure during cool-down were data-logged to simulate the ball's thermal exposure at the January 18, 2015 American Football Conference Championship football game where Deflategate occurred.

Figure 1: (A) With instructor guidance, a chemistry student hand-inflates a game football to regulation pressure under ambient classroom conditions in preparation for a cold soak in the school freezer. (B) To simulate game play at a different ambient temperature than where the ball started, students scrimmaged with the cold-soaked football for 20 minutes to warm it up.

A detailed description of this teaching laboratory apparatus; quantitative results obtained using it; and how to choreograph events during a 50-minute high school class session to facilitate data collection, analysis, and a little play time [Figure 1 (B)] are given in a companion paper[15]. The focus of this current paper is analyzing student indirect assessment responses to evaluate effectiveness of the activity for introducing high schoolers to the experiment's engineering concepts.

Pedagogical Methods & Results

At the end of the experimental activity, student participants were asked to complete an anonymous paper survey to evaluate their self-reported learning and their attitudes about the Deflategate class activity. The survey is included in the appendix of this paper.

Data from the student surveys are represented in two different ways. Since the response population was large enough (n = 63) to present results statistically, Fig. 2 shows the aggregate responses to each question represented as means with error bars based on standard deviations. Since the Likert scale generates discrete data (i.e., the only acceptable responses are represented by whole numbers), definitions for discrete mean and standard deviations are used with the probability function built from data collected from each question.

$$\mu = \sum[x \cdot P(x)] \tag{3}$$

$$\sigma_x = \sqrt{\sum\left(x^2 \cdot P(x)\right) - \mu_x^2} \tag{4}$$

While the data of Figure 2 are easy to visualize, there is ongoing discussion in the pedagogical literature whether it is valid to treat Likert scale data statically[16,17]. Likert data are ordinal, discrete, and have limited range: properties that violate assumptions underpinning most parametric tests. For this Deflategate analysis, for example, the data's discrete nature balloons standard deviation above what it might be for continuous data. Therefore, Fig. 3 provides an alternative visualization, showing the distribution of student responses to each survey question. In addition to quantitative results, the survey also included an open-ended question asking students to comment on their experience. Of the n = 63 survey responses, 21 individuals left unique written comments, and among these responses, 11 described the activity as "fun". Table 1 contains a representative sample of student feedback written on the survey. Repeat instances of "fun" have been removed for brevity.

Discussion

Knowing that interpretation of conflicting evidence by scientists and/or engineers is not always objective is an important element of technical literacy for students to grasp. A more contentious news story that shares Deflategate's effectiveness as a teaching topic is genetic engineering. So, it is interesting to draw parallels between how high school science students responded to these different news items. Khishfe explored student decision making in a case on genetic engineering and found high school students improved their understanding that scientific knowledge is tentative, empirical, and subjective. Interestingly, the activity did not influence students' pre/post decisions regarding whether genetic engineering was ethical, but it changed the stated reasons students gave for their decisions[18].

Table 1: Summary of open-ended question student comments and responses on post-activity indirect assessment survey.

#	**Written Student Feedback**
1	It was a lot of fun! (x11)
2	It's nice to see what we study is true.
3	I am not a football person.
4	It was fun, and you should think of how to connect other labs to the real world.
5	I really enjoyed the connection between a sometimes confusing topic and a relevant and well known event
6	I had a lot of fun doing this and thought it was really interesting!
7	Tom Brady is a cheater.
8	As little math as possible would be absolutely splendid.
9	Really fun! I like the "hands on" type of learning better.
10	More fun than lecture.

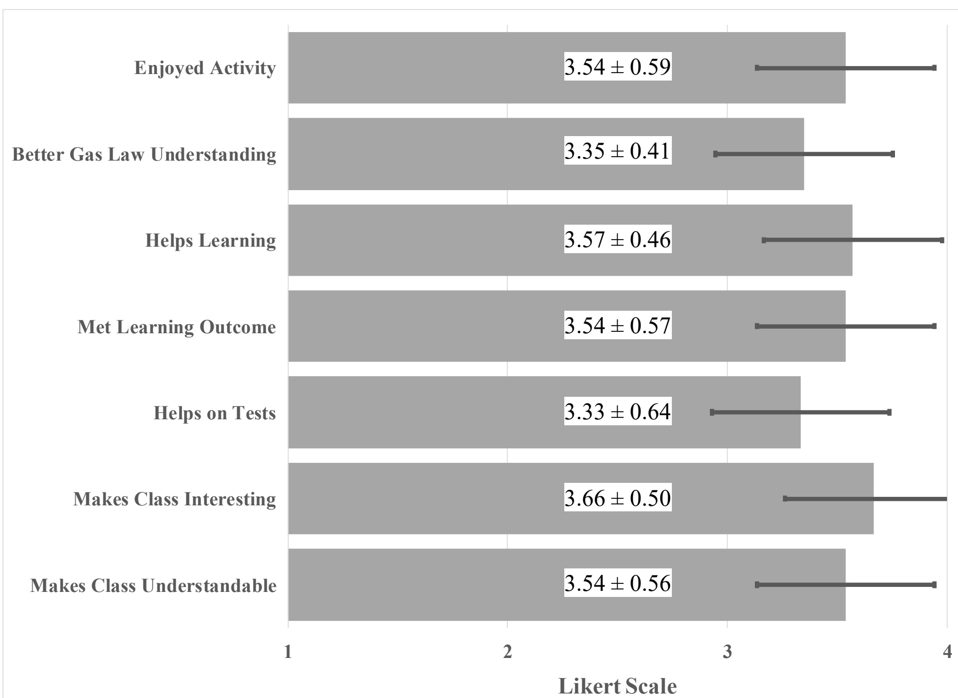

Figure 2: Post-activity indirect student survey responses were collected on a 4-point Likert scale [1 = Strongly Disagree, 4 = Strongly Agree]. This summary shows that the Deflategate activity was received positively by students and helped them feel they had learned and understood the underpinning engineering material.

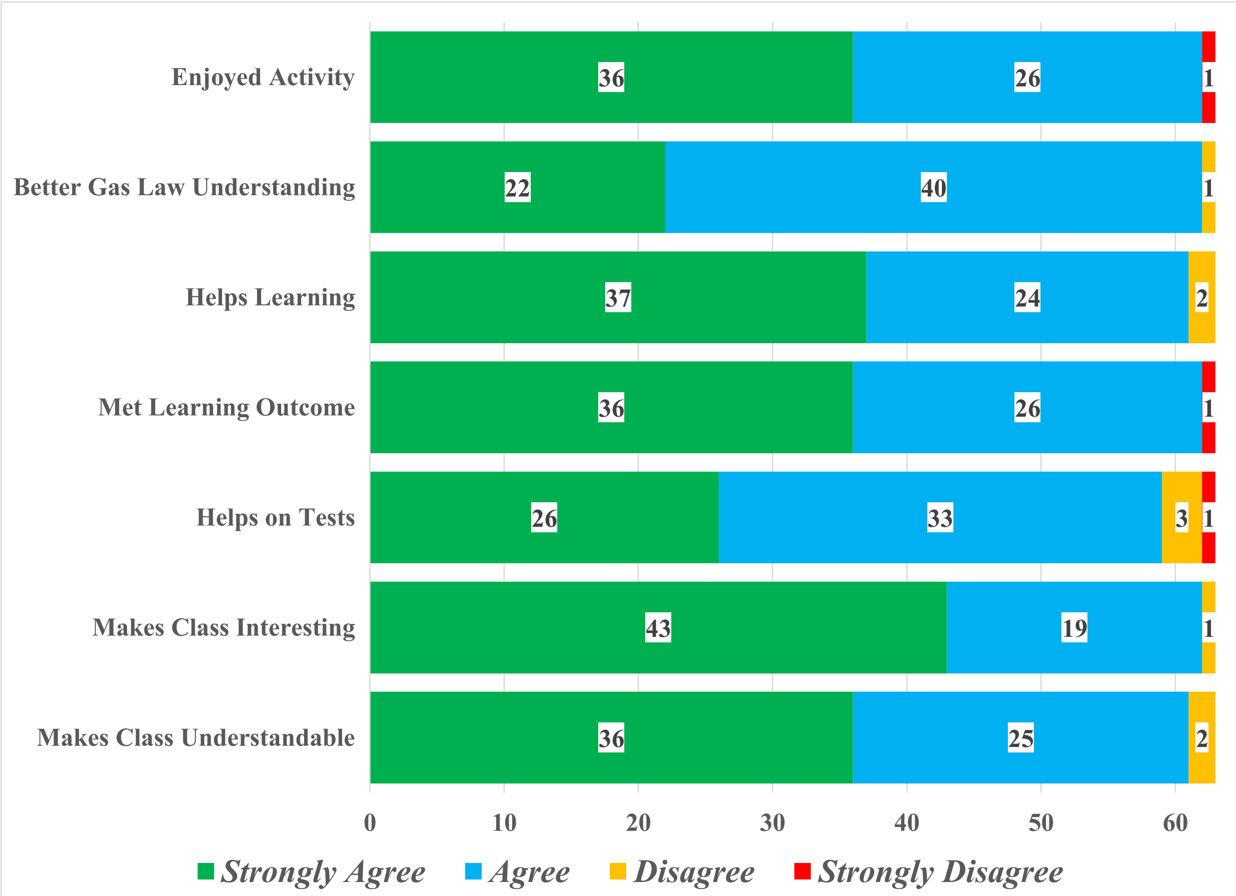

Figure 3: This alternative visualization of post-activity indirect student 4-point Likert survey results [1 = Strongly Disagree, 4 = Strongly Agree] shows most students agreed / strongly agreed that the Deflategate activity was enjoyable, induced learning, and increased understanding.

Along the same lines, student participants in the Deflategate activity displayed biases similar to those reported by Khishfe. Most students aware of the Deflategate controversy entered the activity with preset opinions about whether the Patriots intentionally deflated their game footballs; these opinions were strongly tied to whether students were Patriots fans or supported a rival football team. Once they collected definitive experimental data from the hands-on experiment, student options on whether the Patriots cheated did not change. However, they were able to provide more rigorous scientific reasoning to support their positions. In one example, a student started class claiming the Patriots cheated because evidence was found that Quarterback Tom Brady texted instructions to a locker room ball hander to deflate the game balls. By the end of the experiment, this same student was arguing and showing by calculation that ambient temperature at the Deflategate incident was not cold enough to induce pressure losses observed by referees when the game footballs were measured at half time.

Armed now with deep understanding of the thermodynamics underlying the Deflategate incident, students more deeply appreciated why the incident was contentious and still remains unresolved. Instead of being detrimental to learning, the knowledge that science is uncertain increased student discourse and discussion leading to more advanced technical questions like "Is the Ideal Gas Law always true?" and "What assumptions did we made that were invalid?" Questioning the approaches used is the genesis of engineering thinking and a pathway to accessing the highest

Bloom's Taxonomy levels. K-12 students (who are most often taught that problems have one solution) could benefit from more open-ended experimentation like the Deflategate activity.

Conclusion

An open-ended hands-on experiment was developed and carried out in a high school chemistry class that simulated the January 18, 2015 American Football Conference Championship Game in which the New England Patriots were accused of intentionally deflating game footballs to make them easier to handle. To facilitate this experiment, an instrument was created capable of simultaneously measuring the pressure and temperature inside a football. Using this instrument, students measured the influence on internal pressure if a ball is inflated at ambient temperature and then cold-soaked at lower temperature. This experiment introduced thermophysical engineering concepts, including Ideal Gas Law and Heat Transfer, to high school chemistry classes.

An investigation of the Deflategate football controversy favorably addresses all five parameters established in the literature as essential for successful deployment of the *Chemistry Is in the News* teaching approach: 1) the story was contentious, 2) the ethical values the story's participants were in question, 3) the underpinning science is unresolved, 4) the events were recent, and 5) students obtained nearly instantaneous feedback in their discussion and exploration of the story.

To evaluate the pedagogical impact of this activity on student learning and attitudes, a post-activity survey was completed by n = 63 student participants. Students were asked to evaluate on a four-point Likert scale multiple dimensions of the activity including how much they felt it helped their learning, understanding, and interest in the subject. Responses were favorable with the highest scores assigned to "Making the Class Interesting" (3.66 ± 0.50), "Help Learning the Material" (3.57 ± 0.56), and "Making the Class Enjoyable" (3.54 ± 0.59). Students' overwhelmingly positive response to the Deflategate activity suggests it would be beneficial for dissemination to and adoption by other high school science teachers beyond Oak Hall School.

Acknowledgements

We gratefully acknowledge GEC Instruments of Gainesville, FL, which donated the 40 AWG thermocouples that made the measurements of this project possible.

References

1 J. Milord, "What Was Deflategate? A Refresher Of the Patriots' Greatest Controversy," *Elite Daily*, Bustle Digital Group, Feb. 2, 2018. URL: https://www.elitedaily.com/p/what-was-deflategate-a-refresher-of-the-patriots-greatest-controversy-8091290 [Accessed Jan. 18, 2020]
2 M. K. Barnett, "A brief history of thermometry," *Journal of Chemical Education*, Vol. 18, No. 8, p. 358, Aug 1941.
3 M. J. Traum, S. L. Karackattu, " 'It's Nothing Like October Sky!': Spurring 9th & 10th Graders to Think Like Engineers via Rockets Custom-Designed for Maximum Altitude," *Proceedings of the 126th Annual American Society for Engineering Education (ASEE) Conference and Exposition*, Tampa, FL, USA, June 16-19, 2019.

4 M. J. Traum, S. L. Karackattu, "The Pencil-Top Fidget: Reinventing Shop (Metal Drilling and Tapping) in High School Science Classrooms," *Proceedings of the 126th Annual American Society for Engineering Education (ASEE) Conference and Exposition*, Tampa, FL, USA, June 16-19, 2019.
5 S. A. Widmark, "Rocket physics," *The Physics Teacher*, Vol. 36, No. 3, pp. 148-153, 1998.
6 M. Kalantzis, B. Cope, New Learning: Elements of a Science Education, 2nd Edition, Cambridge University Press, New York, NY, 2012.
7 Z. Yang, H. L. Weiss, M. J. Traum, "Gas Turbine Dynamic Dynamometry: A New Energy Engineering Laboratory Module," *Proceedings of the 2013 American Society for Engineering Education North Midwest Section Conference*, Fargo, ND, USA, October 17-18, 2013.
8 M. J. Traum, L. M. Flewellen, E. L. Legare, "College-Level Multi-Step Energy Conversion Efficiency Experiments Should be Decomposed for High School Deployment," *Proceedings of the American Society for Engineering Education Southeastern Section Conference*, Daytona Beach, FL, USA, March 4-6, 2018.
9 R. E. Glaser, K. M. Carson, "Chemistry Is in the News: Taxonomy of authentic news media-based learning activities," *International Journal of Science Education*, Vol. 27, No. 9, pp. 1083–1098, 15 July 2005.
10 D. L. Hume, K. M. Carson, B. Hodgen, R. E. Glaser, "Chemistry is in the news: Assessment of student attitudes toward authentic news media-based learning activities." *Journal of Chemical Education*, Vol. 83, No. 4, p. 662, 2006.
11 D. Allchin, H. M. Andersen, K. Nielsen, "Complementary approaches to teaching nature of science: integrating student inquiry, historical cases, and contemporary cases in classroom practice," *Science Education*, Vol. 98, No. 3, pp. 461-486, 2014.
12 B. Latour, Science in action: How to follow scientists and engineers through society, Harvard University Press, 1987.
13 T.-Y. Huang, H.-L. Wu, H.-C. She, Y.-R. Lin, "Enhancing Students' NOS Views and Science Knowledge Using Facebook-based Scientific News," *Educational Technology & Society*, Vol. 17, No. 4, pp. 289–301, 2014.
14 G. V. Davidson-Shivers, L. Y. Muilenburg, E. J. Tanner, "How do students participate in synchronous and asynchronous online discussions?", *Journal of Educational Computing Research*, Vol. 25, No. 4, pp. 351-366, 2001.
15 S. Tong, S. L. Karackattu, M. J. Traum, "Deflategate: Classroom Thermophysics Investigation via Simultaneous Pressure and Temperature Measurement Inside a Football," 2020 American Institute for Aeronautics and Astronautics (AIAA) SciTech Forum, Orlando, FL, USA, January 6-10, 2020.
16 B. P. Subedi, "Using likert type data in social science research: confusion, issues and challenge," *International Journal of Contemporary Applied Sciences*, Vol. 3, No. 2, pp.36-49, 2016.
17 J. F. C. de Winter, D. Dodou, "Five-Point Likert Items: t test versus Mann-Whitney-Wilcoxon," *Practical Assessment, Research, and Evaluation*, Volume 15, No. 1, p. 11, 2010.
18 R. Khishfe, "Relationship between nature of science understandings and argumentation skills: A role for counterargument and contextual factors," *Journal of Research in Science Teaching*, Vol. 49, No. 4, pp. 489-514, 2012.

Biographical Information

Shuaicheng Tong is a current Oak Hall School (OHS) senior with two years of experience in chemistry. He won the OHS Upper School's "Excellence in AP Chemistry" award for earning the highest grade in the class for the 2018-2019 school year, and he has a strong interest in thermodynamics and heat transfer.

Sharon L. Karackattu earned a B.S. in Interdisciplinary Studies: Biochemistry and Molecular Biology from the University of Florida in 2000 and completed a Ph.D. in Biology at the Massachusetts Institute of Technology (MIT) in 2006. She served as a postdoctoral associate in MIT's Biological Engineering Division before spending two years as a Research Coordinator for Student Development at University of North Texas - Denton. She is currently a high school science instructor at Oak Hall School specializing in chemistry and the life sciences. She has taught college-level courses in the biosciences and maintains an interest in studying STEM field student learning.

Matthew J. Traum is the founding Chief Executive Officer of Engineer Inc., an education technology company creating unique laboratory equipment and curricula for high schools and colleges. Dr. Traum is also a Senior Lecturer in the Mechanical & Aerospace Engineering Department at the University of Florida. He is an experienced educator, administrator, fund raiser, and researcher with co-authorship of 14 peer-reviewed research and pedagogical journal papers, 44 refereed research and pedagogical conference articles. As PI or Co-PI, Traum has attracted over $865 K in funding for research and education. Traum received Ph.D. and M.S. degrees in mechanical engineering from MIT, and he holds two B.S. degrees from UC Irvine in mechanical and aerospace engineering.

Appendix

The following survey was used verbatim as it appears in this appendix to gather indirect assessment data on the Deflategate activity from each student participant in all five class sections where the experiment was conducted.

==

Deflate-Gate Post-Activity Student Survey

1. I **enjoyed** the Deflate-Gate activity in chemistry class.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

2. The Deflate-Gate chemistry class activity **improved my understanding of gas laws**.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

3. Seeing connections between chemistry class activities and a real event covered in the media (the NFL Deflate-Gate controversy) **helps my learning**.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

4. Based on the Deflate-Gate chemistry class activity, I learned that the pressure of a ball inflated under indoor environmental conditions (room temperature) can change after exposure to and play in outdoor conditions.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

5. Participating in the Deflate-Gate chemistry activity improves my ability to **solve test questions and problems covering the relationship between pressure and temperature for gases (Gay-Lussac's Law)**.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

6. Seeing how chemistry is related to real world issues and problems makes the subject **more interesting**.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

7. Seeing how chemistry is related to real world issues and problems makes the subject **easier to understand and learn**.

Strongly Disagree *Disagree* *Agree* *Strongly Agree*

8. Please write any other comments regarding this activity below. Thank you!

==