SSLEQ-Physics: Developing And Validating A Survey To Measure Student Engagement In Science Laboratories

Srividya D Kota[a], Jacinta den Besten[b], Jasmina Lazendic-Galloway[c], Manjula D Sharma[a]

Corresponding author: Srividya Durga Kota (skot2539@uni.sydney.edu.au)
[a] School of Physics, The University of Sydney, Sydney NSW 2006, Australia
[b] School of Physics, The University of Melbourne, Melbourne VIC 3010, Australia
[c] School of Physics and Astronomy, Monash University, Clayton VIC 3800, Australia

Keywords: Student engagement, undergraduate science, laboratory learning, measuring student engagement, validation of survey

Abstract

Student engagement is a multifaceted construct having different dimensions: cognitive, behavioural, and emotional. Despite its centrality in learning and learning outcomes, student engagement has proven difficult to measure. Furthermore, it is under researched in undergraduate sciences, including physics. The aim of this paper is to present the development, validation, and evaluation of a survey which measures student engagement in physics laboratory learning; the Science Student Laboratory Engagement Questionnaire (SSLEQ). The survey measures undergraduate students' cognitive, behavioural, and emotional engagement while doing experiments. Items from ASLE (ASELL Student Learning Experience) and AEQ (Achievement Emotions Questionnaire)-Physics Prac were adapted in developing this survey. The items for cognitive engagement are about *motivators* underpinning understanding of content and development of skills. The items for behavioural engagement query the *resources* provided such as experimental lab notes and demonstrators' help. For emotional engagement, items explored positive and negative *emotions*. Confirmatory factor analysis and descriptive statistics conducted with a sample of 308 first year physics students confirm the reliability and internal validity of the survey for the purposes. This survey was evaluated with the first year physics students to compare engagement with students who experienced a face to face laboratory session before moving to online and students who experienced only online laboratory sessions. This survey can now be used in other contexts providing academics with measures of three types of engagement for use in science courses to positively influence students' engagement with laboratory exercises.

Introduction

Student engagement is a buzz word in education and plays a critical role in learning. Ongoing student engagement can result in extended student attentiveness and improve their motivation in education. As stated by Newmann (1992), 'student engagement in academic work as the student's psychological investment in and effort directed toward learning' (p.12). Student engagement has received attention in schools, where there is growing evidence on how student engagement is influential in increasing student motivation, in improving their achievements and resulting in positive outcomes in schools (Fredricks, Blumenfeld, & Paris, 2004). In online learning, identifying the importance of student engagement, Meyer (2014) and Martin and Bolliger (2018) believe that student engagement is evidence of student's effort and their ability to create their own knowledge leading to a high level of student success.

In higher education, Kahu and Nelson (2018) argue that student engagement is the key solution of the issues such as learner isolation and graduation rate. Also, research supports that there is a strong connection between student engagement and students' educational outcomes and persistence in first year physics (Kuh et al., 2008). Bond et al. (2020) investigated for indicators of cognitive, behavioural, and emotional engagement, where educational technology was used. While they identified some measures of indicators for each of the dimensions of student engagement, from their systematic literature review on student engagement, it was reported that there is a lack of clear definition of student engagement and theoretical model. A few instruments like the Student Engagement Instrument (Appleton, Christenson, Kim, & Reschly, 2006) and High School Survey of Student Engagement (Yazzie-Mintz, 2007) used several measures of student engagement to infer high school students' perspectives, attitudes, and beliefs. However, there is a requirement of such instruments to measure student engagement in science education. While other instruments in science like MPLEX was used to investigate student beliefs, attitudes, and expectations about physics (Redish, Saul, & Steinberg, 1998) but did not measure student engagement. Hence, there is a requirement for consistent items to represent different dimensions of engagement.

Digging deeper into student engagement, the psychological perspective provides dimensions of student engagement as, cognitive, behavioural, and emotional (Fredricks, 2011).

- *Cognitive engagement:* The cognitive aspect of science includes understanding concepts, skills development and understanding physics. In taking part in scientific investigations, students develop experimental skills, critical thinking skills and improve learning of physics (Ompusunggu, Turnip, & Sirait, 2016). Involvement in an argument about scientific evidence engages students in improving their cognitive elaboration (Nussbaum, 2011). Another aspect of cognitive engagement is shifting learners away from alternative conceptions to understandings more congruent with current scientific understandings (Kota, Cornish & Sharma, 2019; Georgiou & Sharma, 2020).

- *Behavioural engagement:* An aspect of behavioural engagement in science is students' participation through actions in their own learning process. It is involvement in academic tasks (Heddyet al, 2014). In science investigations, these tasks are students' involvement in doing hands on experiments. Another aspect is students' positive conduct (Finn & Voelkl, 1993) in their own learning process, including participating in teamwork while carrying out investigations (Tytler, & Osborne, 2011), seeking help from peers and demonstrators (Rice, Thomas, O'Toole, & Pannizon, 2009). Utilising background information and having an understanding about how these are assessed are important for behaviours. Such aspects are under researched.

- *Emotional engagement:* Emotions play a significant role in learning and need to be considered carefully (Perkun, Goetz, Frenzel, Barchfeld, & Perry, 2011). Bhansali, Angstmann, and Sharma (2020) explored student emotions in undergraduate physics labs and found that positive emotions such as enjoyment and hope can induce more engagement and negative emotions such as boredom and resent are associated with student disengagement. Furthermore, Bhansali and Sharma (2019) found that use of colour and stories in laboratory manuals influence emotions. The work on emotions and science learning by Heddy and Sinatra (2013) showed that students positive emotions result in achieving high scores in learning.

In science learning, engagement is associated with concerted investment in activities students are involved with/in and the overall time students invest in the subject. Since laboratory learning requires substantial time, focusing on engagement in laboratory learning has the potential to reap benefits (Richardson, Sharma, & Khachan, 2008). Sinatra, Heddy, and Lombardi (2015) have identified that student engagement is domain and task specific, hence, focusing on student engagement specifically in undergraduate laboratories, physics in this study, is prudent. In undergraduate physics laboratories, experiments are used to engage students as well as provide hands on experience in connecting theory to practice. While experiments involving inquiry skills, modelling and technology are engaging students in a meaningful manner (Kota, 2019), measuring student engagement is under explored.

Hence, the aim of this paper is to develop, validate and evaluate a survey which measures student engagement in physics undergraduate laboratories. The focus is on the three dimensions of engagement; cognitive, behavioural, and emotional. The first section of this paper describes the development of the survey and its implementation. The next section outlines the extraction of factors which was conducted using Exploratory Factor Analysis (EFA) and validating the underlying factor structure using Confirmatory Factor Analysis (CFA). The developed survey is evaluated using another cohort at the same university. The final section discusses the survey and findings as well as considering the implications.

Development of the survey

Advancing Science and Engineering through Laboratory Learning, (ASELL) conducted workshops Australia wide involving staff and students from universities (Yeung et al., 2011). During the process they produced a survey, ASELL Student Learning Experience (ASLE) survey (Barrie et al., 2015), items from which are associated with cognitive and behavioural engagement. Bhansali and Sharma (2019) and Bhansali et al. (2020) specifically produced the Achievement Emotions Questionnaire for physics practicals (AEQ-Physics Prac). We adapted items from these surveys for our student engagement survey. As the items were adapted from validated surveys, content validity was checked through discussions amongst expert groups namely members of the Sydney University Physics Education Research (SUPER) group at the University of Sydney and Physics Education Research group at the University of New South Wales (some of them are also authors of the papers ASLE and AEQ-Physics surveys). The meetings with these expert groups occurred fortnightly, notes were taken, reviewed and incorporated based on ongoing discussions. The survey was trialled iteratively as is standard in survey development, including with conceptual surveys (Wattanakasiwich et al., 2013). The full survey is presented in Appendix A, Supplementary Material.

Implementation of the survey

The survey was first implemented after students had completed a three-hour experimental session in which students conduct experiments, collect data, perform the analysis, and use logbooks for reporting and then implemented after students had completed a semester long online laboratory program. The implementations are described below.

- ***First implementation****:* In 2018, the survey was first trialled and tested with first-year students at University A. Students had just completed a three-hour laboratory experiment; ‘Waves on a Rope’. Only items on cognitive and behavioural engagement were used. The analysis, using EFA, generated two factors.

- ***Second implementation:*** In 2019, items measuring emotional engagement were added and trialled once again at University A. Students had just completed a three-hour laboratory experiment; ‘Bunjee Jumping’. The analysis generated two other factors on emotional engagement along with the factors from the first implementation.

  For the third implementation, the plan was for the survey to be deployed with a third experiment. However, in March 2020, circumstances changed due to the COVID-19 pandemic. All face-to-face sessions were cancelled and shifted online. This has provided an opportunity to measure student engagement in an online laboratory setting. We submitted modifications to the University Human Ethics committee seeking approval for submitted modifications: a) to run the survey online and b) to run at three research-oriented universities. The modifications were approved.

- ***Final implementation***: In 2020, the word 'experiment' was changed to 'experiments', and the survey with cognitive, behavioural, and emotional engagement was trialled with students from all three universities. The survey was deployed at the end of the semester covering all the online experiments students had done during the semester-long, online laboratory program.

Here, we present a sample of results from the final implementation. We are presenting results from one cohort from University B which had the largest cohort. The results were also consistent with the results from the other samples, be they from different Universities, experiments, or laboratory programs, online and face to face.

Data collection and Analysis

The participants were undergraduate students who were enrolled into a first-year physics subject at University B. The survey was set up online via the Qualtrics program. In the final weeks of their lab sessions, students were notified via announcements about the survey, information about the research, and the consent to participate in the study. Links to the survey were provided. 308 participants completed the survey, and the data were exported to Excel. Incomplete surveys, and surveys with three or more items left blank were removed. The five point Likert scale items were converted to scores: *Strongly Agree- 5, Agree-4, Neutral- 3, Disagree- 2, Strongly Disagree-1.*The data were exported to SPSS Statistics version 28 for further analysis.

Two types of analysis were conducted (Sharma, Stewart, Wilson, & Gokalp, 2013); Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). EFA was to reduce the number of items of our survey into factors, with an intent to identify patterns to represent and interpret the data. CFA was to validate the underlying structure and to ascertain the fitness of the data and to get a model fit.

Exploratory Factor Analysis (EFA)

The data set went through a variety of validity checks (Field, 2009) to ensure they satisfy the criteria and assumptions necessary for EFA. The distribution of the data was not bimodal and or skewed; KMO sampling adequacy was greater than 0.9; multicollinearity tests were satisfactory; Bartlett's test for sphericity was adequate. The inflexion, point on scree plots as well as eigenvalues were greater than one. Factors were extracted from the factor analysis under the method Principal Component Analysis (PCA) and the columns of the factor matrix were simplified using Varimax Kaiser normalization. The factors extracted using scree plots and factor rotation satisfied all criteria. The magnitude of all four factor loadings met the required criteria of >0.4 (Field, 2009).

Appendix A, Supplementary Material shows the complete survey and the short names of each item as well as factor loadings. Table 1 provides a summary with short names for each item. Six items (1, 2, 3, 6, 10, 12) load onto one factor in agreement with Barrie et al. (2015). This factor is called *motivators* and measures *cognitive engagemen*t. Five items (4, 5, 7, 8, and 9) load onto another factor agreeing with Barrie et al. (2015). This factor is called *resources* and measures *behavioural engagement*. Four items (15, 16, 19, 20) load onto a factor agreeing with Bhansali and Sharma (2019). This factor is called *positive emotions* and measures *emotional engagement*. Four items (21, 22, 23, 24) load onto another factor agreeing with Bhansali and Sharma (2019). This factor is called *negative emotions* and measures emotional engagement. EFA showed that the criteria were satisfied allowing for further analysis.

Table 1: A summary of the factors using short names for each item.

Motivators	Resources	Positive Emotions	Negative Emotions
Data interpretation skills	Clear assessment guidelines	Enjoyment	Boredom
Laboratory skills	Clear learning expectations	Satisfaction	Dull
Interest	Background material	Excitement	Annoy
Understanding of physics	Demonstrators help	Happy	Resent
Relevance	Experimental procedure		
Responsibility for own learning			

Confirmatory Factor Analysis (CFA)

CFA was carried out using AMOS version 28 to check the underlying structure and validity of the data set. In CFA, if the model fit parameters are suitable, the model structure is stable across time (Browne & Cudeck, 1992). Furthermore, CFA provides a mechanism for considering the factors from EFA, termed ‘latent factors’ and examining if there are correlations. The prediction is that there will be a positive relationship between latent factors of the same valence, and the same directionality, and a negative relationship between the factors of the opposite valance. CFA was conducted using maximum-likelihood estimation. For our dataset, the Confirmatory Factor Index (CFI) was a good fit >=0.9; the Root Mean Square of Approximation (RMSEA) was <0.08, and Relative Chi-squared was >3 (p<0.005).

The underlying internal structure and the correlational analysis of the data set are shown in Figure 1. The larger rectangular boxes represent the measures of student engagement. These reflect the factors in ovals, which in turn point to the items of the survey in smaller rectangular boxes. One loading, the first in each case, is fixed to 1. There are four factors, *motivators, resources, and positive* and *negative emotions*. We are trying to explain the covariation among responses to these factors using the model. Double arrows are reflecting covariances or correlations between factors.

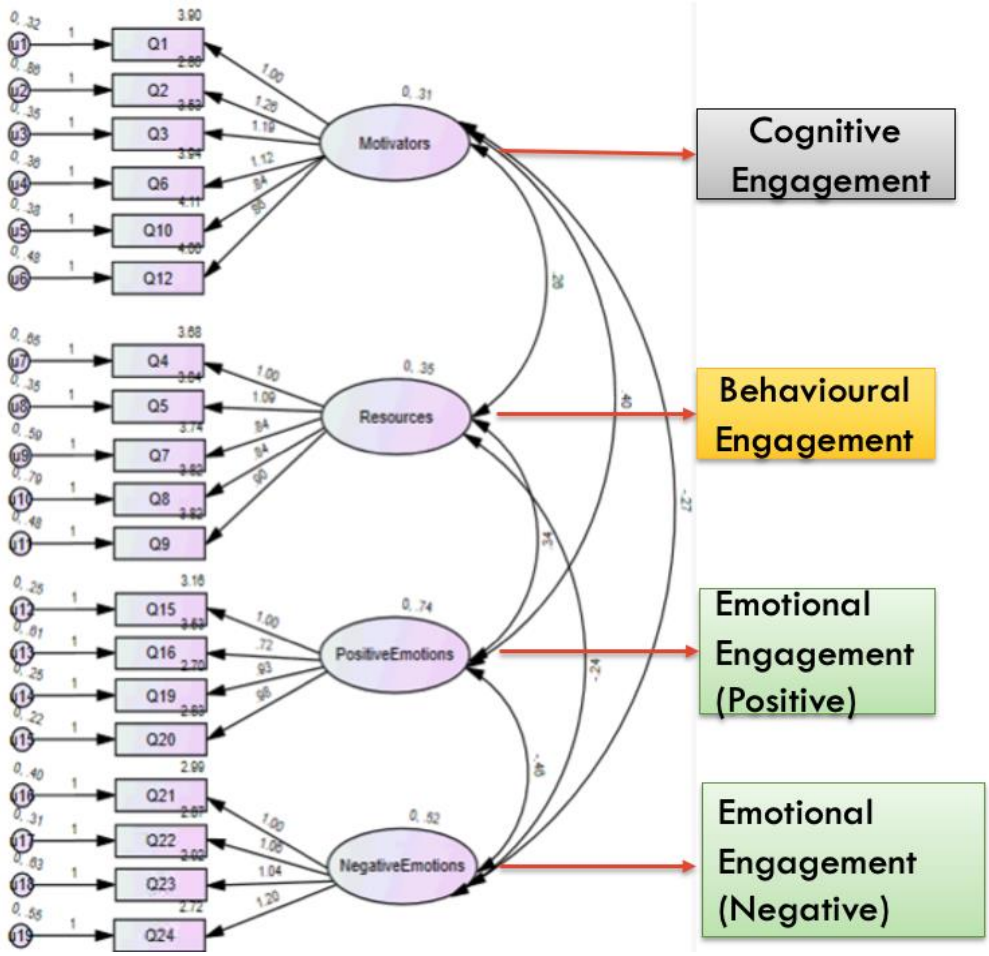

Figure 1: Four factor model for student engagement with physics experiments. The boxes represent the measures of student engagement, the ovals represent the latent factors, and the curves represent the covariances, correlations.

The development and validation with the sample of 308 students showed that the survey could be used as a measuring tool for student engagement in physics laboratories. At this stage, the survey was given a name, the Science Student Laboratory Engagement Questionnaire; SSLEQ. We used ‘science’ rather than physics as the items, conceptual basis extends beyond physics. In the next section, we present an evaluation comparing 3 cohorts, the first is the cohort above and two others who were studying in the same university, at the same time but undertaking different first year physics courses.

Evaluation of the survey

We implemented SSLEQ with three cohorts at University B. The three cohorts were studying the following courses:

- The sample of 308 students mentioned earlier belongs to the Foundations subject. Upon entry, Foundations students had minimal or no physics background in secondary school. Students experienced one face to face lab session before experiencing online sessions for the rest of the semester. We call this category of laboratory programs as Mixed COVID-19 labs, see Table 2.

- Mainstream had a sample of 298 students. Upon entry students in Mainstream subject had a prior experience of physics learning and have been successful in higher secondary physics. Students didn't experience any face to face lab session before experiencing online sessions for the rest of the semester. We call this category of laboratory programs as Online COVID-19 labs, see Table 2.

- Advanced had a sample of 86 students. Upon entry students in Advanced subject had a prior experience of physics learning and achieved high scores in senior secondary physics studies. Advanced students also belong to the category of Online COVID-19 Labs, see Table 2.

Table 2: Data sample of first year physics students at University B who experienced two types of laboratory programs for during COVID-19.

Laboratory program type	Subject	Sample
Mixed COVID-19 Labs	Foundations	308
Online COVID-19 Labs	Mainstream	298
	Advanced	86

The difference between these two types of labs is shown in Figure 1. In Mixed COVID-19 labs there were a few weeks in which laboratory sessions run face to face before running the labs online, and in Online COVID-19 labs, all the laboratory sessions were run online only. Hence, in the Mixed COVID-19 labs during the face to face sessions students carried out the experiments in the laboratory space and collected the data. Tasks such as data analysis were carried out within the laboratory space and had face to face discussions with peers and tutors. In online laboratory sessions, a few experiments were carried out at home and for some experiments data was provided. Tasks such as data analysis and discussions were carried out via Zoom.

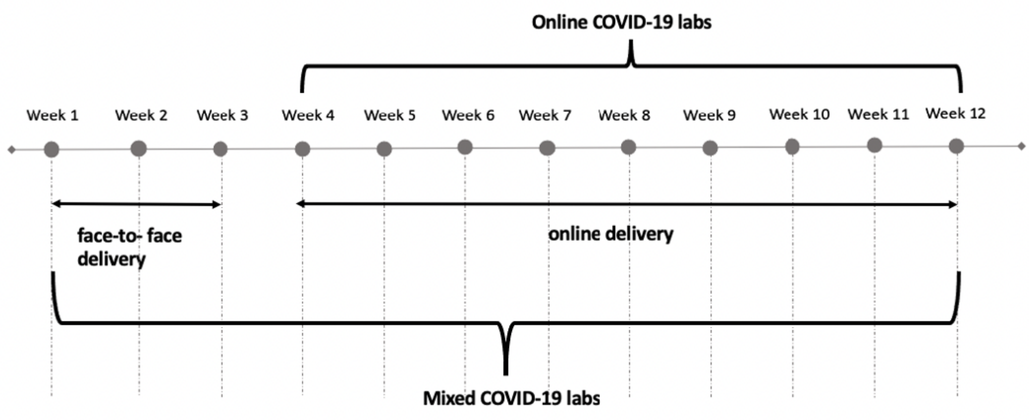

Figure 1: A schematic diagram of the Mixed COVID-19 and Online COVID-19 labs.

In all cases, the SSLEQ was administered online during the last two weeks of the semester using Qualtrics and the administration was the same. In all cases, the data were analysed. EFA and CFA were conducted with the results cognisant of what is presented for the Foundations course shown above. For each factor *motivators, resources, positive emotions, and negative* *emotions*, factor scores were calculated in a four step process mentioned below. For all student responses,

- Initially the five point Likert scale items are converted to scores: *Strongly Agree- 5, Agree-4, Neutral- 3, Disagree- 2, Strongly Disagree-1.*
- All items belonging to one factor are grouped.
- Item scores belonging to one factor are summed up to get a total factor score.
- Total factor scores are converted to percentages

In all cases, the above steps are repeated for each student's response. Descriptive and inferential statistics were performed for both types of labs and all four factors.

In summary, the sample sizes are from the same university and the data has been collected at the same time with COVID-19 entry into the picture and rapid transfer to online learning. The cohort was different in the sense of students' prior experience of physics learning. The second difference was that Foundation had Mixed COVID-19 Labs whereas Advanced and Mainstream students had Online COVID-19 Labs. The question the evaluation asks is:

Can the SSLEQ measure any differences between these cohorts and are these measurements meaningful?

Findings for all cases, Advanced, Mainstream, and Foundations students' *cognitive, behavioural, and emotional engagement* measured through *motivators, resources, positive emotions, and negative emotions* are shown in Figure 2. In each graph, Online COVID-19 Labs and Mixed COVID-19 Labs are separated by a dashed line. The total factor scores in percentages are indicated on the y-axis. Box plots contain four quartile regions of factor scores (%), the mean (the cross), and the median (the line in the middle). The statistical significance results are reported below, and the complete test results are presented in the Supplementary Material.

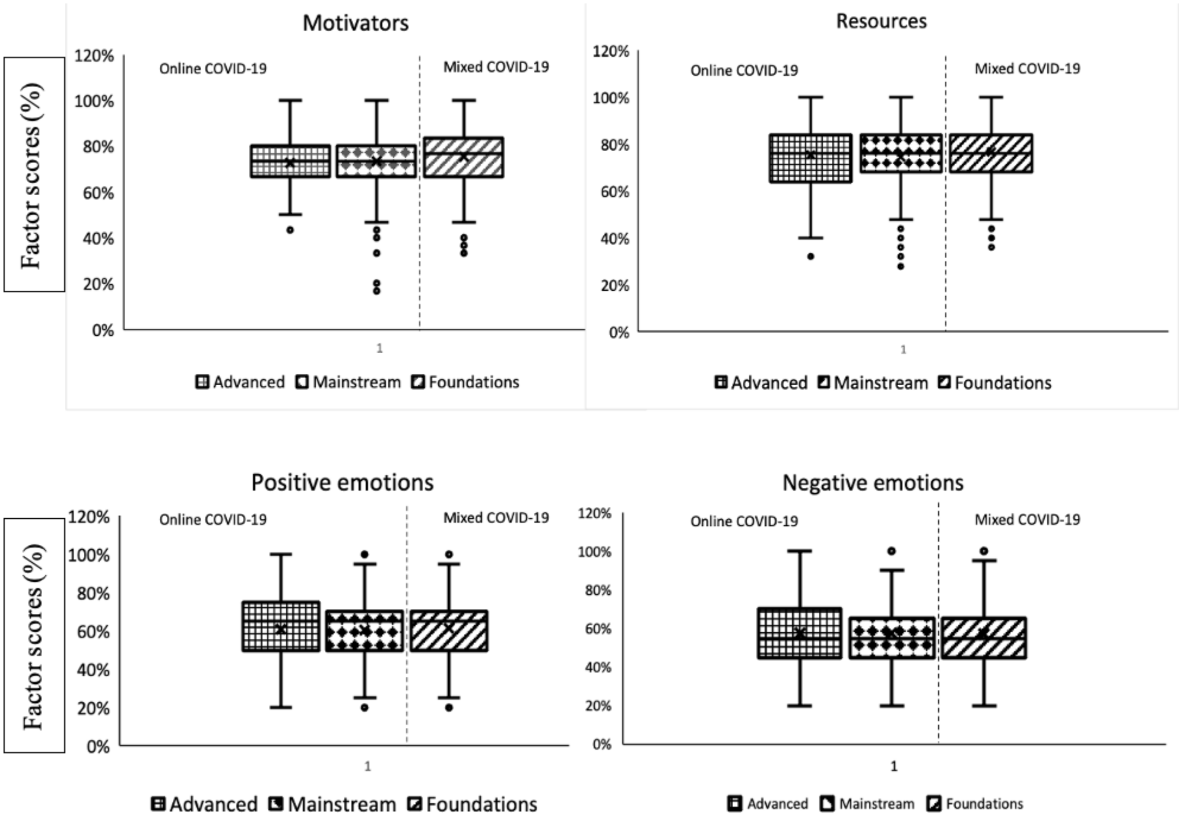

Figure 2: Students' engagement measured through motivators, resources, positive emotions, and negative emotions in the first semester of 2020. The box plots on the left of the dashed line represents Online COVID-19 labs and on the right represents Mixed COVID-19. The plots show the mean (the cross), median (the line in the middle of the box), outliers (the circles) and the four quartiles of the data distribution.

***Cognitive engagement between the two labs**:* In *motivators,* Mixed COVID-19 lab students reported 75% cognitive engagement which is higher than Online COVID-19 lab students, 73%. The students who experienced one face to face lab session at the beginning of the semester, their motivations continued throughout the semester and have shown higher cognitive engagement. A statistical significance test between these two independent samples, the Mann-Whitney U test, was performed to see whether this difference is significant. The test results were shown as significant between the two groups with $p=0.035 <0.05$ showing the higher level of cognitive engagement among Mixed COVID-19 labs students. While there is no difference in cognitive engagement between Advanced and Mainstream students, it is lower than among Foundations students.

***Behavioural engagement between the two labs**:* In *resources*, both Online COVID-19 lab students and Mixed COVID-19 students showed the same high level of engagement, 74%. Statistical significance results from the Mann-Whitney U test, $p=0.290 >0.05$ confirm this same level of behavioural engagement between Online COVID-19 labs and Mixed COVID-19 labs. Even though the mean values remained the same, the second quartile region for Advanced students started slightly lower than the other two cohorts showing slightly less engagement. For Mainstream and Foundations, students' results were the same. Having a different level of physics background, Advanced students' expectations are presented differently.

***Emotional engagement between the two labs**:* For *positive emotions*, both Mixed COVID-19 and Online COVID-19 lab students showed the same medium level of emotional engagement, 60%. This was also confirmed by the Mann-Whitney U test with a sig value p=0.631 >0.05. For Advanced students, the range of the data is larger than the other two cohorts and the third quartile region ends at the higher level with no outliers, showing slightly more positive emotions. Interestingly, there is no difference between Mainstream and Foundations. For *negative emotions*, in both Mixed COVID-19 and Online COVID-19 labs, 57% of students showed a medium level of negative emotions. This same level of negative engagement between Mixed COVID-19 labs and Online COVID-19 labs was also confirmed by the Mann-Whitney U test with a sig value p=0.719 >0.05. Again, for Advanced students, there is a slight variation in the upper quartile region compared to the other two cohorts.

In summary, Mixed COVID-19 labs students are more cognitively engaged than Online COVID-19 labs students. Advanced students have shown a different range of engagement than Mainstream and Foundation students.

Discussion

Due to the complex nature of student engagement, definition and measurement issues in this construct persist (Bond et al., 2020). Even though a few instruments like the Student Engagement Instrument (Appleton et al., 2006) and High School Survey of Student Engagement (Yazzie-Mintz, 2007) measured student engagement in terms of cognitive, behavioural, and emotional engagement, these instruments did not include questions or items addressing engagement with scientific processes or attitudes. In science, instruments like MPLEX were used to investigate student beliefs, attitudes, and expectations about physics (Redish et al., 1998), but not student engagement. Hence, there is a requirement for developing a consistent measure of student engagement.

In this paper, the focus is on measuring students' cognitive, behavioural, and emotional engagement in physics laboratories. A survey drawing on the ASELL Student Learning Experience (ASLE) survey (Barrie et al., 2015) and Achievement Emotions Questionnaire for physics practicals (AEQ-Physics Prac) from Bhansali, Angstmann, and Sharma (2020) was developed, validated, and evaluated with first year physics students. From EFA, four factors were extracted for a sample from University B and meeting the required criteria for further analysis, hence CFA was conducted. A fit model was produced. Our findings indicate that SSLEQ is a valid and reliable tool. The four factors extracted from the survey data, *motivators, resources, positive emotions, and negative emotions* highlight students' cognitive, behavioural, and emotional engagement in their lab experiments. Cognitive engagement measures underpin the conceptual understanding and development of skills, behavioural engagement measures support discussions with peers and demonstrators. Emotional engagement measures queries on emotions like happiness and boredom. It is important to note that the indicators are subjective to the discipline and there is overlap between them.

The survey, SSLEQ was evaluated at a metropolitan university with first year physics students having different physics backgrounds and experiencing different types of laboratory sessions. The evaluation shows that the SSLEQ successfully measured students' cognitive, behavioural, and emotional engagement. While a high level of cognitive engagement through items from *motivators* showed that the majority of students, the first year laboratory tasks engaged them well, however, student motivations in an online laboratory setting were slightly low. A high level of behavioural engagement from *resources* shows that resources provided helped complete their academic activities and students engage well in both types of sessions. While emotional engagement through *positive emotions* shows that their enjoyment is reasonably good, through *negative emotions* it shows that their satisfaction levels are not too low. However, there is a slight difference in the cohort with a high level of physics background.

Implication for research and practice

The results suggest that practitioners should reflect on the experiments they offer and evaluate them with a focus on these factors. By understanding what students' perceptions are in doing experiments, the teaching can be focused on those factors and can increase student engagement. Introducing one face to face session before experiencing an online session would be beneficial in maintaining students' interest in the laboratory programs. In addition to the results presented, further analysis involving inferential statistics analysis and open-ended response questions need to be performed to explore more insights for student engagement.

Further research on different samples and at different universities are underway, as well as checking the statistical and conceptual basis of the work on student engagement in laboratories.

Limitations of the study

There are some limitations that need to be considered. The nature of this construct has many issues in defining and measuring engagement. As this is implemented in first year physics laboratories at two universities in Australia, with data presented from only one university in this paper, the findings may not be representative of different cohorts more broadly. The survey was implemented during the COVID-19 pandemic which again is a constraint.

Further research on different samples and at different universities are underway, as well as checking the statistical and conceptual basis of the work on student engagement in laboratories.

Conclusion

Our experiences in adaptation, validation and checking for reliability is of potential use for others engaged in contextualizing the Student engagement Questionnaire and adds value to the use of the questionnaire. The SSLEQ survey can be a useful tool for understanding student engagement in physics and science laboratories. The tool provides an opportunity for obtaining different measures for cognitive, behavioural, and emotional aspects while conducting the experiments.

Acknowledgments

I would like to thank all first year physics students who participated in this study. My grateful thanks to the University of Sydney Human Ethics committee. Without the committee's approval, this study was not able to be conducted. The technicians' and coordinators' help was very helpful, thank you for agreeing to conduct this study in the first year laboratories. My heartful thanks to my supervisors for their enormous support and guidance all the way through my research.

References

Appleton, J. J., Christenson, S. L., Kim, D., & Reschly, A. L. (2006). Measuring cognitive and psychological engagement: Validation of the Student Engagement Instrument. *Journal of School Psychology*, 44, 427 – 445.

Barrie, S. C., Bucat, R. B., Buntine, M. A., Burke Da Silva, K., Crisp, G. T., George, A. V., Jamie, I. M., Kable, S. H., Lim, K. F., Pyke, S. M., Read, J. R., Sharma, M. D., & Yeung. (2015). Development, evaluation, and use of a student experience survey in undergraduate science laboratories: The Advancing Science by

Enhancing Learning in the Laboratory Student Laboratory Learning Experience Survey. *International Journal of Science Education*, 37(11), 1795–1814.

Bhansali, A., Sharma, M. D. (2019) The Achievement Emotions Questionnaire: Validation And Implementation For Undergraduate Physics Practicals. *International Journal of Innovation in Science and Mathematics Education*, 27(9), 34-46.

Bhansali, A., Angstmann, E., & Sharma, M. D. (2020). AEQ-physics: a valid and reliable tool to measure emotions in physics. *In Proceedings of The Australian Conference on Science and Mathematics Education* (pp. 93–98).

Bond, M., Buntins, K., Bedenlier, S., Zawacki-Richter, O., & Kerres, M. (2020). Mapping research in student engagement and educational technology in higher education: a systematic evidence map. *International Journal of Educational Technology in Higher Education*, *17*(1), 1-30. https://doi.org/10.1186/s41239-019-0176-8.

Browne, M. W., & Cudeck, R. (1992). Alternative Ways of Assessing Model Fit. *Sociological Methods & Research*, 21(2), 230–258.

Chipchase, L., Davidson, M., Blackstock, F., Bye, R., Colthier, P., Krupp, N., & Williams, M. (2017). Conceptualising and measuring student disengagement in higher education: A synthesis of the literature. *International Journal of Higher Education*, 6(2), 31. doi:10.5430/ijhe.v6n2p31.

Field, A. (2009). Discovering statistics using SPSS (Third edit). *London and New York: Sage*

Finn, J. D., & Voelkl, K. E. (1993). School characteristics related to student engagement. *The Journal of Negro Education*, 62(3), 249. doi:10.2307/2295464..

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of educational research*, 74(1), 59-109.

Fredricks, J. A. (2011). Engagement in school and out-of-school contexts: A multidimensional view of engagement. Theory into Practice, 50(4), 327–335. doi:10.1080/00405841.2011.607401.

Georgiou, H. & Sharma, M. D. (2020) Engaging science academics with evidence based practices: Use of concept inventories in chemistry and physics across eight universities. *International Journal of Innovation in Science and Mathematics Education*, 28(4), 28-43 http://dx.doi.org/10.30722/IJISME.28.04.003.

Heddy, B. C., Sinatra, G. M., Seli, H., & Mukhopadhyay, A. (2014). Transformative experience as a facilitator of interest development and transfer in a college success course for at-risk students. *American Educational Research Association, Philadelphia, PA*.

Heddy, B. C., & Sinatra, G. M. (2013). Transforming Misconceptions: Using Transformative Experience to Promote Positive Affect and Conceptual Change in Students Learning About Biological Evolution. *Science Education (Salem, Mass.)*, *97*(5), 723–744. https://doi.org/10.1002/sce.21072

Kahu, E. R., & Nelson, K. (2018). Student engagement in the educational interface: understanding the mechanisms of student success. *Higher Education Research & Development*, 37(1), 58–71. doi:10.1080/07294360.2017.1344197.

Kota, S. D., Cornish, S., & Sharma, M. D. (2019). Switched on! Student and teacher engagement in an electricity practical. *Physics Education*, 54(1), 015007. doi:10.1088/1361-6552/aadeee.

Kota, S, D., (2019). Increasing student engagement through the integration of digital technologies in inquiry-based investigations [master's thesis, Sydney], The University of Sydney.

Kuh, G. D., Cruce, T. M., Shoup, R., Kinzie, J., & Gonyea, R. M. (2008). Unmasking the effects of student engagement on first-year college grades and persistence. *The journal of higher education*, 79(5), 540-563.

Martin, F., & Bolliger, D. U. (2018). Engagement matters: Student perceptions on the importance of engagement strategies in the online learning environment. *Online Learning*, 22(1). doi:10.24059/oljv22i1.1092.

Meyer, K. A. (2014). Student engagement in online learning: What works and why. *ASHE Higher Education Report*, 40(6), 1–114. doi:10.1002/aehe.20018.

Newmann, F. M. (1992). *Student engagement and achievement in American secondary schools*. New York: Teachers College Press.

Nussbaum, E. M., (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist* 46(2), 84–106.

Ompusunggu, T., Turnip, B. M., & Sirait, M. (2016). Effects of Inquiry on Training and Critical Thinking Process Skill Science Physics. *Jurnal Pendidikan Fisika Unimed*, *5*(2), 96-100.

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary educational psychology*, 36(1), 36-48.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1998). Student expectations in introductory physics. *American journal of physics*, 66(3), 212-224.

Rice, J. W., Thomas, S. M., O'Toole, P., & Pannizon, D. (2009). Tertiary science education in the 21st century (p. 13). Melbourne, Australia: *Australian Council of Deans of Science*.

Richardson, A., Sharma, M. D., Khachan, J. (2008) What are students learning in practicals? A cross sectional study in university physics laboratories. *CAL-laborate International*, 16(1), 20-27.

Sharma, M., Stewart, C., Wilson, R., & Gokalp, M. (2013). Student Approaches to Learning in Physics Validity and Exploration Using Adapted SPQ. *International Journal of Environmental & Science Education* (IJESE), 8(2), 241-253.

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational psychologist*, 50(1), 1-13.

Tytler, R., & Osborne, J. (2011). Student Attitudes and Aspirations Towards Science. In *Second International Handbook of Science Education* (pp. 597–625). Springer Netherlands. https://doi.org/10.1007/978-1-4020-9041-7_41.

Wattanakasiwich, P., Taleab, P., Sharma, M. D. and Johnston, I. D. (2013) Construction and implementation of a conceptual survey in thermodynamics, *International Journal of Innovation in Science and Mathematics Education*, 21(1), 29-53.

Yazzie-Mintz, E. (2007). *Voices of students on engagement: A report on the 2006 High School Survey of Student Engagement*. Bloomington: Center for Evaluation & Education Policy, Indiana University. Retrieved January 18, 2008, from *http://ceep.indiana.edu/hssse/pdf/HSSSE 2006*.

Yeung, A., Pyke, S. M., Sharma, M. D., Barrie, S. C., Buntine, M. A., Burke Da Silva, K., Kable, S. H and Lim K. F. (2011) The Advancing Science by Enhancing Learning in the Laboratory (ASELL) Project: The first Australian multidisciplinary workshop, *Int. J. of Innovation in Science and Mathematics Education*, 19(2), 51-72.

Appendix A:

The Science Student Learning Engagement Questionnaire and short names.

No	SSLEQ items	Short names
1	This experiment helped me to develop my data interpretation skills.	Data Interpretation skills
2	This experiment helped me to develop my laboratory skills.	Laboratory skills
3	Completing this experiment has increased my understanding of physics.	Interest
5	It was clear to me how this laboratory exercise would be assessed.	Clear assessment
6	The experiment provided me with the opportunity to take responsibility for my own learning.	Understanding physics
7	Sufficient background information, of an appropriate standard, is provided in the introduction.	Background Information
8	The demonstrators offered effective supervision and guidance.	Demonstrators help
9	The experimental procedure was clearly explained in the lab manual or notes.	Experimental procedure
10	I found this to be an interesting experiment.	Relevance
11	I can see the relevance of this experiment to my physics studies.	Responsibility for own learning
12	I enjoyed this experiment.	Enjoy
13	I am satisfied that I did this experiment.	Satisfy
14	During this experiment I was excited.	Excite
15	While doing this experiment I was happy.	Happy
16	While doing this experiment I was bored.	Boredom
17	I found this experiment is dull.	Dull
18	During this experiment I was annoyed.	Annoy
19	I resented doing this experiment.	Resent

Notes: Scales used: (a) A = ‘strongly agree’, B=‘agree’, C=‘neither agree nor disagree’, D =‘disagree’, E=‘strongly disagree’; (b) A = ‘way too much’, B=‘too much’, C=‘about right’, D =‘not enough’, E=‘nowhere near enough’; (c) A = ‘excellent’, B=‘good’, C=‘average’, D =‘poor’, E=‘very poor’.

Supplementary Material accessible by readers:

Factor scores extracted from Exploratory Factor Analysis (EFA)

Factors, short names and scores (λ >0.5)				
Motivators				
Data interpretation skills	.732			
Laboratory skills	.522			
Interest	.645			
Understanding of physics	.799			
Relevance	.659			
Responsibility for own learning	.680			
Resources				
Clear assessment guidelines		.610		
Clear learning expectations		.543		
Background material		.760		
Demonstrators help		.625		
Experimental procedure		.605		
Positive Emotions				
Enjoyment			.777	
Satisfaction			.530	
Excitement			.807	
Happy			.831	
Negative Emotions				
Boredom				.682
Dull				.800
Annoy				.562
Resent				.626

Non-parametric test results for two independent samples Mixed COVID-19 labs and Online COVID-19 labs

Factor	**Mann-Whitney U**	**Wilcoxon W**	**sig(p)**
Motivators	53797.000	128102.000	0.035
Resources	56346.000	130651.000	0.290
Positive Emotions	58229.500	132534.000	0.631
Negative Emotions	58543.000	132848.000	0.719