Design and Validation of an Instrument to Measure Students' Interactions and Satisfaction in Undergraduate Chemistry Laboratory Classes

Wei, J. and Treagust, D.F. and Mocerino, M. and Vishnumolakala, V.R. and Zadnik, M.G. and Lucey, A.D. and Lindsay, E.D

Abstract This paper describes the development, final design and validation of an instrument that measures a range of student interactions and satisfaction in undergraduate chemistry laboratories. Student surveys or conceptual and attitudinal instruments are widely used techniques for collecting relevant information on student learning. However, there is a lack of specific instruments for collecting data on the relationships between social factors and learning. Consequently, this study attempted to fill this gap by introducing an instrument - the Interactions in Undergraduate Laboratory Classes (IULC). The design of the IULC instrument is based on the theory of distributed cognition, meaning that knowledge is not rooted in an individual's mind, but develops in the process of interacting with the environment. The instrument covers three aspects, (i) Frequency of Interactions, (ii) Satisfaction, and (iii) Importance of Interactions for the specific laboratory. Undergraduate students (N = 204) enrolled in a first-year chemistry course participated in a test case for the instrument and the corresponding data were analysed using different methods for each of the three parts. The factor structure of the data obtained from the first part of the instrument and internal consistency measures are discussed. Among findings captured by the instrument, Student-Teacher (instructors in the university context) Interactions correlated positively with students' satisfaction levels. Implications and suggestions for the use of the instrument are discussed.

Keywords First-Year Undergraduate/General, Graduate Education/Research, Chemical Education Research, Testing/Assessment, Social Presences.

Introduction

A large number of studies-analysing learning through laboratory classes have identified those instructor activities used to engage students in meaningful learning consistent with current educational goals (Sadler, Puig, and Trutschel 2011; Velasco et al. 2016; West, Paul, Webb, and Potter 2013). While instructors do play pivotal roles in the teaching process, students' perspectives also need to be incorporated into the laboratory design because students are the key stakeholders who are actually engaged in conducting experiments, analysing data, and constructing knowledge. Furthermore, research has shown that students' perceptions of the laboratory learning environment are mostly inconsistent with those of teachers (Tsai 2003). Hence there is a need for this study which has its emphasis on the design of an instrument that captures students' perceptions of laboratory learning.

One method of investigating students' perceptions of the laboratory was by the use of survey instruments. Various survey instruments designed to probe different facets of science and engineering learning include the *Attitude toward the Subject of Chemistry Inventory (ASCI)* (Barrie et al. 2015), the *Meaningful Learning in the Laboratory Instrument* (*MLLI*) (Galloway and Bretz 2015), the *College Chemistry Self-Efficacy Scale (CCSS)* (Uzuntiryaki and Çapa Aydın 2009), and the *Constructivist Multimedia Learning Environment Survey* (*CMLES)* (Maor and Fraser 2005).

The above instruments provide valuable information about students' perceptions of one or more aspects of the science laboratory. However, none of these studies measured social factors that incorporate the relationships between human behaviours and the environment. The importance of the social environment on learning originated from a cultural-historical approach and was reinforced as distributed cognition; a study by Cole and Engeström (1993) illustrated how learning to read was a process of distributed among learners, instructors, and the environment. Similarly, in their review of learning chemistry in a laboratory environment, Nakhleh, Polles, and Malina (2002) emphasized that knowledge was a process, not an entity rooted in the mind of one individual. Research to investigate the applicability of distributed cognition in education has primarily involved studies about the connection between psychology and education such as the book-length study reporting research in biomedical engineering laboratories, in which the laboratories were considered as systems of distributed cognition (Osbeck, Nersessian, Malone, and Newstetter 2010). In a review of this book, Giere (2011) reaffirmed that scientific cognition, especially problem-solving ability, was distributed and was developed in the process of interactions between humans and the equipment in laboratories. From this viewpoint, learners construct knowledge not in a static way but by interacting with the environment both physically and socially.

The laboratory has a unique characteristic in that the social environment is less formal than the typical classroom or lecture hall and where the learning process can play crucial roles in students' learning experiences. In this way, the extent to which learners interact with the laboratory environment, the instructors and each other, may have a powerful influence on the learners' laboratory experiences. On the other hand, students' ratings of satisfaction levels with individual laboratories may reflect students' learning experiences and consequently be an evaluation of their learning process. However, according to Hofstein and Lunetta (2004), little attention has been paid to the promotion of communication and collaboration in science laboratories and much less on the analysis of group processes and reflective discourse. A review of more recent literature shows that there also is a scarcity of studies pertaining to the correlation between the frequency of interactions and satisfaction in undergraduate science laboratories (Wei et al. 2019). Therefore, the purpose of this paper is to present the development of a new instrument and associated statistical analysis for measuring undergraduate student interactions and satisfaction in chemistry laboratories.

This paper presents the design and validation of an instrument entitled *Interactions in Undergraduate Laboratory Classes* (*IULC*) that measures a range of interactions and students' satisfaction in undergraduate chemistry laboratories. The instrument is designed to collect information about the frequency of interactions, the learners' overall satisfaction levels per laboratory class and the importance of these interactions, ranked in order. Evidence of the quality of the instrument and possible uses are addressed.

Methodology

Background to the Development of the Instrument

Initially, a group of seven education researchers with different research and teaching backgrounds, in education, physics, chemistry, and engineering, considered and documented the possible interactions that each considered might occur in undergraduate laboratories during a fixed period of time. The ideas were shared and discussed, a literature review search was conducted, and on-site laboratory class observations were carried out, resulting in the preliminary version of the *IULC* instrument. The interaction classifications in the *IULC* were organized into four types: Student-Student (S-S) Interactions, Student-Teacher (S-T) Interactions, Student-Equipment (S-E) Interactions, and Indirect Interactions (I-I) (Moore 1989; Sutton 2001). Specifically, the interactions were divided into different sub-items based on the content of behaviours between students and the laboratory environment. For example, in S-S and S-T interactions, topics related to the laboratory content were divided into 'procedures', 'results' or 'concepts', while unrelated topics were separated into 'not directly related' or 'not related'. The type of activity when students discussed chemistry concepts that were not part of the current experiment was assigned as 'not directly related'. Also, the types of topics discussed by students such as sports or entertainment were assigned as 'not related'. A detailed description with regard to each kind of interactions is shown in Part 1 of Figure 1. A previous study (Wei et al. 2018) only included the frequency of interactions in the laboratory using the four types. Two methods to measure the frequency of interaction were used, namely, a self-report form (the post-lab survey) and on-site observations conducted by the researchers. The intention was to provide multi-dimensional data on the frequency of interactions. Results from the observers aligned well with the students' self-report with regard to the frequency of interactions. This alignment demonstrated that the self-report instrument was suitable for the introductory chemistry unit and therefore the instrument was used as the only data collection method within the broader context of a large number of classes. However, after the initial study was implemented, a need was seen to better account for students' perceptions of the chemistry laboratory learning environment. Therefore, modifications were made on the survey instrument to enable correlations with students' level of satisfaction.

Final Design of the Instrument

In the final version of the IULC instrument shown in Figure 1, in addition to the Frequency of Interactions (Part 1), two new parts, Satisfaction (Part 2) and the Importance of Interactions (Part 3) were included. The Frequency of Interactions (Part 1) measured by four response categories (Never, Only Once, A Few Times and Many Times) to 15 interactions meant that the occurrence of interactions in the science laboratories provided a quantitative measure of student behaviours. In other words, the results from Part 1 illustrated how the frequency of each item occurred when the students were engaged in the laboratories. The satisfaction level (Part 2) measured by a 5-point Likert scale (Strongly Disagree-1 to Strongly Agree-5) was designed as a single measure to depict the overall experience of the students immediately after the completion of the laboratory work.

From previous studies, no definite findings were found about the relationship between the frequency of interactions and learning outcomes (Stang and Roll 2014). Nevertheless, a comparison between the frequency and the importance of interactions was assumed to provide a deeper understanding of student behaviours. Consequently, the importance of interactions (Part 3) was introduced to understand what types of interactions the students believed were important for learning. Part 3 required the students to select five important interactions (ranked from 1-5 in terms of relative importance) out of the previous 15 interactions in Part 1. It was believed that the multiple dimensions in the revised instrument had the possibility to provide richer information than did the version used in the Wei et al. (2018) study. The details of the current instrument are presented in Figure 1.

Date: ____________ Time: __________ Unit: ______________________________________

Student ID								Family Name	Given Name(s)

Part1：Reflecting on the laboratory class you just completed

1. *(Student-Student Interactions)* **Did you talk to another student about ...**	**Never**	**Only Once**	**A Few Times**	**Many Times**
1.1 the procedures, protocols or lab equipment?	0	1	2	3
1.2 the basic science concepts behind the lab?	0	1	2	3
1.3 analysing your results?	0	1	2	3
1.4 discipline topics not directly related to the lab?	0	1	2	3
1.5 topics not related to the lab?	0	1	2	3
2. *(Student-Teacher Interactions)* **Did you ask the teacher about ...**				
2.1 the procedures, protocols or lab equipment?	0	1	2	3
2.2 the basic science concepts behind the lab?	0	1	2	3
2.3 analysing your results?	0	1	2	3
2.4 discipline topics not directly related to the lab?	0	1	2	3
2.5 topics not related to the lab?	0	1	2	3
3. *(Student-Equipment Interactions)* **Did you ...**				
3.1 read the lab manual/instructions associated with this lab?	0	1	2	3
3.2 use the Internet for technical assistance, data analysis or for concepts behind this lab?	0	1	2	3
4. *(Indirect Interactions)* **Did you learn by observing someone else's interactions in the lab, such as ...**				
4.1 observing another students experimental setup or behaviour	0	1	2	3
4.2 listening to a student/group of students asking another student for help/advice	0	1	2	3
4.3 listening to a student/group of students asking a teacher for help/advice	0	1	2	3

Part 2:

(Student Satisfaction) **Did you think…?**	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
Did you think the quality of this experiment compared favourably with your other face-to-face laboratory experiments?	1	2	3	4	5

Part 3: Please **choose ONLY 5 of those 15 items (from 1.1 to 4.3)** that you think are most important in helping you successfully complete the lab that you just finished and **rank them.**

Rank	1	2	3	4	5
Item Name					
Example	*2.2*	*1.3*	*1.4*	*3.2*	*2.4*

Fig. 1 Items and students' choices for the three parts of the IULC instrument

Participants

In order to validate the results from the *IULC* instrument, a typical first-year undergraduate chemistry laboratory class with a high number of student enrolments was selected to participate in a test-case upon which to base an analysis of the instrument's accuracy. This study was carried out in an Australian university, in each of the 19 classes of a unit called *Introduction to Chemistry*. This unit was designed to provide a chemistry background for first-year students' future learning in the areas of biology and biomedical sciences. Many of the students had a limited chemistry background; some had never studied chemistry in senior high school, while a few others had studied high school chemistry but failed their examination in the subject. Overall, there were 575 students enrolled in this unit.

Laboratory Content

The IULC instrument was used to collect data toward the end of the laboratory classes. The goals of the laboratory involved in this study, titled '*Identification of Common Ions in Solution*', included conducting qualitative chemical tests, inferring chemical concepts from experimental observations and using an appropriate style to report the findings. In this experiment, the students were provided with a brief pre-lab explanation of the safety rules and key procedures at the beginning of the class. The students, arranged in random pairs, mixed different solutions together as specified in the laboratory manual, observed the resulting phenomenon, recorded their observations and answered the questions in the laboratory worksheet.

Data Collection

This project had been approved by the Human Research Ethics Committee (HRECs) in 2014. Before the beginning of Lab Session one, the students were provided with a Participant Consent Form and informed that the project would be carried out in line with the National Statement on Ethical Conduct in Human Research (2007). The students were also informed that their participation was completely voluntary and they could withdraw at any time without penalty. Each student was provided with a survey toward the end of the laboratory and 204 out of the 575 students completed the survey. All data were collected in paper form and then entered into Excel spreadsheets for further analysis using R version 3.5.1 (R Core Team 2018).

Data Analysis Strategy

Multiple methods were used to analyse the data collected through the three parts of the instrument. For Part 1 of the instrument, namely, Frequency of the Interactions, the data obtained from Part 1 of the instrument were validated via Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA), followed by scale reliability. For Part 2 of the instrument, Satisfaction, Spearman correlation coefficients were calculated to find the strength of the relationship between students' perceptions of the frequency of interactions and their overall satisfaction. For Part 3 of the instrument, Importance of Interactions, the percentage of responses on the importance of the types of interactions was calculated. The results of Many Times obtained in Part 1 of the instrument were graphed with the results of Part 3 as a comparison between Frequency and Importance of Interactions.

Factor Analysis A viable approach to explain data from self-reporting instruments is factor analysis (FA) (Bryant, Yarnold, and Michelson 1999), a process which reduces the number of variables to some latent sets and to find the links between the measured factors and the latent dimensions (Taherdoost, Sahibuddin, and Jalaliyoon 2014). Among the two types of FA, EFA is used when there are no clear expectations about the number of factors, while CFA is used to validate the fit of presumed theories or expectations about the number of constructs (Williams, Onsman, and Brown 2010). In this study, the data from Part 1 were randomly split into two parts initially (Creswell and Creswell 2018). For one part of the data, EFA of the results was conducted to identify the underlying factors in the instrument. For the other half of the data, CFA was conducted to assess how well the model fitted the data. A one-factor model was implemented as a comparison. In the whole study, the following values were used as cut-offs: Comparative Fit Index (CFI) or Tucker–Lewis Index (TLI) $\geq .95$ and the Standardized Root-Mean-Squared Residual (SRMR) $< .08$ (Hu and Bentler 1999).

Scale Reliability Firstly, to increase the sample size, the two parts of data were recombined together to test the reliability. For scale reliability, the analysis process was as follows: firstly, results from the factor analysis were analysed to check whether the items were unidimensional. Consequently, an overall internal consistency value or a single-administration reliability coefficient for each interaction scale was calculated (Komperda, Hosbein, and Barbera 2018). Secondly, to determine which coefficient was appropriate in this study, a single-factor CFA model for each interaction scale was analysed using the congeneric and tau-equivalent models (Komperda, Pentecost, and Barbera 2018). In the congeneric model, the degrees of association between each item and the common construct are not necessarily the same, while in the tau-equivalent model, the factor loadings are restricted to be equivalent (Cho and Kim 2015; Graham 2006; Harshman and Stains 2017). Cronbach's Alpha is appropriate under a condition when the assumptions for the tau-equivalent model are met, and Omega is suitable when the assumptions for the tau-equivalent model are not met but fit for the congeneric model (Komperda, Pentecost, et al. 2018). In this study, as shown below, two items fit the tau-equivalent model and three items fit the congeneric model. The coefficient value was calculated by the R package userfriendlyscience (Version 0.7-2) (Gadermann, Guhn, and Zumbo 2012; Peters 2018).

Results and Discussions

Analysis of Part 1 of the Instrument

The item response distributions in terms of Part 1 of *IULC*, Frequency of Interactions, are presented in Figure 2. Overall, more interactions occurred for 1.3 (S-S Results) and 3.1 (S-E Manual), whereas 2.4 (S-T Not Directly Related) and 2.5 (S-T Not Related) happened much less. In addition, within each type of interactions (procedures, concepts, or results), more 1.1 (S-S Procedures), 1.2 (S-S Concepts), 1.3 (S-S Results) occurred than 2.1 (S-T Procedures), 2.2 (S-T Concepts), and 2.3 (S-T Results), respectively.

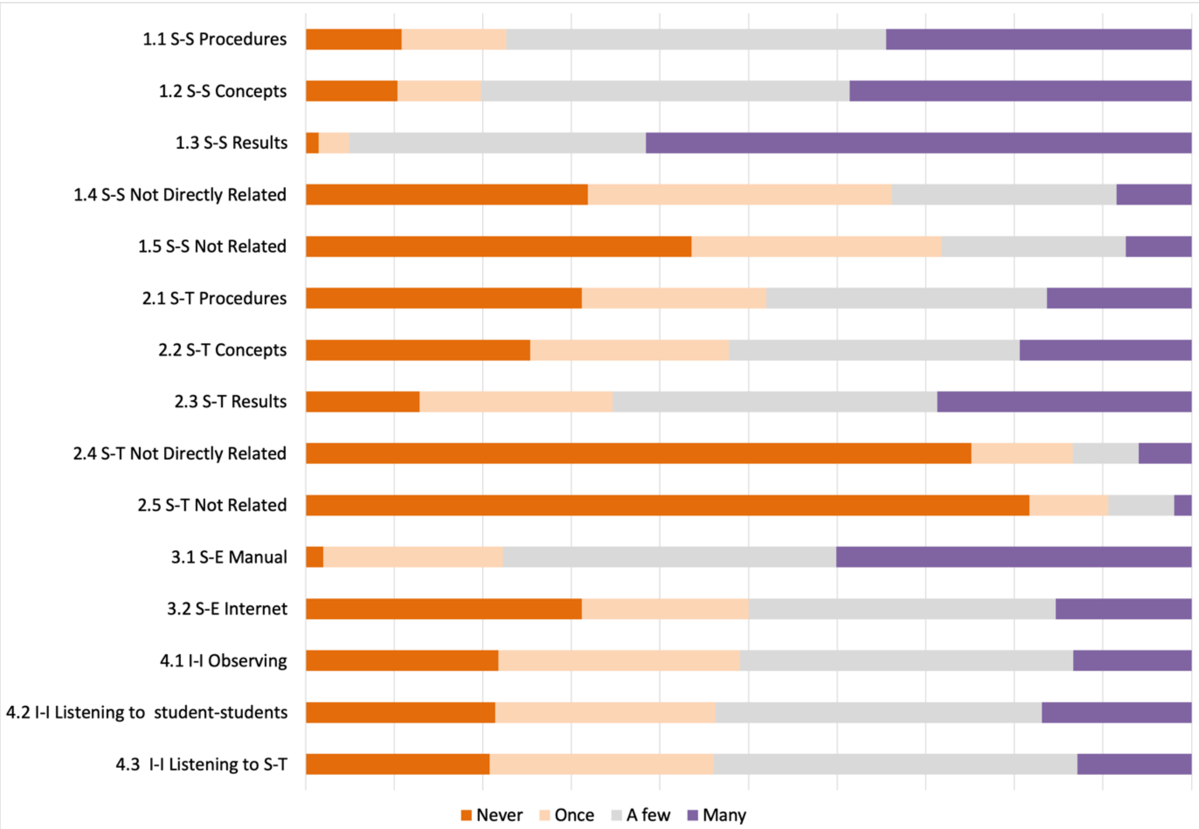

Fig. 2 Distribution of student responses to Frequency of Interactions (Part 1 of IULC), N=204.

Note: the items on the vertical axis refer to the item numbers in the instrument. For a full description of the items see Figure 1.

Out of the 204 responses, 195 without missing data were used for FA. A random separation led to the two parts of data, with the first part including 109 responses and the second part including 86 responses. EFA was conducted with the first part of the data and CFA was carried out using the second part of the data.

Exploratory Factor Analysis Initially, a large number of values from the two-by-two matrix correlation were in the midrange (0.30-0.70), indicating that factor analysis is highly likely to be applicable in this context. The rotation process was an oblique, varimax rotation method. After the initial EFA was conducted, all items fell clearly into five factors, with factor scores in the range 0.61–0.97. No significant cross-loadings were found, all secondary loadings had eigenvalues that were at least 0.25 smaller than the dominant loadings.

Five strong distinct factors emerged, and the instrument statements were organized by factors and ranked by loadings magnitude within the factor as shown in Table 1. The percentage of variance explained by each factor was: I-I (13.1%), S-S Lab-related (11.5%), S-T Lab-related (11.2%), S-T Lab-unrelated (10.5%), and S-S Lab-unrelated (10.4%). The cumulative percent of variance explained by the factors was 56.7%.

Table 1 Interaction items with factor and loading profiles

Factors and Items	Factor Loadings				
	*F*1	*F*2	*F*3	*F*4	*F*5
Factor 1 (*F*1): I-I					
4.2 Listening to Conversations between Students	.87				
4.3 Listening to Conversations between Student(s) and the Teacher	.76				
4.1 Observing Others	.65				
Factor 2 (*F*2): S-S Lab-related Interactions					
1.1 Procedures		.83			
1.3 Results		.72			
1.2 Concepts		.63			
Factor 3 (*F*3): S-T Lab-related Interactions					
2.2 Concepts			.79		
2.3 Results			.69		
2.1 Procedures			.61		
Factor 4 (*F*4): S-T Lab-unrelated Interactions					
2.4 Not Directly Related				.95	
2.5 Not Related				.65	
Factor 5 (*F*5): S-S Lab-unrelated Interactions					
1.5 Not Related					.97
1.4 Not Directly Related					.68

Factor 1, named Indirect Interactions, involves indirect interpersonal practical interactions, including listening to conversations between and among learners and/or instructors, as well as observing other students' behaviours. This scale comprises the learning that happens indirectly or is assumed to have happened among some group of students.

Factor 2 comprises S-S Lab-related Interactions, with three items, namely S–S procedures, concepts, and results. All of these items can be viewed as student-centred interactions pertaining to laboratory activities with their peers.

Factor 3 includes three items, comprising S-T Interactions, talking about concepts, procedures, and results. All of these items concern relevant interactions between learners and instructors. This factor accounts for the guidance provided by instructors during the learners' laboratory activity.

Factor 4 and Factor 5 are both Interpersonal Interactions that are not directly or indirectly related to the individual laboratory context or between students and other students/instructors. In this study, the plausibility of the two-item factor scales is considered to be acceptable when taking into account the theoretical assumptions and correlations between Factor 4 and Factor 5 and students' Satisfaction. This is now discussed in more detail. Firstly, the scales fit into the theoretical assumption of the differentiation of interactions in laboratories and both of the two items within Factor 4 and Factor 5 represent the domain of each variable. The initial theory suggested that the items under S-T and S-S interactions were different, and the EFA results confirmed the assumption that some activities were connected directly with the existent laboratory content (Factors 2 and 3), while other interactions were not connected directly with the content (Factors 4 and 5). These results are confirmed in the CFA (Hurley et al. 1997) as shown in Appendix 1. Secondly, further work was conducted to assess the correlation between the five factors and students' Satisfaction. Factor 4 has a significant correlation with students' Satisfaction as shown later in Table 3. (Furthermore, a follow-up study – not reported here - with second-year students showed that Factor 5 had correlations with students' Satisfaction).

Confirmatory Factor Analysis CFA was conducted to estimate the goodness of fit for the five-factor method from the EFA. A five-factor measurement model was conducted, with 13 items from Figure 1 showing the same five types of interactions based on results from EFA. An alternate one-factor model was also conducted to investigate more parsimonious models. The fit indices of the five-factor model (CFI = .954, TLI = .935, and SRMR = .058) fit the data reasonably well according to accepted criteria (Hu and Bentler 1999). By contrast, the fit indices of the one-factor model (CFI = .508, TLI = .410, and SRMR = .146) were uniformly worse than those for the five-factor model and the CFI did not meet the accepted criteria. CFA without the two-item factors were conducted with the following results (CFI = .93, TLI = .89, SRMR = .68) which do not meet the cut-offs for good fits. Therefore, the five-factor model was more acceptable even though Factors 4 and 5 only included two items.

Scale Reliability Results from the factor analysis showed that this was not a unidimensional model, therefore, additional CFA models were analysed to test the assumptions of congeneric and tau-equivalent models. The results are listed in Appendix 2. Of the five tau-equivalent model values, only S-S Lab-unrelated and S-T Lab-unrelated showed acceptable data-model fit according to the cut-off values used in this study (CFI or TLI ≥ .95, SRMR < .08). For these two values, Cronbach's alpha was reported in Table 2. Three of the five tau-equivalent model values did not fit the cut-offs; therefore, a value of Cronbach's alpha was not appropriate. However, in the congeneric model, the three scales meet the criteria and an omega value is therefore reported in Table 2.

Table 2 Scale internal consistency estimates, either omega or Cronbach's alpha presented

Scale	*F*1	*F*2	*F*3	*F*4	*F*5
Internal Consistency	.80#	.78#	.82#	.86^	.83^

\# omega values, ^ Cronbach's alpha.

Analysis of Part 2 of the Instrument

Spearman's rank-order correlation was calculated to correlate the Frequency of Interactions in terms of the previous five scales and Satisfaction as shown in Table 3. There was fewer overall number of respondents (N=187) compared with results from Part 1 (N=195) because some students did not attempt Part 2 after completing Part 1.

As seen from Table 3, the Spearman's rank-order correlation coefficients for S-T Lab-related and S-T Lab-unrelated (number of Many Times) and Satisfaction were positive and significant, while the coefficients for S-S Lab-related and S-T Lab-unrelated (number of Never) and Satisfaction were negative and significant. This finding illustrated that when more S-T Lab-related and S-T Lab-unrelated interactions appeared, the more satisfied the students were with the laboratory. Similarly, the more that S-S Lab-related and S-T Lab-unrelated interactions did not happen, the students were less satisfied with the laboratory. By contrast, the other interactions had no significant correlations with the satisfaction levels.

To compare the results from Figure 2 and Table 3, firstly S-T Lab-related activities did not occur as many times as they did with S-S Lab-related ones. However, the number of Many Times of S-T Lab-related interactions rather than S-S Lab-related ones, had a significant correlation with Satisfaction levels. Furthermore, even though S-T Lab-unrelated interactions did not occur very frequently, they still correlated significantly with the Satisfaction levels.

Table 3 Spearman's rank-order correlation coefficients for the Frequency of factors/items with Satisfaction (N = 187)

Factors/Items	# of Never and Satisfaction	# of Only Once and Satisfaction	# of A Few Times and Satisfaction	# of Many Times and Satisfaction
F1				
F2	-.160*			
F3				.166*
F4	-.176*			.147*
F5				

*p<0.05, only statistically significant values are shown

Analysis of Part 3 of the Instrument

The Frequency of Interactions reported as Many Times in Part 1 of *IULC* and the Importance of Interactions obtained from Part 3 were analysed. The data in Figure 3 showed that interacting with other students (S-S) about results was the most important interaction, followed by S-T concepts, S-T results, and S-S concepts, respectively. Interestingly, I-I was reported to be important interactions in the laboratories. As shown in Figure 3, there were more Lab-related interactions between the students than among between students and teacher/instructor, while the importance of S-T Lab-related was relatively high.

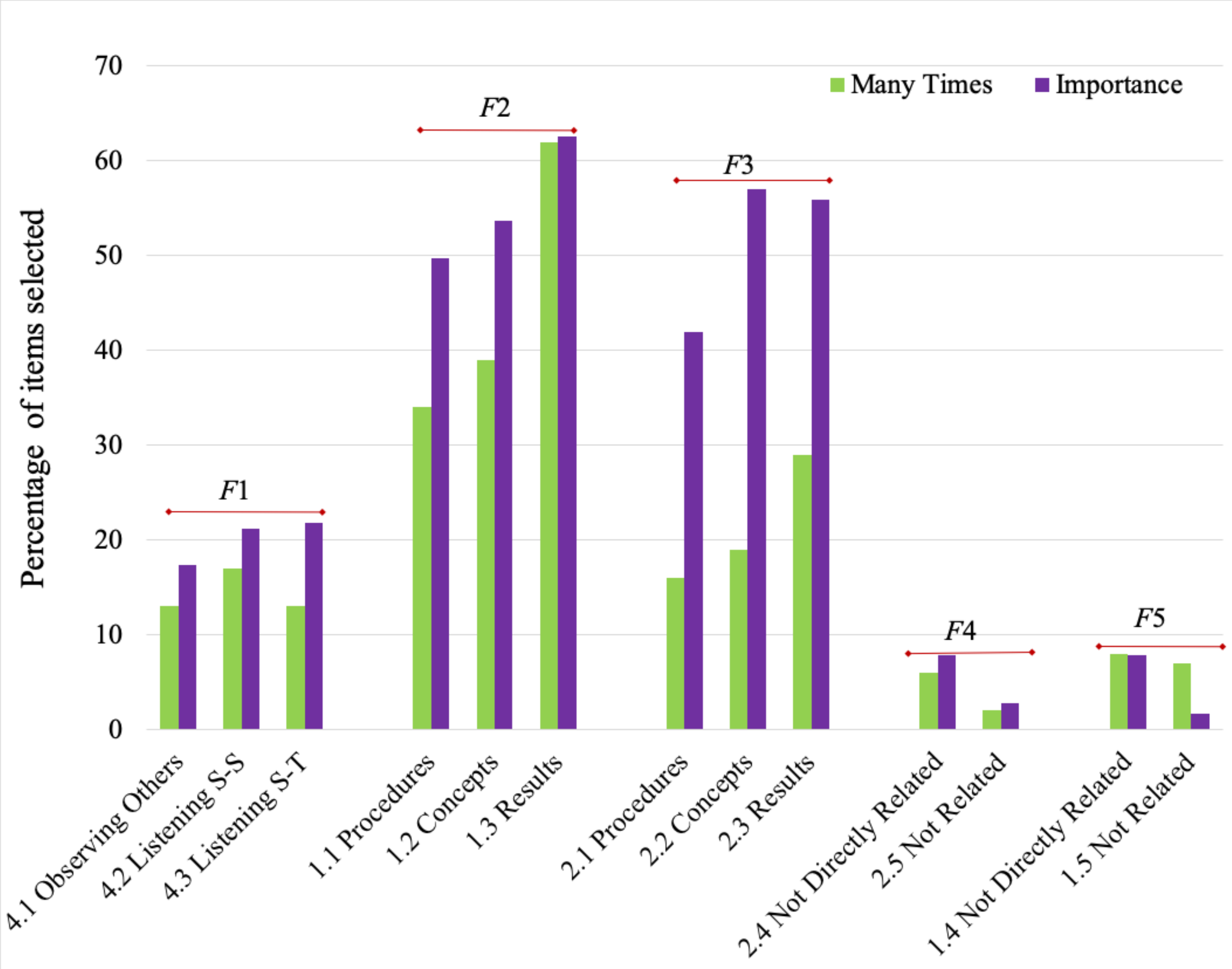

Fig. 3 Percentage of Many Times of Frequency and Percentage of Importance of the Five Scales, Sorted by Task Types, Reported by Students after Undertaking the Laboratory. Data Obtained from the Post-lab Survey (N=203 for Frequency, N= 179 for Importance).

Note: The percentage of each item is not equal to 100% because only data of Many Times are presented, data of Never and A Few Times are not included.

Implications

Implications for Improved Understanding of Teaching and Learning in Undergraduate Laboratories

Motivated by, and aligned with the theory of distributed cognition, the development of the IULC instrument presented in this paper captured student experiences from the viewpoint of learners in a science laboratory. Consistent with the theoretical background behind the study, the students' learning processes were influenced by the learning environment. Thus, the present work is able to contribute to the literature on social characteristics of undergraduate science laboratories by providing an instrument that can be used to collect and analyse students' perceptions of laboratory interactions and satisfaction levels.

Exploratory and confirmatory factor analyses were conducted to determine the internal structure of the data resulting from the first part of the instrument. Five factors emerged from the EFA, and the results were validated by the CFA. The second and third parts, Satisfaction, and Importance were analysed based on the five-factor dimensions. The results obtained using the *IULC* instrument were used to identify significant relationships between the interactions and their Satisfaction levels and these relationships were further discussed. Although the results are not presented in this paper, a correlation analysis was conducted to investigate the relationship between the five-factor interactions and student achievement levels. The main finding was that both the students' laboratory marks and their final examination marks had no significant correlations with the interactions.

The present study showed that there were significant relationships between the interactions and Satisfaction reported by students; these are described as follows. Even though S-T Lab-related interactions did not occur so often, these were reported to be very important after the completion of the laboratory. Considering that only S-T interactions, both lab-related and lab-unrelated, had positive correlations with the satisfaction levels, the frequency and length of productive S-T interactions need to be further studied. Stang and Roll (2014) suggested that increasing the number of interactions between teaching assistants (or tutors) and students had positive effects on students' motivation and engagement. In addition, Velasco et al. (2016) reported that most of the S-T verbal conversations were initiated by students and they were independent of the instructors' instructional styles. It is, therefore, necessary to include pedagogy strategies in laboratory instructor training programs to encourage productive and effective S-T interactions (Mocerino, Yeo, and Zadnik 2015).

Indirect Interactions (I-I) have long been ignored or taken for granted in undergraduate laboratories. However, from this study, at least the students thought they had learned a great deal in this way. It is suggested that more emphasis is placed upon the effects of I-I in the curriculum and laboratory design. An example can be the arrangement of group pairs, with students of different levels of academic ability being in close proximity to each other.

Implications for Future Research in Undergraduate Laboratories

The instrument developed, validated and trialled in this research provides information about students' experiences from the viewpoint of social factors that occur in the laboratory. The instrument is easy to use when collecting data from students’ self-reporting of the frequency of interactions in science laboratories. The aim of this instrument was not to assess the efficiency or effectiveness of learning in chemistry laboratories, but rather to provide a concise overview of the interactions occurring during a laboratory activity. Results from this instrument can be further used to investigate the influences of interactions on students’ learning in all science disciplines. In addition, the results obtained through the use of the instrument can be used for curriculum designers, laboratory instructors, as well as students. For example, in our further study (results not presented herein) the interrelations between the frequency of interactions within three categories of student achievement levels were identified and suggestions were made for educators and learners. Educators interested in the learning process and learning outcomes of various laboratory types could use the present instrument as a first-step analysis that informs research on students’ learning in different laboratories.

Limitations

The first limitation of this study is that the instrument was used to collect data only at one university; further studies in other institutions can evaluate the applicability and generalizability of this instrument. A second limitation is that when designing the instrument, there were just two sub-items under the S-E interaction category (laboratory manual and internet use). This may be the reason why no aggregated factors were identified relating to S-E. However, it is believed that the laboratory manual is an influencing factor in the learning process and future studies should investigate the effect of laboratory manuals on learning. A third limitation of this study is the sample size which resulted in split data for CFA of only 86 students: however, this number was acceptable for the research reported (MacCallum, Widaman, Zhang, and Hong 1999). In addition, the subjects-to-variables ratio locates moderately within 5-10. However, this shortage was offset by the follow-up face-to-face interviews with chemistry educators and laboratory instructors after the implementation of factor analysis. Discussion with experienced laboratory instructors affirmed that the variables were representative domains for interactions in chemistry undergraduate laboratories. Nevertheless, further studies should include a larger number of participants. Furthermore, while small changes in the wordings of instruments can influence the results, the applicability of this instrument needs to be further validated in other institutions and with a broader range of students (Komperda, Hosbein, et al. 2018). Additionally, in this study, quantitative data collection was prioritised; it is suggested that further qualitative data collection and analysis method be performed to test the trustworthiness of the description of interactions in individual science and engineering laboratories (Luckay and Laugksch 2015). A fourth limitation is that there are only two items within two factors (S-S Lab-unrelated and S-T Lab-unrelated). However, the items and the five factors aligned well with the theory of distributed cognition and there were previously reported studies where factors containing two items or even one item existed (Gosling, Rentfrow, and Swann 2003; Panizzon and Levins 1997; Zhao, Hu, He, and Chen 2019). Therefore, the two factors were deemed reliable and were retained in this instrument.

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