Conceptualization, Development and Validation of an Instrument for Investigating Elements of Undergraduate Physics Laboratory Learning Environments: The UPLLES (Undergraduate Physics Laboratory Learning Environment Survey)

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Abstract
First-year undergraduate physics laboratories are important physics learning environments. However, there is a lack of empirically informed literature regarding how students perceive their overall laboratory learning experiences. Recipe formats persist as the dominant form of instructional design in these sites, and these formats do not adequately support the development of students' inquiry processes. There may be valid reasons for the lack of research into students' views of their undergraduate physics laboratory learning environments, but work should be done to address these issues so that such research can occur. This paper describes the development and validation of a 23-item instrument, the UPLLES (Undergraduate Physics Laboratory Learning Environment Survey) that was undertaken as part of a multi-year project aimed to develop guided-inquiry oriented Physics laboratories for first-year students at the University of Alberta. The UPLLES was developed and validated through factor analysis using 476 student responses. The five sub-scales of the UPLLES are, Inquiry Orientation, Integration, Material Environment, Student Community, and Instructor Support. The value of the UPLLES within a battery of measures for evaluating reform efforts in undergraduate physics laboratories is discussed.
Keywords: Learning Environments, Undergraduate Laboratory, Physics, Survey Methodology.

Background: The Need To Understand Undergraduate Physics Laboratory Learning Environments

Undergraduate physics laboratories are important physics learning sites in colleges and universities. Students with various academic and career goals take first year physics courses. Generally they are taken as terminating pre-requisite courses for those seeking entry into specific career options, e.g., medicine or dentistry, elements of a non-physics science or arts major where a number of required science credits are specified, or as stepping stones towards more advanced science courses and study in physics. Therefore the aims, content, organization, and pedagogy informing such laboratory experiences need to accommodate a variety of student intentions and aspirations. Further, in addition to students' intentions, the intentions of the physics professoriate and physics community also need to be accounted for when considering the aims of undergraduate physics laboratories and their role in students' physics education. Within the broader science education literature these intentions tend to center on the development of (a) students' conceptual understanding, (e.g., Treagust & Duit, 2008; Vosniadou, 2012), (b) students' understanding of the nature of science (e.g., Abd-El-Khalick, 2012;

Ibrahim, Buffler, & Lubben, 2009), (c) experimental and analytic techniques (e.g., Lunetta, Hofstein, & Clogh, 2007), and (d) students' inquiry processes and thinking (e.g., Jiménez-Aleixandre & Puig, 2012; Thomas, 2012). Typically however, the majority of this broader science education literature attends to pre-college/university education. Much of the literature related to undergraduate laboratory instruction in university/college physics education, as evidenced with reference to journals such as Physics Education and Physical Review Special Topics - Physics Education Research, focuses on laboratory experiments and activities that are proposed predominantly to attend to (a) and (c) above. Empirical research exploring undergraduate physics laboratories in relation to, for example, what occurs in them, the type of thinking that students engage in, and how students view their experiences in them is much less common.

There could be several reasons for the lack of such research. It may be that the large number of students in undergraduate physics cohorts and lab classes, especially at the first year level, makes the logistics of data collection problematic. It may be that the existing, aforementioned foci on exploring conceptual understanding and the development of experimental and analytic skills have subjugated the consideration of issues associated with laboratories and what happens in them and students' perceptions of their laboratory experiences. Whatever the reasons, there is no doubt that undergraduate physics laboratories could be paid greater attention in physics education and physics education research. This is especially the case given their importance and the time, financial cost, and effort expended for their operation. It should also be noted that for many students taking first year physics courses, it might be their only exposure to systematic physics instruction at the university level. Therefore, it follows that it might also be the only opportunity they have to come to at least a partial understanding of the work that physicists do and the thinking associated with that work. This consideration also adds to their educational importance.

The educational position guiding this paper is that there is a need to understand what happens in undergraduate physics laboratory learning environments so that improvements can be made to instruction in those settings. Such improvements would involve shifting, to some extent, from the use of recipe type formats and the predominant foci on conceptual development and the development of experimental and analytic skills. Of course, such foci would still be regarded as essential. However, we contend that increased attention should be paid to the development of students' inquiry skills in such settings as a means to helping them develop some understanding of the thinking and activities that physicists engage in. We also propose that investigating what happens in physics laboratories, and the consequences of any change to the conduct and structure of what students are asked to do and think, requires a methodological stance that seeks the views of various stakeholders, but especially students. This is because it is students' experiences and learning that are central to understanding the impact of the aims, content, organization, and pedagogy of the laboratory.

Seeking students' views on learning environments can only be accomplished by asking them about those views. Further, to understand students' views it is desirable where possible to use multiple methods. Typically, such methods would be interviews and surveys. Interviews have the advantage of being able to seek very detailed information about student experiences, albeit usually with fewer number of students than surveys. Surveys, conversely, are able to solicit the views of many students, but not with the same depth or reflexivity as interviews. Therefore, ideally both would be used. This paper reports on the development and validation of a survey instrument for exploring students' views of their undergraduate physics laboratory learning environments. In the next few sections we provide a brief overview of the field of learning environments and its relation to this study. Then we outline the institutional context within which the study took place, and explain why the study was needed and where it fits in with a larger change agenda at our university.

The Field of Learning Environments: A Brief Overview

The study of learning environments is well established within education circles. In science education the study of learning environments has a history of over 30 years. Fraser (2002, 2012) has undertaken reviews of research and scholarship in the field of learning environments. Research in this field is premised on the works of Lewin (1936) and Murray (1938). Lewin suggested that human behavior should be understood as being determined substantially by both the "environment and its interaction with personal characteristics of the individual" (Fraser, 2012, p. 1192). Lewin also distinguished between 'beta' press and 'alpha' press. Beta press refers to the perceptions of an environment by those within that environment, while alpha press refers to the perceptions of an environment as noted by a detached observer. Consistent with our aforementioned view of the importance of seeking the students' views, the instrument we developed sought students' beta press perceptions. Murray endorsed and followed Lewin's approach and proposed a 'needs-press' model in which an individual's aims, goals and needs and the tendency to achieve or meet those was moderated by the environment and the situations within which the individual finds him/herself. Out of these ideas, the first learning environment surveys were developed. Among these were the Learning Environment Inventory (Walberg & Anderson, 1968) and the Classroom Environment Scale (Moos, 1979). These instruments were influential in establishing a predominantly quantitative orientation to this field that, in recent times, has given ground to the aforementioned mixed, interview, survey, and sometimes observation approaches. Typically, the surveys and the items within them reflect and indicate respondents' views regarding the extent to which particular psychosocial dimensions that take the form of sub-scales within the survey are prominent or otherwise for those respondents within their learning environments.

Particularly salient to this study is the previous work exploring learning environments in science laboratories using the Science Laboratory Environment Inventory (SLEI) reported by Fraser, Giddings and McRobbie (1992, 1995) and Fraser and Griffiths (1992). These studies, published around 20 years ago, established that learning environments instruments could be developed and used to help understand the psychosocial environments of science laboratories in schools and in universities. Instruments such as the SLEI have typically been used to characterize and compare learning environments with reference to particular theoretical and practical dimensions. Often, and not surprisingly, these dimensions and the items written to represent and qualify them have reflected paradigms and constructs that were prominent in science education thought and scholarship at the times they were developed. It can be argued that when the SLEI was developed, attention to need to develop students' understanding of scientific inquiry and how it can be undertaken was not as pronounced in the literature as it is today. Further, it is important to note that Fraser *et al* and Fraser and Griffiths used students from both high schools and universities and from across science disciplines as respondents in their studies. Apart from a minor reference to the use of high school chemistry students in the Fraser *et al* (1995) study, there is no indication of the science subjects the students were studying at the time they were involved in these studies. Therefore, it is our view that this current study is among the first, if not the first study that looks at developing and using an instrument specifically for providing insights into students' perceptions of their undergraduate physics laboratory learning environments. Accordingly, we contend that this study is important for physics education.

Institutional Context of this study

The University of Alberta is a publicly funded, comprehensive university located in Edmonton, Canada. Its enrolment in undergraduate, graduate and professional programs is approximately 39,000. The Science and Education Faculties are two of eighteen within the university. The reasons students choose to undertake Physics at the first year level vary across universities and educational contexts. In the case of the University of Alberta, two streams of physics students are easily identified. One strand is for those who are taking physics with the aim of developing a potential major in physics. The other is for those taking physics as part of a program other than one with a major in physics, as part of the pre-requisite courses for other disciplines such as medicine or dentistry, or as a part of their required general science credits, generally taken at first year level, towards another program of study within or outside the science faculty. It is the second group of students that this study focuses on, as they constitute the vast majority of first year physics students at the University of Alberta. These students typically take two consecutive courses: Physics 124, which is offered in the Fall, and Physics 126, which is offered in Winter. Both courses are Algebra-based (not Calculus based as for the other strand) and primarily for students in life, environmental, and medical sciences. Physics 124 attends to motion of matter (particles) and wave motion and includes content on vectors, forces, bodies in equilibrium, review of kinematics and basic dynamics; conservation of momentum and energy; circular motion; vibrations; elastic waves in matter; sound; wave optics; black body radiation, photons, de Broglie waves. Physics 126 is a continuation of Physics 124 and covers topics such as fluids, electricity and magnetism, and nuclear physics.

For each of the Physics 124 and 126 courses students are scheduled to conduct 10 laboratories in which topics taught in the lectures are further explored. Due to the large number of students enrolling in first year physics (905 initially registered in 124 for beginning of 2011/12 academic year) many sections of lab sessions are scheduled. For example, 38 sections of between 20 and 30 students were scheduled for Physics 124 in Fall 2011. Over 20 instructors staffed these sections. Most of them were graduate students enrolled in higher degree studies in the Physics department.

Concerns had been raised about the nature of the students' laboratory experiences at the university as early as 2002 when one of the authors, Beamish, with others conducted a review of the first year physics labs (Beamish *et al*, 2002). Their findings were annotated as part of the application for funding to address the learning experience of students in the grant proposal (Meldrum, Beamish, & Thomas, 2011) that funded this research:

> *A clear indication that our labs may not be adequately challenging students to become independent and creative thinkers came in 2002, in a report to the curriculum committee of the Department of Physics from a team led by Dr. John Beamish, a Co-PI on this project. The committee's findings were worrying. Students were "uniformly negative about their overall laboratory experience, despite liking the hands-on aspects of the lab, the opportunity to work in groups, and their TAs." First year students were especially critical. Only 3 of 240 students considered the lab component of the course excellent. In PHYS 124, (Our largest course with over 1,000 registered students in 2010-11), 73 out of 87 students rated the lab component at 3 or lower on a 5-point scale. Only 14 out of 87 students found the labs interesting and stimulating. The report proposed that "significant changes" were needed. (p. 1)*

As is common in the aforementioned science education literature, concerns were raised by Beamish et al, (2002) regarding the extent to which the students' laboratory experiences focused on the confirmation of material taught in lectures and through the course text rather than the development and enhancement of students' inquiry skills. These concerns persisted for the period from 2002 until 2011 when the authors of this paper applied for funding from the Teaching and Learning Enhancement Fund through which the University of Alberta funds initiatives that aim to improve the quality of teaching and learning at the university. At the time of the application for funding, it was obvious from perusal of the Physics 124/126 laboratory manuals that the first-year labs had remained almost entirely confirmatory in orientation and therefore unsatisfactory as authentic physics learning experiences. Meldrum, Beamish, & Thomas (2011) noted that, “For each lab, students get a set of instructions that they are expected to follow exactly. There is little opportunity for independent thought and virtually no authentic inquiry” (p. 1). Other easily identifiable, persistent issues were that, (a) the laboratories and the lectures were not well sequenced, with the material being introduced in lectures sometimes weeks after the related lab, (b) there was no interaction between the class lecturer and the laboratories, and (c) there was a vast difference in teaching ability of the TAs in different lab sections. Therefore, the situation as it existed was contrary to and unsupportive of inquiry-based approaches that have been shown to foster creativity, interest, enhanced understanding and a positive attitude to the subject matter.

The application for the project ‘*Transforming the Undergraduate Physics Laboratory Experience: A Guided Inquiry Approach*’ was successful and funding of CAN$137,579 for two years was granted. The overall aim of this ongoing project, recently extended to a third year, is to introduce a ‘guided inquiry’ orientation to the first-year laboratory activities, consistent with what is considered in contemporary science education circles to be essential for the developing scientifically literate individuals.

This study reports on the development of a learning environments instrument to be used as part of the methodology to assess the impact of changes to the organization, content and orientation of the laboratory components of Physics 124 and 126 courses. As a condition of the project funding it is necessary to engage reliable and valid means of evaluating the impact of planned changes. To do this, in the absence of any previously published instruments for use in a physics context such as ours and for such a purpose, it was decided that an instrument should be developed that was specific to the project’s context and needs. The use of a learning environments instrument is appropriate for helping to understand the influence of pedagogical changes, especially given the logistics of the operation of the physics laboratories and the large number of students engaged in them during any term or semester. This paper reports on the conceptualization, development and validation of that instrument. In using an instrument in this way we aim to add to the literature on the use of such instruments for evaluating curricular and pedagogical change, further extending the potential use of such measures.

Methodology

Development of Instrument for Field Testing

The first phase of the instrument development was to review the literature to understand what had been done before regarding the use of learning environments instruments for evaluating and measuring psychosocial dimensions of science laboratories that were salient to the purposes of our project, predominantly in relation to undergraduate physics laboratories. As is the case in much learning environments research, we reviewed and eventually ‘borrowed’ some sub-scales from other, previously published instruments and modified them as necessary for field-testing. An initial instrument consisting of 40 items was developed. The 40 items of the initial instrument are shown as Appendix A. The instrument consisted of the following seven sub-scales, named as follows and drawn either directly or as derivations from the following instruments: Reflective thinking, Inquiry learning (CCEI: Computer Classroom Environment Inventory; Maor and Fraser, 1996), Student negotiation (CLES: Constructivist Learning Environment Survey; Taylor, Fraser and White, 1994), Student Cohesiveness, Integration, Open-endedness, Material environment (SLEI: Science Laboratory Environment Inventory; Fraser, Giddings and McRobbie, 1995). An eighth subscale, Instructor Support was developed by Thomas with the intention that it might provide insights into the extent and quality of interactions between the laboratory instructors and students. All initial sub-scales contained 5 items. Table 1, to be used in conjunction with Appendix A, shows the items numbers of the initial instrument and their respective initial sub-scale affiliations. We considered that the items contained within these eight sub-scales reflected the issues we saw as important to try to measure and understand in relation to our project's initiative. We stress that the most recent of the instruments from which we drew the seven aforementioned sub-scales for field-testing was published 17 years ago. Consequently, we were very open to the notion that the sub-scales and items we chose to include in the initial 40-item instrument might not have retained their salience and validity over that time period. As is the case with learning environments instruments, we anticipated that there might be possible deletion of some sub-scale/s completely, merging of items to form new sub-scales consistent with new theoretical underpinnings and significance, and deletion of individual items from the sub-scales drawn from these earlier instruments. A key consideration guiding our thinking on this matter was to let the data and their analysis inform the final content of the instrument. We considered this stance preferable to trying to 'squeeze' items into sub-scales that might not make contemporary theoretical sense or have little practical significance for our project.

Table 1. *Item numbers of items the initial instrument and their respective initial sub-scale affiliations.*

Sub-scale name	**Item numbers**
Reflective thinking	1, 9, 17, 25, 33
Inquiry learning	2, 10, 18, 26, 34
Student negotiation	3, 11, 19, 27, 35
Student Cohesiveness	4, 12, 20, 28, 36
Integration	5, 13, 21, 29, 37
Open-endedness	6, 14, 22, 30, 38
Material environment	7, 15, 23, 31, 39
Instructor Support	8, 16, 24, 32, 40

Data Collection

Ethics approval for the study was granted according to University and Federal guidelines. The instrument development described in this paper was conducted in the first year of the project. We considered it necessary to develop an instrument and collect baseline data that could be used and form the basis of informing the team regarding the impact of the forthcoming pedagogical changes. Students in the Physics 124 class were approached and their consent was sought, with the understanding that their consent could be withdrawn or granted at any time. At the start of the winter term the students in the Physics 126 class were approached with the same information and request. It was also understood that completion of the survey also represented consent to participate, should they change their minds. The surveys could be completed either anonymously or with students identifying themselves. Students identifying themselves also had the option to signal their intention to be interviewed by providing an email address for Thomas to contact them. 476 students, 275 from Physics 124 and 201 from Physics 126 completed the 40-item instrument. These response rates were satisfactory in terms of establishing a representative sample of the first year physics students for the purposes of conducting factor analysis (e.g., Reise, Waller & Comfrey, 2000).

Analyses and Results

The analytic procedures we employed and that are reported in this paper are standard within the field of learning environments in relation to the development of survey instruments (see, for example, Fraser, Giddings, & McRobbie, 1995; Schultz-Jones & Ledbetter, 2013; Thomas, 2003; Ward & Fisher, 2013). The data were analyzed using principal components factor analysis followed by varimax rotation (see, for example, Joliffe, 2002; Paz, 2008; Reise, Waller and Comfrey, 2000) and estimation of the internal consistency as represented by Cronbach alpha coefficients (see, for example, Santos, 1999; Tavakol & Dennick, 2011). These analyses lead to the refinement of the initial, 40-item instrument through the deletion of items and reduction of the sub-scales from eight to five. In some cases reconceptualization of the dimensions we had initially included was necessary. For example, two items from the previously used Inquiry learning Sub-scale (Maor and Fraser, 1996), items 13 and 17 on the final instrument (Appendix 1), and three items from the previously used Open-endedness sub-scale (Fraser, Giddings and McRobbie, 1995), items 5, 16, and 21 on the final instrument, loaded onto the same factor. These items, upon reflection, were considered theoretically and collectively consistent with contemporary perspectives regarding scientific inquiry to the extent that they could be considered a distinct dimension of the students' laboratory learning environment. Hence it was decided that it was appropriate to label the five-item sub-scale Inquiry Orientation to reflect their communality.

Five sub-scales employing a total of 23 items were derived from the statistical analysis. These 23 items and 5 sub-scales comprise what we have named the Undergraduate Physics Laboratory Learning Environment Survey (UPLLES). Table 2 is a description of each of the five subscales and the learning environment dimensions they represent. A copy of the UPLLES is attached as Appendix B.

Table 2.*Description of Scales and a Sample Item for Each Scale on the UPLLES*

Scale Name	**Description (Extent to which students consider:)**	**Sample item (In my physics laboratory classes:)**
Integration	… that laboratory activities and content are integrated with non-laboratory & theory classes.	…students understand the relevance of what they are learning in their physics lectures.
Student Community	…that students are helpful and supportive of each other and their physics learning.	…students carefully consider the ideas of others in the class.
Inquiry Orientation	… they are asked to engage in inquiry-type investigations and thinking to learn about physics.	…students design their own ways of investigating problems.
Instructor Support	…they are supported and encouraged by laboratory instructors to engage in and improve their physics learning.	…instructors encourage students to think about how to improve their lab performance.
Material Environment	… that the material resources in the physics laboratories are adequate for the performance of the required tasks.	…the materials that students need are readily available.

The discriminant validity, a measure of the extent to which the dimensions represented by the sub-scales overlap, was calculated using the mean correlation of a sub-scale with the other four scales as a convenient index. The discriminant validity data suggest that the UPLLES measures distinct, but somewhat overlapping aspects of the laboratory learning environment. The instrument's ability to discriminate between classes/sections was not explored using standard ANOVA analysis as this would have compromised the confidentiality of the instructors, which was beyond the ethical approval granted

Table 3. *Internal Consistency (Cronbach's Alpha Coefficient), Sub-scale Item Means, and Discriminant Validity (Mean Correlation of a Scale with Other Scales) for the UPLLES*

Sub-Scale & Number of Items	**Alpha Reliability**	**Sub-scale Item Mean**	**Discriminant Validity**
Integration (5)	0.76	3.19	0.33
Student Community (6)	0.84	3.60	0.31
Inquiry Orientation (5)	0.75	2.30	0.34
Instructor Support (3)	0.71	2.85	0.38
Material Environment (4)	0.66	3.68	0.33

Table 4. *Factor Loadings of Items in the UPLLES*

Item no.	**Factor Loading**				
	Integration	**Student Community**	**Inquiry Orientation**	**Instructor Support**	**Material Environment**
1	0.76				
15	0.72				
4	0.71				
11	0.70				
20	0.62				
14		0.81			
10		0.77			
23		0.75			
18		0.71			
2		0.71			
8		0.59			
13			0.82		
5			0.77		
17			0.55		
16			0.53		
21			0.50		
3				0.80	
7				0.73	
19				0.61	
12					0.71
22					0.70
6					0.61
9					0.56

**All loadings smaller than 0.4 have been omitted.*

to us. Statistical information in the form of internal consistency, each sub-scale's item mean, variances for the sub-scale item means, and discriminant validity is provided in Table 3.

Table 4 shows the factor loadings for each of the items. Each item of the UPLLES loaded onto a only single factor representing a particular stand-alone sub-scale at between 0.50 and 0.82 indicating strong factorial validity of the scale. The 23-item structure means that the item is focused and parsimonious.

Discussion

The items and the sub-scales of the UPLLES attend to the issues that are salient to the project we are engaged in and, we suggest, reasonable in terms of what might be attended to in physics courses offered at the undergraduate level with large classes and numerous laboratory sections. In such contexts, students do not have the same level of contact with each other as high school students might. The expectations of high school labs in terms of what can be and has to be accomplished are different to that of a 3-hour university lab.

The nature of the teaching practices are difficult to manage as instructors are variously experienced, proficient and knowledgeable, and often 'guaranteed' such employment as an element of their Masters or PhD programs. Therefore, we were not surprised when some of the pre-existing sub-scales we used to develop the initial 40-item instrument for field-testing did not perform in the factor analysis as expected or as they had in the previously cited studies. In many ways it would be unreasonable to expect that all pre-existing scales would be relevant across all science laboratory contexts, for example from high school to university, or across cultures, irrespective of the theoretical and ideological underpinnings of the instrument. For a learning environment instrument to be useful for the purposes described above, it must reflect a balance of ideology and pragmatism that are both theoretically and practically defensible within the context it is to be used.

The sub-scale means reflect what we already knew about the situation in the Physics 124 and 126 laboratories, adding to the validity of the UPLLES. For Student Community and Material Support the item means were 3.6 and 3.68 respectively suggesting that students were, on average, more than sometimes but less than often satisfied with the material environment and the level and nature of the interaction they had with each other in the laboratories. Students responded less favorably regarding Integration (sub-scale item mean 3.1) suggesting that the alignment of the experiments was not adequately synchronized with the lecture material. Students' responses on the Instructor Support sub-scale (sub-scale item mean of 2.8) suggest that they were not particularly satisfied with the quality of the support they were receiving from the laboratory instructors. Given the aforementioned issues regarding the overall teaching abilities of the TAs in different lab sections, this is not surprising. Finally, in terms of the level of inquiry, which is the central issue for the *Transforming the Undergraduate Physics Laboratory Experience: A Guided Inquiry Approach* project, students reported little if any control over the nature of their thinking or activity in the laboratory. The sub-scale item mean for Inquiry Orientation of 2.3 confirms the view held by members of the Physics Department at the University of Alberta since 2002 that students consider that are not asked to consider alternatives to procedures in the lab manual or to be creative or engage in inquiry-oriented thinking. Therefore, we are of the view that the rationale for the aforementioned project is well founded. Further, we speculate that one might not expect to find too much, if any, variation in students' responses to items on the UPLLES across universities in relation to first year physics laboratory programmes. Therefore we suggest the UPLLES might have applications in other universities where there is impetus to change what occurs in undergraduate laboratories.

This paper has described the development and validation of a 23-item instrument, the UPLLES (Undergraduate Physics Laboratory Learning Environment Survey). We consider that the instrument is theoretically and statistically valid for use in research into undergraduate physics laboratory learning environments, particularly in relation to the purposes of our project which aims to introduce a guided inquiry approach within those laboratories. At the same time, we acknowledge that the sub-scales do not encompass all dimensions of laboratory learning environments that others engaged in physics education might be interested in. The dimensions that physics teachers, administrators and physics education researchers might be interested in will be reflections of their contexts, cultures, and the educational practices and priorities within their universities, school and education systems. The same might be said of many survey instruments. They serve a specific purpose in educational research and the limits of their use and of the findings from that use should be recognized. When a learning environments instrument is to be used in a context outside of that for which it was originally developed those planning to use the instrument should consider the context within which it was developed and evaluate its potential suitability for use in the new context. This may require field-testing the instrument in the new context and confirming or otherwise its validity and reliability within that context.

Additionally, it is acknowledged that the technique of Confirmatory Factor Analysis (CFA) would add to further establishing the validity and reliability of the UPLLES. We plan to collect data from the use of the UPLLES over three consecutive years in Physics 124 and Physics 126 and then conduct CFA on that data. CFA has been employed in relation to establishing the validity and reliability of other learning environments instruments, and the timing of the use of CFA varies as evidenced by, for example, Johnson and Stevens (2001), Küçüközer et al, (2012) and Thomas (2003, 2004). Our choice to conduct CFA at a later time can justified in terms of the variability of the timing of CFA use as found in the literature. It will also be fitting to check the discriminant validity with the larger sample of students to confirm or otherwise the extent to which each sub-scale measures particular aspects of the laboratory learning environment, as suggested by Maor (2000).

Finally, as outlined earlier, it is appropriate to combine survey techniques with other, qualitative methods such as interviews and observations. This would enable researchers to explore undergraduate physics laboratory learning environments in depth and breadth, and to foreground particular aspects or dimensions of those environments that they were most interested in. This is the methodological orientation we bring to our project. The development of the UPLLES is one aspect of the research component of that project through which we seek to evaluate the effect of pedagogical changes to the learning environment that are focused on developing students' inquiry thinking processes.

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Appendix A

The 40 items of the initial UPLLES instrument

1. Students think carefully about how they learn physics.
2. Students find out answers to questions by conducting investigations.
3. Students get a chance to talk to each other.
4. Students get along well as a group.
5. The activities students do are related to content from physics lectures.
6. There are opportunities for students to pursue their own physics interests.
7. The materials that students need are readily available.
8. The instructor supports students to plan their laboratory activities.
9. Students think critically about their own physics ideas.
10. Students carry out investigations to test their physics ideas.
11. Students discuss with each other how to conduct investigations.
12. Students get to know each other well.
13. Students use theory from their physics lectures to solve problems.
14. Students are required to design their own experiments to solve a given problem.
15. The equipment is in good working order.
16. The instructor supports students to self-assess their physics learning.
17. Students carefully consider the ideas of others in the class.
18. Students conduct follow-up investigations to answer emerging questions.
19. Students ask each other to explain their physics ideas.
20. Students help each other.
21. The investigations students do relate to theories and ideas from physics lectures.
22. Different students collect different data for the same problem.
23. The working environment is comfortable.
24. The instructor encourages students to consider how theory from physics lectures can be applied to laboratory activities.
25. Students think about how to become better physics learners.
26. Students design their own ways of investigating problems.
27. Other students ask me to explain my physics ideas to them.
28. Students can depend on each other for help.
29. Students understand the relevance of what they are learning in their physics lectures.
30. Students can go beyond assigned tasks and so some experimenting of their own.
31. Students use computer technology to assist them with their investigations.
32. Instructors support students to design their own ways of investigating problems.
33. Students think critically about their own physics understanding.
34. Students approach a problem from more than one perspective.
35. Students explain their physics ideas to me.
36. Students work collaboratively.
37. Students see how the theories and practices of physics are related.
38. Students decide the best way to proceed with their laboratory work.
39. There is enough room for individual and group work.
40. Instructors encourage students to think about how to improve their lab performance.

Appendix B

UPLLES

What actually happens in this laboratory class?

DIRECTIONS

1. **Purpose of the Questionnaire**
This questionnaire asks you to describe HOW OFTEN each of the following practices actually takes place in your physics laboratory classes. There are no right or wrong answers. Your opinion is what is wanted. This is not a test, and your answers will not affect your assessment. Your answers will enable us to improve future physics laboratory classes.

2. **How to Answer each Question**
On the next page (the reverse of this page) you will find 23 statements. For each statement, circle only one number corresponding to your answer. For example:

	Almost Always	Often	Some-times	Seldom	Almost Never
In my physics laboratory classes: 5. Students are required to design their own experiment to solve a given problem.	5	4	3	2	1

- If you think students are *almost always* required to design their own experiment to solve a given problem, circle the 5.
- If you think students are *almost never* required to design their own experiment to solve a given problem circle the 1.
- Or you can choose the number 2, 3, or 4 if one of these seems like a more accurate answer.

3. **How to Change Your Answer**
If you want to change your answer, cross it out and circle a new number. For example:

In my physics laboratory classes: 5. Students are required to design their own experiment to solve a given problem.	~~5~~	4	3	2	1

4. **Your Information**
Please provide information in the box below. Please be assured that your answers to this questionnaire and your identity will be treated strictly confidentially.

Name (OPTIONAL):	Date:
Email (OPTIONAL):	Gender: M F

5. **Completing the Questionnaire**
Now turn the page over and please give an answer for **every** question on the page.

	Almost Always	Often	Some-times	Seldom	Almost Never
In my physics laboratory classes:					
1. The activities students do are related to content from physics lectures.	5	4	3	2	1
2. Students ask each other to explain their physics ideas.	5	4	3	2	1
3. The instructor supports students to plan their laboratory activities.	5	4	3	2	1
4. Students use theory from their physics lectures to solve problems.	5	4	3	2	1
5. Students are required to design their own experiments to solve a given problem.	5	4	3	2	1
6. The equipment is in good working order.	5	4	3	2	1
7. The instructor supports students to self-assess their physics learning.	5	4	3	2	1
8. Students carefully consider the ideas of others in the class.	5	4	3	2	1
9. The materials that students need are readily available.	5	4	3	2	1
10. Students help each other.	5	4	3	2	1
11. The investigations students do relate to theories and ideas from physics lectures.	5	4	3	2	1
12. The working environment is comfortable.	5	4	3	2	1
13. Students design their own ways of investigating problems.	5	4	3	2	1
14. Students can depend on each other for help.	5	4	3	2	1
15. Students understand the relevance of what they are learning in their physics lectures.	5	4	3	2	1
16. Students can go beyond assigned tasks and so some experimenting of their own.	5	4	3	2	1
17. Students approach a problem from more than one perspective.	5	4	3	2	1
18. Students explain their physics ideas to me.	5	4	3	2	1
19. Instructors encourage students to think. about how to improve their lab performance	5	4	3	2	1
20. Students see how the theories and practices of physics are related.	5	4	3	2	1
21. Students decide the best way to proceed with their laboratory work.	5	4	3	2	1
22. There is enough room for individual and group work.	5	4	3	2	1
23. Students work collaboratively.	5	4	3	2	1