

Students' Opinions, Views, and Perceptions of Science Laboratory Learning: A Systematic Review of the Literature

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Abstract

The scientific community continues to give conflicting impressions about the contribution of laboratory activities to science learning and yet ignores the views of students who are the focus of learning. In this paper, we reviewed postsecondary school students' experiences in the science laboratories. Students were most concerned about the impact of the laboratory activities and their preferences pointed more towards greater independent, participatory and interactive learning engagements. This review has implied that students should not be left out in science laboratory learning reform efforts and their views about what obtains in the science laboratories should be routinely monitored to inform such reforms.

Keywords: science laboratories, laboratory activities, students' views, students' preferences, laboratory learning

INTRODUCTION

Science laboratory learning activities have frequently come under the spotlight and therefore preoccupied educational researchers. Some have expressed scepticism about the effectiveness of laboratory practical work. For instance, it is believed that laboratory practical work most often leads to limited academic gain (Wieman & Holmes, 2015). Also, Hodson (1993), referring to teachers added that "much that we provide is ill-conceived, muddled and lacking in real educational value" (p. 105). According to Hofstein and Lunnetta (1982), laboratory learning activities were principally aimed in the 1800s at enhancing technical skills needed for industrial work. However, this has tremendously changed over time. Today, the science laboratory as a learning platform has evolved and represents a complex learning environment with a lot of dimensions that need to be unravelled if progress should be made in science education.

There is overwhelming empirical evidence available in the research literature on the contribution of science laboratories to the attainment of science educational goals. However, most of these omit students'

experiences and perspectives. According to Thomas and Meldrum (2018), students' experiences and perceptions about the laboratory is key to understanding the laboratory environment and in making curriculum decisions. In this paper, we argue that students' experiences are critical to the full understanding of the relationship between the pedagogical strategies in the laboratories and the learning outcomes therein. It is the students' views, opinions and perceptions that provide important insights into the influence of the pedagogical changes that are implemented. These insights provide the basis for designing new strategies to inform pedagogies that will enhance students' learning of science inquiry processes.

In students' opinions, the science laboratory includes a place where experiments are conducted to demonstrate the applications of theoretical ideas, a place that affords learners opportunities to put scientific theory into practice (Harman et al., 2016). In one study, students' use of metaphors to describe their perceptions of the physics laboratory generated conceptual categories principal among which was the learning through visual impact, and working in an atelier was the most commonly used metaphor in this category (Aykutlu et al., 2019). Also,

Contribution to the literature

- As science educators voice scepticisms about the real academic value of science laboratory learning, the research literature shows that students' views have mostly been omitted in this regard.
- To understand the relationship between the pedagogical strategies in science laboratories and their learning outcomes, students' experiences are critical, being at the centre of instruction. Students' insights provide the basis for designing new pedagogical strategies.
- The authors were not aware of any systematic review on the topic for the period under review at the time of writing, as the literature search from various databases did not reveal such.

Burrows et al. (2017) identified students' opinions about categories of learners in a science project-based laboratory as independent researchers, socialites, explorers of mastery and skill.

Aim of the Study

To address the problem in this study, we embarked on a systematic review of the literature on students' views, perceptions and opinions on science laboratory learning over twelve years; from 2008 to 2020, and the following questions guided the process;

1. What are students' views, opinions and perceptions about learning in the science laboratory?
2. How might these experiences inform current science laboratory instructional practices and future research on laboratory instruction research?

For the purpose of this study, a laboratory refers to a traditional laboratory as well as a virtual laboratory. Also, pre-service teachers are considered students.

METHOD

The authors were not aware of any systematic review on the topic of this study, and the literature search in five databases for the period under review did not prove otherwise. The authors started the scope search for sources using keywords such as "students' perception of experiments", "laboratory learning", "students' opinions on laboratory", "students' perspectives of laboratory learning". This search was done in the following five electronic databases; ERIC, Google Scholar, ProQuest, EBSCO, and Research4life between June and August 2020. A total of 3,965 sources that were published online were initially gathered. The subject content areas varied and included agriculture, computer science, geology, biology, chemistry, and physics. Initial sources reported studies at all levels of education; elementary schools, high schools, and tertiary institutions.

Filtering of the cumulative sources was done by considering the following reasons for exclusion; duplication of study or titles, non-alignment between the content of the abstract and the construct projected in the

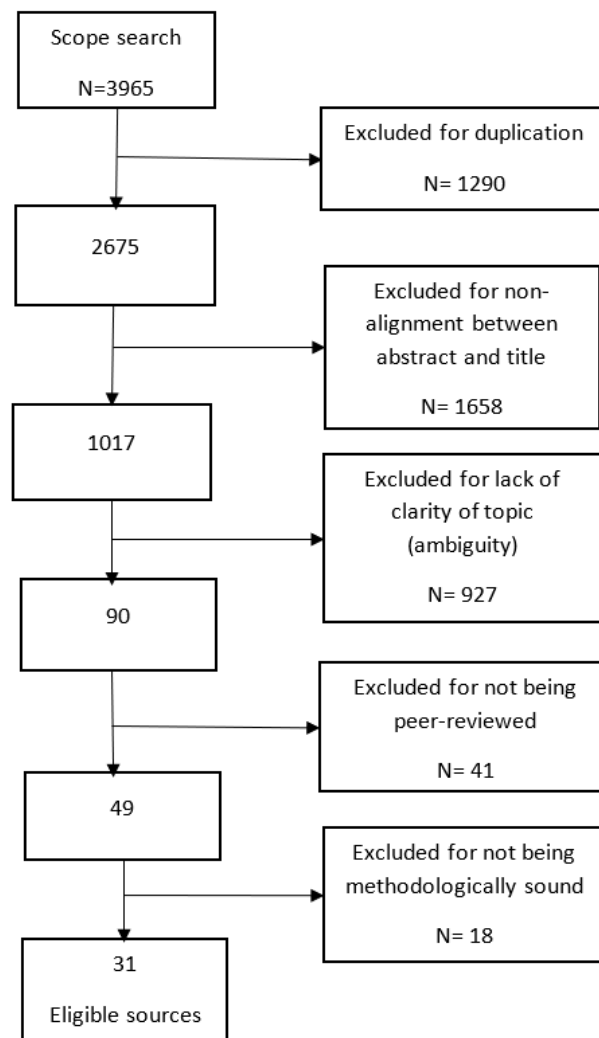


Figure 1. Flow chart of research literature filtering process

title, the lack of clarity of study title, peer-review, methodological soundness, especially the psychometric properties of the data collection instruments. Details of the filtering process are provided in the flow diagram in Figure 1.

In the final stage of the selection of eligible sources, the authors used a methodological quality assessment rubric that was constructed by the corresponding author, and validated by the co-authors and an external auditor. In order to reduce the bias in the judgment of quality and enhance the quality of selected sources, each source was evaluated for construct validity. If a survey was used, a reliability coefficient of at least 0.70 was a

criterion for inclusion. This process resulted in 31 eligible sources (Appendix A) for thematic analysis.

Therefore, the final selection was based on the following predetermined criteria:

- a. If the study subjects were post-secondary school students;
- b. If the laboratory studied was in the chemistry, biology, physics, or general science;
- c. If the study was peer-reviewed;
- d. If the study used an interview or survey;
- e. If the topic was not ambiguous, but clearly written; and
- f. If the study used sound psychometric properties (statistical or otherwise).

Finally, the full papers were read by each author and the findings (Appendix B) compared for harmonization. Thereafter, the themes “students’ perceptions of aims and purposes of laboratory learning, students’ perceptions about the effectiveness and impact of laboratory learning and students’ preferences in laboratory learning settings” (outcome variables) emerged by consensus among the authors. Every step of the filtering process was conducted by individual authors, followed by a conference for the comparison of outcomes. Where there were disagreements between two authors, the view of the third author reigned supreme. Therefore, every decision in the filtering and selection process was by consensus of the authors’ opinions.

RESULTS

Table 1, Table 2, and Table 3 present the data collected in this study.

Table 1. Included sources of articles by country

Country	Number (n)	Percentage (%)
Australia	2	6.45
Australia & the UK	1	3.23
Canada	3	9.67
Finland	1	3.23
New Zealand	1	3.23
Turkey	9	29.03
UK	3	9.67
USA	11	35.49
Total	31	100.00

Table 2. Subjects in which science laboratory activities were conducted

Subject	Number (n)	Percentage (%)
Biology	4	12.90
Chemistry	11	35.48
Biology/Chemistry/Physics	2	6.45
Chemistry & Physics	1	3.23
General Science	4	12.90
Physics	9	29.03
Total	31	100.00

Table 3. The percentage distribution of the various outcome categories

Outcome variable	n	%
Students’ perceptions of aims & purposes of laboratory learning	9	20.45
Students’ perceptions about effectiveness & impact of laboratory learning	19	43.18
Students’ perceptions about anxiety & challenges in science laboratory learning process	8	18.18
Students’ preferences in laboratory learning settings	8	18.18
Total	44	99.99

Aims and Purposes of Laboratory Learning

In terms of the purpose of laboratory learning, students’ opinions included; the development of practical and scientific process skills, as well as enhancing understanding of the theoretical concepts (Dikmenli, 2009; George-Williams et al., 2018; Hanif et al., 2009), learning science by fun (Aykutlu et al., 2019; Harman et al., 2016; Sadoglu & Durukan, 2018), effective and meaningful learning (Dikmenli, 2009; Harman et al., 2016), motivation and the development of positive attitude towards science (Dikmenli, 2009), permanent learning and the application of learned concepts (Harman et al., 2016), verification of known scientific theories and principles, conceptual understanding of the nature of science, creation of a link between scientific knowledge and contemporary experiences, and the creation of a link between science, technology, and society (Dikmenli, 2009). With the use of metaphors, students described the purpose of the science laboratory as learning for curiosity, learning by direction and learning by labour (Aykutlu et al., 2019).

Students in George-Williams et al.’s (2018) study stated the purpose as imparting the knowledge of scientific ways of reasoning and the appropriate use of scientific language. Also, students indicated that laboratory instruction is meant to assist them in learning about their learning abilities and developing everyday scientific problem-solving and critical thinking skills (Yildirim, 2016). Interestingly, students held the view that laboratory instruction was meant to help tactile learners more because it afforded them greater opportunities to engage in their preferred styles of learning (Russel & Weaver, 2008). Also, cited were purposes such as to repeat and reinforce lecture content (Russel & Weaver, 2008), the enhancement of theoretical understanding, development of practical skills, gaining of laboratory experience (George-Williams et al., 2018), and preparation for the workforce and development of transferable skills (Burrows et al., 2017). However, a section of the students’ included the verification of scientific theories and laws (Dikmenli, 2009).

The Effectiveness and Impact of Laboratory Learning

Impact was expressed in the cognitive, affective and psychomotor domains. Students stated improvement in their conceptual understanding of science through laboratory exploration (Moozeh et al., 2019; Priest et al., 2014; Whelan et al., 2015) and level of engagement and interaction (Goldina & Barattini, 2018). Concerning video-based techniques, students rated the level of inquiry as very low but still valued the educational short videos and the majority acknowledged that it was a new experience for them.

The impact of the laboratory experiments also translated into affective attributes as students indicated that they enjoyed the experiments (George-Williams et al., 2018; Henige, 2011; Horsley & Moeed, 2018), and became motivated and acquired attitudinal change towards science (Chatterjee et al., 2009; Tartar, 2012; Uyulgan & Akkuzu, 2018; Wright, 2012). Students liked the station-based teaching approach because it made learning less stressful and made shy students more comfortable to ask questions (Goldina & Barattini, 2018). Thomas and Meldrum (2018) reported a significant positive effect of laboratory instruction on students' perception of their learning environment. However, Karacop and Diken (2017) realized that there was no significant difference in students' opinions regarding the Jig-saw cooperative approach and the confirmatory approach to laboratory instruction. On the psychomotor front, students realized enhancement in experimental design and laboratory skills (Galloway & Bretz, 2016; Koretrsky et al., 2011; Tartar, 2012; Yildirim, 2016) as well as communication skills (Whelan et al., 2015).

Anxieties and Challenges in the Science Laboratory Learning Process

Students' anxieties included the lack of synchronization between the classroom course content and laboratory topics, vague instructions, malfunctioning equipment and the lack of skills in data analysis (Deacon & Hajek, 2011). Therefore, laboratory experiments were confusing and students expressed fear of making mistakes (Sneddon et al., 2009). In the inquiry-based instructional method, students complained about the lack of structure and complete guidance (Henige, 2011). Students performed laboratory experiments without a clear sense of the purpose of the activity and very few demonstrated knowledge of the purpose of the experiments. Students' high expectations that laboratory practicals would be aligned with the lecture contents were not met (Deacon & Hajek, 2011). Also, students experienced great challenges with the presentation of data in graphs in addition to the lack of understanding of units conversion (Berber, 2013).

For cooperative learning, students struggled in their groups with what to do in their assigned roles, and team

roles did not help them complete the laboratory task efficiently and promptly. Instead, it deterred their progress because they were confused and wasted a lot of time determining what every member was supposed to do (Ott et al., 2018). Whelan et al. (2015) highlighted the lack of appropriate instructions and feedback from instructors. Students recounted their experiences in being rushed into completing the procedures to be able to write laboratory reports. Therefore, the focus was shifted from conceptualizing the science behind the experiment to strictly following the procedures (Galloway & Bretz, 2016). Besides, insufficient assessment in small group class assignments was raised (Whelan et al., 2015). Security and fear of dangerous chemicals were also reported (Priest et al., 2014). Moozeh et al. (2019) also reported students' dissatisfaction with the use of laboratory manuals, which they said did not provide detailed instructions or descriptions of experiments.

Students' Preferences in Laboratory Instruction

Students' opinions were divided on the preference for virtual or traditional physical laboratory learning. Some students preferred virtual experiments and simulated teaching methods to the traditional wet laboratory one because they could progress with the experiments at their pace; they could stop to review the procedures and continue at will. Students who preferred the traditional wet laboratory teaching method cited the advantage of working in groups and immediate access to the instructor (Crandall et al., 2015; Leung et al., 2016). Also, they preferred written instructions in laboratory manuals (Chatterjee et al., 2009). They enjoyed doing the high-level inquiry experiments more than the low-level inquiry (Henige, 2011) and said that the pre-laboratory modules helped them more than did laboratory manuals in understanding the concepts (Moozeh et al., 2019).

Ott et al. (2018) reported that for the cooperative learning groups, students indicated their highest preference for the role of the data recorder among rotationally assigned roles. Besides they found strength from their peers since they did not feel confident performing the tasks alone. Also, students were attracted to the video-based laboratory instructional approach (Moozeh et al., 2019). The majority of the students preferred that laboratory teaching assistants offer more guidance in carrying out experiments to make them more comfortable (Sandstrom et al., 2014; Sneddon et al., 2009). These students indicated that they would want to design and conduct their experiments with increased guidance (King et al., 2016).

DISCUSSION OF FINDINGS

Between 2008 and 2020, students' perspectives on science laboratory learning were investigated in peer-reviewed sources the most in the USA (Table 1), where

nearly a third (31.43%) of all eligible sources in this review came from. This result might not be unconnected with the importance that the USA's science education places on learners' perspectives in educational reform efforts. The findings in this study reflect students' say about laboratory learning in core science subjects, with chemistry being the most represented (35.48%), followed by physics (29.03%). This implies that the sample of eligible sources considered in this review contained laboratory investigations in chemistry the most. In respect of the four outcome variables in Table 3, which were thematically generated, the matter that amounts to the most concern in students' opinions and views is the effectiveness and impact of laboratory learning, which accounts for 43.18%, followed by the aims and purposes of laboratory learning (20.45%). Students made the least mention about anxiety (18.18%) and preferences (18.18%). Notwithstanding, the fact that students have demonstrated their greatest concern to be the impact of the activities in laboratory sessions somewhat places importance on the need for routinely monitoring laboratory work and gauging students' views on reform strategies. Their experiences of numerous anxieties and challenges are reminiscent of the fears and scepticism expressed by some science educators about the potential of laboratory activities in enhancing meaningful learning.

There are a lot of expectations for the results of the laboratory activities, which may affect students' notion of the purpose of the science laboratory. Students' collective views of the aims and purposes of laboratory learning reported in this paper go beyond the scope of just verifying scientific laws and essentially agree with the findings of previous studies. For instance, Hofstein and Lunetta (2004) report the aims and purpose of laboratory learning as consisting; arousal of students' interests and enhancement of their motivation, while McDonnell et al. (2007) found the purposes to be; bringing meaning into the learning process by developing cognitive and analytical skills and making the links between life and science interesting to learners.

The students' views also mirror the National Science Educational Standards' goals for inquiry active learning (NRC, 2006), which highlights students' understanding of the nature of science, enhancement of conceptual understanding and scientific reasoning, motivation towards science and development of practical and social skills. Even so, Trumper (2003) argues that the laboratory should prioritize the teaching of skills and not the nature of science or scientific concepts. However, the views expressed by students corroborate the argument by Aufschnaiter and Aufschnaiter (2007) that laboratory instruction should be targeted at the enhancement and development of conceptual understanding in addition to bridging the gap between theory and practice.

Additionally, students' perspectives in this paper include interesting new insights. Whereas

individualized laboratory demonstrations may not be designed to solely help a few learners, students claim that kinesthetic learners stand to benefit more as it affords them more opportunities to engage in their preferred style of learning. Students think that imparting the knowledge of scientific ways of reasoning and the appropriate use of scientific language could be a plausible rationale for the laboratory components and activities in science (George-Williams et al., 2018). The consistency of students' perspectives on the aims of laboratory learning with the views of prominent science educators is suggestive of a need for a shift towards viewing students as partners in the efforts towards the building of a better science community.

Both experience and research have taught us that the environment has an important influence on the success or otherwise of a learning process. As stated by Lewin (1936) cited in Fraser (2012), human behaviour is dependent on both the environment and the interaction of the individual in that environment. The laboratory learning environment has largely been reported in the literature to depict an apprenticeship model, where learners follow a step-by-step procedure after their laboratory instructor or a laboratory manual. This narrows the opportunity and freedom that should be afforded to students in trying out their inquiry techniques, where they make errors, learn from those errors and make learning more interesting and permanent (Hofstein & Kind, 2012; Hofstein & Lunetta, 2004). In this study, significant positive learning experiences are reported to accompany changes in students' learning environment as exemplified by the inquiry-based method (Thomas & Meldrum, 2018), the cooperative jig-saw technique (Karcop & Diken, 2017), and the station-based teaching approach by Goldina and Barattini (2018). This is corroborated by the findings of Yildirim (2016) who observed between 50% and 74% of students expressing that laboratory experiments enhanced key competencies in learners including learning, problem-solving and critical thinking. In all of the aforementioned findings, students demonstrated the relevance of laboratory activities in learning.

Of particular interest is the students' comparative rating of laboratory demonstrators on the levels of preparedness for which the peer demonstrators had 8% higher scores than PhD student demonstrators (Braun & Kirkup, 2016). This might mean that students have a greater inclination to work with their peers as laboratory instructors. Many studies have established the varying strengths of correlation between learners' expressed attitudes and academic achievements (Osborne et al., 1998). Freedman (1997) realized that hands-on experiences promote learners' attitudes towards science, which in turn influences academic achievement. Based on this observation, it may be plausible to infer that students' attitudes are a good predictor of academic excellence.

Clear team members' roles in a cooperative learning environment is a fundamental requirement if learning must be meaningful. In Ott et al.'s (2018) investigation, students had mixed feelings about the benefit of the team roles to individual and group learning. Students generally cited greater productivity, development of social skills and team spirit as achievements in the exercise. In support of the cooperative learning technique, students in Whelan et al.'s (2016) study also believed that facilitated active learning yields a greater academic gain than independent learning. Besides, Springer et al. (1999) found that students demonstrate more positive attitudes towards the subject content materials if they are organized in small groups. Students in this review were enthused by experiments and described as fun, the mixing of two or more chemical substances in chemistry and the dissection experiments in biology (Horsley & Mooed, 2018). The experiments helped students to learn the science concepts as they demonstrated this in their long term retention of learned content. Therefore, for cooperative working groups, students in this review were divided on their support for group work by their indication of advantages of the two approaches.

Eliciting students' views on what constitutes their fears and anxieties in the science laboratory should be seen as key to attaining academic gains as are the methods of instruction. A more noticeable challenge was associated with the use of multimedia in laboratory instructions. One such study conducted by Priest et al. (2014) reported the lack of familiarity in the use of the technique. Most times, the vast nature of the curriculum and teachers' deficiency in pedagogical and content knowledge compound the problems of the use of technology in teaching (Thornton & Sokoloff, 1990). Safety and security in the light of the fear of dangerous chemicals have been a concern to students in chemistry laboratory work. As suggested by Harman et al. (2016), there should be visible signs to direct students in the laboratory for any accidents that might occur. The authors also suggest that it might be a good idea for students to be informed in advance about the equipment and chemical substances that they will use in the laboratory. This review has revealed that most students equate preparation for laboratory sessions with reading their laboratory manuals. However, it seems reasonable to think that seeking theoretical information on the subject of the activities from textbooks and other sources in addition to mastering the procedures in the laboratory manuals would better prepare students in advance of experimentation.

Pre-laboratory activities should be designed to not only motivate students but also trigger their thought processes about the relevance and purpose of the upcoming laboratory activity. Students can also prepare for the laboratory by identifying the main theoretical ideas in the experiment, reading those underlying

concepts from textbooks. This might immerse students into the experiments more and thus provide them with informed justifications for the activities.

Instructions that accompany tasks and assignments can either ease or confound learning. Students were challenged with clarity of instructions and they realized that this was key to carrying out the experimental procedures. Beyond the instructions, instructors could also model the intended action in the procedures with sufficient illustrations. This will serve to complement the clarity in instructions. According to Tsai (2003), having clearer instructions for students' guidance in the procedures and use of supportive equipment is crucial to the attainment of quality results in the science laboratory. Amidst the challenges, students in this study realize the importance of science laboratory work. Evidence of this is seen in their demonstration of high expectations about the need for the laboratory practical work to be aligned with, and complement the lecture content. However, the high cost of laboratory supplies and the time to be dedicated to laboratory instruction can sometimes lead to not only non-alignment of the classroom and laboratory instructional contents, but the total omission of the laboratory components of science courses in the curriculum (Carnduff & Reid, 2003).

Students' who were involved in inquiry types of activities indicated the importance of group work and group member contribution to the achievement of the general goal of the activity. These students were given a wide scope of freedom for exploration and critical analysis of the experiments. They were made to design their experiments amidst challenges. They also experienced challenges that stretched their critical thinking and reasoning, especially with partial guidance.

Students' preferences in this study point towards more freedom, greater autonomy and active engagement, which they indicated to enjoy in the learning process: this probably explains why they liked the inquiry-based and innovative teaching techniques. However, the absence of a total dislike for either the traditional or virtual and simulated laboratory approach is suggestive of the need for a combination of both approaches into science laboratory learning in the future. This may meet the affective learning needs of learners, which is undoubtedly related to the cognitive and psychomotor learning gains. In the cooperative learning groups, they preferred the role of data recorder most and the researcher the least, based on the rigour involved in executing the roles (Ott et al., 2018). Guided and high-level inquiry instruction appealed to the students more than an open inquiry. This might be due to their attribution of higher value and importance to partial guidance than non-guidance in their experience. Besides, the fact that the analysis of data in the guided inquiry approach stretched their thinking abilities might have led them into believing that they learned more with high-level inquiry instruction. Students are not alone in

their preference for guided inquiry over open inquiry. The open inquiry, which requires learners total freedom and autonomy to explore scientific concepts unguided, has been challenged by a section of scholars. For instance, Blanchard (2010) argues that its high demands for sufficient prior knowledge, skills and experience in scientific inquiry, may render it non-applicable in most instances. This high demand can constitute cognitive overload for learners, a situation, which can impair learning. For this reason, Settlage (2007) described it as a highly impracticable level of inquiry for amateurs.

The fact that students liked the high-level guided inquiry approach that did not negatively affect their motivation but led to a lower academic gain, demonstrates a complex nature of the relationship between students' preferred teaching methods and academic achievement. Therefore, a highly rated teaching strategy by students does not always translate into meaningful learning. This is at variance with a generally held notion that anything tending to arouse students' interest in science practical work constitutes a means of motivating them, leading to academic success and the achievement of set learning goals. However, in many cases in this study, there was little evidence of learning although students enjoyed the practical activities. Although Landis and Reschly (2013) conclude that students will become bored and lose out on the lesson if they don't appreciate and get motivated in the classroom especially at the beginning, Taber (2007) cautioned that irrespective of students' appreciation for the practical activities, there is a need for them to demonstrate a high level of cognitive achievement. There is therefore a need for an in-depth study to prove learning gains beyond students' approval of a teaching approach.

CONCLUSIONS AND IMPLICATIONS

This review set out to examine students' views, opinions and perspectives of laboratory learning and the implications that these would have on current science laboratory practices as well as science education research. This review informs existing literature that most studies of students' perspectives on laboratory learning in the last twelve years have been carried out in the USA, and activities in chemistry have dominated. Among topics for reflection in the science laboratories, students are most interested to talk about the effectiveness and impact of learning. Therefore, they took a keen interest in and demonstrated sufficient knowledge of the aims and purposes of laboratory learning, effectiveness or impact, challenges and anxieties, as well as their preferences in laboratory learning activities.

This has an important implication on the design of laboratory activities. Students should hold a major stake in the design of laboratory activities because their

opinions and perspectives of learning are related to the attainment of affective and psychomotor goals in their learning. However, the correlation between the affective and cognitive goals remains inconclusive as far as the analyses have proved. Therefore, improvement in the science laboratory learning would require a more careful examination with respect to the relevance of activities, and students' impressions of the learning process. Routine empirical research should be done to inform needed reforms in science laboratory education. As long as students form the right opinions about activity in the laboratory, the learning becomes intrinsically motivational and might lead to greater cognitive and psychomotor gains.

Views on teaching methods largely favour the high-level inquiry, innovative and inquiry teaching approaches that offer greater guidance including cooperative jig-saw, station-based and video-based approaches. Students enjoy autonomy and independence while carrying out experiments and prefer written instructions to accompany experiments. Although students appreciate cooperative groups, instructions on assigned roles may need to be complemented by modelling instructions for greater clarity. Students are wary about the non-alignment of the classroom instructional materials with the laboratory content for reinforcement of learning. Also, insufficient time to complete the activities and the safety of laboratory chemicals are a great concern. Multi-media techniques promise a lot of benefits for use in the laboratories, however, mastery of the use of these technologies represents a major challenge. Therefore, professional development efforts for instructors must include training in the use of these technologies in laboratory instruction. Although some students will always demonstrate good performance on laboratory tasks amidst challenges, the obvious thing to do is to identify these challenges by way of empirical research that solicits their views and thereafter, incorporates these and their suggestions into a broader plan for improvement. Incorporating students' preferred styles of learning into the lesson design will improve their motivation and possibly, performance rate. This requires a paradigm shift in the way laboratory lessons are designed.

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APPENDIX A

List of Eligible Sources that Met the Inclusion Criteria

Author(s)	Year	Title
1 Aykutlu et al.	2019	An examination of pre-service teachers' metaphorical perceptions concerning physics lab applications
2 Berber	2013	Anxieties, preferences, expectations and opinions of pre-service teachers related to physics laboratory
3 Braun and Kirkup	2016	Non-physics peer demonstrators in undergraduate laboratories: A study of students' perceptions
4 Burrows et al.	2017	Students' perceptions of a project-based organic chemistry laboratory environment: A phenomenographic approach
5 Chatterjee et al.	2009	Surveying students' attitudes and perceptions toward guided-inquiry and open-inquiry laboratories
6 Crandall et al.	2015	A comparison of the degree of student satisfaction using a simulation or a traditional wet lab to teach physical properties of ice
7 Deacon and Hajek	2011	Student perceptions of the value of physics laboratories
8 Dikmenli	2009	Biology student teachers' ideas about the purpose of laboratory work
9 Galloway and Bretz	2015	Video episodes and action cameras in the undergraduate chemistry laboratory: Eliciting student perceptions of meaningful learning
10 George-Williams et al.	2018	'What do you think the aims of doing a practical chemistry course are?' A comparison of the views of students and teaching staff across three universities.
11 Goldina and Barattini	2018	Exploring student perceptions of a station-based teaching approach in the human anatomy and physiology laboratory
12 Hanif et al.	2009	The perceptions, views and opinions of university students about physics learning during undergraduate laboratory work
13 Harman et al.	2016	Pre-service science teachers' views on laboratory applications in science education: The effect of a two-semester course
14 Henige	2011	Undergraduate student attitudes and perceptions toward low- and high-level inquiry exercise physiology teaching laboratory experiences
15 Horsley and Moeed	2018	"Inspire me" - High-ability students' perceptions of school science
16 Karacop and Diken	2017	The effects of jigsaw technique based on cooperative learning on prospective science teachers' science process skill
17 King et al.	2016	A scoping study investigating student perceptions towards inquiry-based learning in the laboratory
18 Leung et al.	2016	Students' opinions on the educational value of physics laboratories: A cross-sectional survey
19 Moozeh et al.	2019	A pre-laboratory framework toward integrating theory and utility value with laboratories: Student perceptions on learning and motivation
20 Ott et al.	2018	Students' understanding and perceptions of assigned team roles in a classroom laboratory environment
21 Priest et al.	2014	Student perceptions of chemistry experiments with different technological interfaces: A comparative study
22 Russell and Weaver	2008	Student perceptions of the purpose and function of the laboratory in science: A grounded theory study
23 Sadoglu and Durukan	2018	Determining the perceptions of teacher candidates on the concepts of science course, science laboratory, science teacher and science student via metaphors
24 Sandström et al.	2014	The experience of laboratory learning-How do chemistry students perceive their learning environment?
25 Sneddon et al.	2009	Perceptions, views and opinions of university students about physics learning during practical work at school.
26 Tatar	2012	Inquiry-based science laboratories: An analysis of pre-service teachers' beliefs about learning science through inquiry and their performances
27 Thomas and Meldrum	2018	Students' perceptions of changes to the learning environments of undergraduate physics laboratories: An empirical study
28 Uyulgan and Akkuzu	2018	Educational short videos to utilize in the biochemistry laboratory: Opinions of university students
29 Whelan et al.	2016	Students' perceptions of independent versus facilitated small group learning approaches to compressed medical anatomy education
30 Wright	2012	Student perceptions of an upper-level, undergraduate human anatomy laboratory course without cadavers
31 Yildirim	2016	Opinions of pre-service classroom teachers towards laboratory using in science instruction and their preferences towards laboratory approaches

APPENDIX B

Data from Eligible Articles by Outcome Variables

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Students' views about what constitute the aims & purposes of laboratory learning						
Aykutlu et al. (2019)	46	Physics	Turkey	Pre-service physics teachers' perceptions concerning "physics lab application"	Metaphors form designed by researchers	The most frequently used metaphor is under conceptual category of learning through visual impact Learning by labour (19.56%), learning by having fun (6.52%), learning by being curious (4.34%), & learning by getting directions (4.34%)
Burrows et al. (2017)	18	Chemistry	USA	Ways students perceive a project-based organic chemistry lab	Phenomenology & semi-structured interview	Exploring unknown in science Cultivating independence Practice understanding of concept Social interactions Developing tech skills for future career Gathering details of lab & experiments Efficiency & saving time
Dikmenli (2009)	82	Biology	Turkey	Biology student teachers' ideas about the purpose of laboratory work in teaching biology	Open-ended questionnaire	To verify theories & principles, learning laboratory techniques, meaningful learning, making abstract concepts concrete, motivation towards science, acquire scientific process skills, create links between scientific knowledge & daily life, mastery of nature of science, critical thinking skills, create links between science, technology, & society
George-Williams et al. (2018)	120	Chemistry	Australia & UK	Students' perceptions of aims of practical lab activities within degree programs	Survey questionnaire & interviews	To develop practical skills, enhance the application of theoretical concepts, & better understand theoretical concepts
Hanif et al. (2009)	143	Physics	UK	Undergraduate students' perceptions, views, & opinions about physics learning during their laboratory work	Survey Focus group interviews	To learn practical skills as well as to illustrate theory taught in lectures Providing a medium to improve collaborative work
Harman et al. (2016)	63	Chemistry & Physics	Turkey	Views on concept & purpose of laboratory	Survey questionnaire Before & after laboratory teaching	Effective learning, permanent learning, & better understanding, faster learning & learning with fun Observation & experiment for quality of learning
Russel and Weaver (2008)	13	General Science	USA	Students' perceptions of purpose of laboratory	Interview	To perform procedures, not to learn the theory To repeat & reinforce lecture materials
Sadoglu and Durukan (2018)	58	General Science	Turkey	Students' concepts of science course, science lab science teachers, & science student using metaphors	Phenomenology Students were asked to complete sentences	Science course as understanding/discovering life science laboratory as "a place that provides experience & entertainment", science teacher as "a mentor", science student as "a valuable being"

Data from Eligible Articles by Outcome Variables (continued)

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Sneddon et al. (2009)	500	Physics	UK	View of undergraduate physics students in relation to their experiences of practical physics at school	Survey questionnaire & interview	Students view practical side of course as a way they encounter new matter/concepts in their courses
Students opinions about the impact of science laboratory learning						
Braun and Kirkup (2016)	1,700	Physics	Australia	Effect of introduction of non-physics major peer demonstrators on student perception of demonstrator-student interactions in laboratory	Survey	Compared to PhD demonstrators, less experienced demonstrators (peer & honors students) received 8% higher scores in perception of demonstrator being well prepared to help in encouraging student to think deeply about experiment
Chatterjee et al. (2009)	703	Chemistry	USA	Students' perceptions & attitudes toward guided & open inquiry-based labs laboratory	Survey questionnaire	Students have a more positive attitude toward guided inquiry laboratory than open-inquiry laboratory Students believe that they learn more with guided-inquiry laboratory than open-inquiry laboratory
Galloway and Bretz (2016)	13	Chemistry	USA	Students' cognitive & affective learning experiences in undergraduate chemistry laboratory	Video recording & interview	The laboratory gives students an opportunity to use their hands to physically carry out experiments
George-Williams et al. (2018)	3,202	Chemistry	Australia & UK	Perceptions of cognitive, psychomotor, & affective expectations of students during laboratory sessions	Survey Questionnaire	Students agreed to statements on survey instrument that aided their meaningful learning Students also tended to select either neutral, disagree, or strongly disagree to statements that would have a negative impact on their meaningful learning (e.g. I expect to be frustrated)
Goldina and Barattini (2018)	88	Biology	USA	Student perceptions of the effectiveness of SBA method	Survey questionnaire	SBA method was more engaging, interactive, less intimidating, & learning experience less stressful for students with diverse science backgrounds It allowed students to feel more comfortable asking questions Although the content was challenging, students in the SBA method felt more positive about their lab experience
Henige (2011)	39	General Science	USA	Comparison between students reactions to traditional, cookbook style, low-inquiry level (LL) activities, & a high-inquiry level (HL) investigative project	Survey questionnaire	Students enjoy HL projects more than LL activity HL inquiry does not have a negative effect on students' motivation Students perceived that they learned more about physiology principles with LL activity

Data from Eligible Articles by Outcome Variables (continued)

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Horsley and Moeed (2018)	56	Biology, Chemistry, & Physics	New Zealand	Students' views about their learning experiences in science	Questionnaire & focus group	Students' enjoyed experiences Appreciated pedagogy
Karacop and Diken (2017)	48	Biology, Chemistry, & Physics	Turkey	Students' opinions regarding cooperative pre-learning-based jigsaw method & confirmatory laboratory method Differences in terms of students' science process skills (jigsaw & traditional lab)	Questionnaire survey in a pre-test-post-test design	There was no statistically significant difference between opinions of the students regarding applied laboratory approaches
Koretsky et al. (2011)	111	Physics	USA	Students' perceptions of nature of cognition, experimental design, & ambiguity	Survey questionnaire	Students show enhanced awareness of experimental design, greater references to critical thinking, & higher order cognition in virtual laboratory & an enhanced awareness of laboratory protocol in laboratory Many students indicated an ability to suspend disbelief & demonstrate psychological immersion in the virtual laboratory project
Moozeh et al. (2019)	89	Chemistry	USA	Students' opinions about anticipated benefits including related theory, procedural justification, & relevance of experiments in a prelab module through multimedia design	Survey questionnaire & videos	More than 60% of students thought that prelab modules helped them understand supportive information Students also indicated that prelab modules helped them understand theory better than laboratory manual 50% to 68% of students responded positively to statements regarding utility value /relevance justification
Priest et al. (2014)	187	Chemistry	Australia	Differences in student perception in chemistry experiments conducted by two different cohorts of students	Survey questionnaire	Widespread improvements in student perceptions of their laboratory experience were observed, prominently including reduced negativity concerning equipment, an increased perception of understanding, an increased perception of simplicity, & more positive perceptions of overall laboratory experience
Sneddon et al. (2009)	500	Physics	UK	View of undergraduate physics students in relation to their experiences of practical physics at school	Survey questionnaire & interview	Students felt that experiencing self-driven experiments prepared them for inevitable day when there would not always be written instructions for work they would be doing

Data from Eligible Articles by Outcome Variables (continued)

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Tartar (2012)	41	General Science	Turkey	Students' beliefs about learning science through inquiry before & after inquiry-based instruction	Interviews & observations	Past experiences of students were effective on beliefs about learning science through inquiry The open inquiry science activity in decision making, discussion, collaboration, & interaction were effective in developing their beliefs concerning learning science through inquiry & increasing their ability to apply scientific inquiry process
Thomas and Meldrum (2018)	-	Physics	USA	Impact, thinking process, value, & appropriateness of a changed laboratory environment	Undergraduate physics laboratory learning environment survey (UPLLES) & semi-structured interviews	Changes had a significant positive effect on students' perceptions of their laboratory learning environments Reforms stimulated "inquiry" thinking Large effect sizes & confirmed marked changes in students' perceptions
Uyulgan and Akkuzu (2018)	40	Chemistry	Turkey	Students' opinion about short videos in biochemistry laboratory	Semi-structured interview	Activity interested students & it was instructive Use of videos in laboratory environment had a positive effect & improved students' attitudes & interests towards laboratory course Students stated that educational video learning activities positively affected their intrinsic motivation Educational videos improved student's communication skills
Whelan et al. (2015)	225	Biology	Canada	Students' perceptions regarding the comparison between two small group learning approaches to compressed integrated anatomy education	Quantitative (Likert-style questions) & interview	Gains in collaboration & communication skills Students taught by facilitated active learning performed better on practical examinations
Wright (2012)	30	Chemistry	USA	Student reactions to an upper-level human anatomy laboratory course for undergraduate students	Survey questionnaire	Students embraced the use of models in the course It deepened, focused, & increased their interest in their learning of anatomy Laboratory manual helped them learn about anatomical models & know how to navigate primal pictures Students agreed that prelab exercises made their learning more interesting
Yildirim (2016)	236	General Science	Turkey	Opinions on laboratory applications	Survey questionnaires	Laboratory learning improves learning skills, consolidates subject matter, improves self-expression with group, enhances critical thinking & problem solving skills, & helps in making associations with daily life experiences

Data from Eligible Articles by Outcome Variables (continued)

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Students' opinions on their challenges & anxieties in laboratory learning						
Berber (2013)	245	Physics	Turkey	Level of pre-service teachers' anxieties about physics laboratory	Qualitative & quantitative methods & semi-structured interviews with 20 students	Students had difficulty drawing graphs, converting units of measure, & using laboratory materials They also had difficulty in understanding purpose of experiment
Deacon and Hajek (2011)	168	Physics	Canada	Students' perceptions of value of physics laboratories	Survey	Lack of synchronization between course & laboratory topics, influences students' ability to successfully complete laboratory exercise Waiting for help from TAs, 'vague' instructions, malfunctioning equipment, & lack of familiarity with data analysis software were problems taking up precious time in laboratory
Galloway and Bretz (2016)	13	Chemistry	USA	Students' cognitive & affective learning experiences in undergraduate chemistry laboratory	Video recording/ interview doing & why they were doing it	Few students discussed learning chemical ideas while in laboratory, & some declared to not learn anything at all
Henige (2011)	39	General Science	USA	Students reactions to traditional, cook-book style, low-inquiry level (LL) activities, & a high-inquiry level (HL) investigative project were compared	Survey questionnaire	Of students who did not like HL project, many reported being uncomfortable with lack of structure & guidance
Moozeh et al. (2019)	89	Chemistry	USA	Students views about usefulness of laboratory manual	Survey questionnaire & videos	Laboratory manual did not usually provide detailed theory description or experimental procedure
Ott et al. (2018)	20	General Science	USA	Student understanding & perceptions of assigned team roles in a classroom laboratory environment	Survey questionnaire & focus group interview	Students' understanding of team roles contradicted somewhat original descriptions they were given Students did not perceive roles as a requirement to obtain team productivity & cohesion, given that many students reported ignoring roles altogether
Sneddon et al. (2009)	500	Physics	UK	Views of undergraduate physics students in relation to their experiences of practical physics at school	Survey questionnaire & interview	Students find laboratory environment a confusing one & want to minimize chance of making mistakes
Whelan et al. (2015)	225	Biology	Canada	Students' opinion about adequacy of time & assessment	Survey, Likert-scale, & interview	Lack of sufficient time & assessment

Data from Eligible Articles by Outcome Variables (continued)

Author(s)	No of students	Subject	Country	Variables of interest	How measured	Key findings
Students' opinions about their preferences in laboratory learning						
Chatterjee et al. (2009)	703	Chemistry	USA	Students' preference in guided & open inquiry laboratories	Survey questionnaire	More students preferred guided inquiry to open inquiry laboratory
Crandall et al. (2015)	48	Chemistry	USA	Students' satisfaction of use of simulation vs. traditional wet laboratory to teach physical properties of ice	Survey questionnaire	There was a general preference of simulated laboratory over traditional wet laboratory. Students who preferred simulated laboratory felt they could move at their own pace & were able to stop & review simulation to understand concepts more clearly. Traditional wet laboratory proponents liked working in groups & having immediate access to instructors
Henige (2011)	39	General Science	USA	Students reactions to traditional, cookbook style, low-inquiry level (LL) activities, & a high-inquiry level (HL) investigative project	Survey questionnaire	Students enjoyed HL projects more than LL activity Most students liked HL project, particularly independence, responsibility, freedom, & personal relevance
King et al. (2016)	81	Biology	UK	Students' perceptions towards inquiry-based instruction	Survey questionnaire	Students clearly wanted detailed instructions, which was not provided in inquiry-based instruction. 40% of them said they would value the opportunity to design & carry out their own experiments. Students believed that explaining your results to others is an important part of practical work
Leung et al. (2016)	445	Physics	Canada	What kinds of laboratory technologies do students prefer?	Internet-based survey created through Google forms	Students preferred physical equipment in traditional laboratories more than virtual laboratories
Moozeh et al. (2019)	89	Chemistry	USA	Students' preferences for experiments in a prelab module through multimedia design	Survey questionnaire & videos	Prelab modules helped students understand theoretical concepts better than lab manual Students were attracted to video-based instruction
Sandström et al. (2014)	9	Chemistry	Finland	Perceptions of learning environment	Interview	Many students expressed a wish to have more agile learning spaces outside laboratory. Many of them reported a need to have differentiated spaces also either within laboratory or in close proximity to it
Sneddon et al. (2009)	500	Physics	UK	Views of undergraduate physics students in relation to their experiences of practical physics at school	Survey questionnaire & interview	Students preferred clearer guidance since experiment was confusing