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Factors influencing student perceptions of high-school science laboratory environments

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Abstract

Science laboratory learning has been lauded for decades for its role in fostering positive student attitudes about science and developing students' interest in science and ability to use equipment. An expanding body of research has demonstrated the significant influence of laboratory environment on student learning. Further research has demonstrated differences in student perceptions based on giftedness. To explore the relationship between giftedness and students' perceptions of their learning environment, we examined students' perceptions of their laboratory learning environment in biology courses, including courses designated for high-achieving versus regular-achieving students. In addition, to explore the relationship between students' perceptions and the extent of their experience with laboratory learning in a particular discipline, we examined students' perceptions of their laboratory learning environment in first-year biology courses versus elective biology courses that require first-year biology as a prerequisite. We found that students in high-achieving courses had a more favourable perception of all aspects of their learning environment when compared with students in regular courses. In addition, student perceptions of their laboratory appeared to be influenced by the extent of their experience in learning science. Perceptions were consistent amongst regular- and high-achieving students regardless of grade level. In addition, perceptions of students in first year and beyond were consistent regardless of grade level. These findings have critical applications in curriculum development as well as in the classroom. Teachers can use student perceptions of their learning environment to emphasize critical pedagogical approaches and modify other areas that enable enhancement of the science laboratory learning environment.

Keywords

High-school science; Learning environment research; Rasch measurement; Structural equation modeling

Introduction

Science laboratory learning has been lauded for decades for its role in fostering positive student attitudes about science and developing students' interest in science and ability to use equipment (Bates 1978; Freedman 1997; Hofstein and Lunetta 1982; Thompson and Soyibo 2002). Because the science laboratory offers opportunities for students to investigate

scientific phenomena while working in small groups, the goals for laboratory learning extend beyond enhancing mastery of subject matter as is typical of other coursework. Indeed, laboratory learning aims to develop students' scientific reasoning skills, technical or practical skills, teamwork abilities, and understanding of the processes and nature of science, including the complexity and ambiguity of empirical work (NRC 1996).

An expanding body of research has demonstrated the significant influence of the laboratory environment on student learning. For example, students' positive perceptions of their classroom environment and, in particular, of their science laboratory learning environment are linked with positive attitudinal and cognitive outcomes (Fraser 1981; Rentoul and Fraser 1979). Wong and Fraser (1997) used the Science Laboratory Environment Inventory (SLEI) with a group of high-school chemistry students from Singapore, determining that students' perceptions on all of the dimensions except open-endedness were positively related to students' attitudinal outcomes. Fraser et al. (1993) further determined that students' perceptions of their laboratory learning environment accounted for significant variance in their learning beyond that attributable to differences in their ability.

Given the potential for students' perceptions to enhance their attitudes about, interest in, and understanding of science, other student, teacher, and classroom qualities have been explored to determine their relationship with students' perceptions of their laboratory learning environment. For example, correlational studies have identified significant differences in students' perceptions according to gender, age or grade level, and achievement (Dart et al. 1999; Kim et al. 1999; Quek et al. 2005). Causal relationships have also been identified between instructional approaches, including those identified as constructivist or inquiry-based, and tighter alignment between students' perceptions of their actual and preferred laboratory learning environments (Hofstein et al. 2001; Kim et al. 1999).

In addition, Quek et al. (2005) investigated the relationship between students' 'giftedness' and their perceptions of their chemistry laboratory learning environment. Gifted students perceived their actual laboratory learning environment more positively with respect to student cohesiveness, integration, and material environment. However, a number of factors confound the interpretation that students' positive perceptions are attributable to their giftedness in this study. First, the gifted-stream students had smaller class sizes than the regular-stream students. Second, the participating students were enrolled in chemistry classes, and such differences could not be observable in classes in other disciplines. Chemistry laboratory environments are thought to differ from those in biology because of the nature and type of laboratory classes typically taught. For example, Hertz-Lazarowitz et al. (1984) found that biology laboratory activities more often engage students in work with their peers, while others have found that these activities are less often integrated into the flow of classroom learning compared with chemistry courses (Schwab 1963; Tamir and Friedler 1994).

In addition, Hofstein et al. (1996) found significant differences between students' perceptions of their actual chemistry and biology laboratory environments, specifically for the dimensions of integration, open-endedness, rule clarity, and organization (Hofstein et al. 1996). In that study, the biology and chemistry laboratory environments differed in the extent to which they engaged students in group work and investigation as well as more open-ended problem-solving and discussion. These differences could be due to differences in the nature and type of laboratory experiences in these disciplines. Biology laboratory classes could more often include open-ended investigation, setting a tone that openendedness is of value and offering more opportunities for students to become familiar with and be successful in open-ended learning environments.

Finally, in studies examining correlations between students' perceptions of their learning environment and their achievement levels, few details are provided about gifted versus regular laboratory learning environments, for example, whether the character of the environment differs with respect to instructional materials, pedagogy, or other aspects of the classroom context. To explore the relationship between giftedness and students' perceptions of their learning environment in other disciplinary contexts beyond chemistry, we examined students' perceptions of their laboratory learning environment in biology courses, including courses designated for high-achieving versus regular-achieving students. Because the students included in the sample were participating in two university—high school outreach programs, they were known to be experiencing some form of laboratory learning with access to a similar core set of materials. In addition, to explore the relationship between students' perceptions and the extent of their experience with laboratory learning in a particular discipline, we examined students' perceptions of their laboratory learning environment in first-year biology courses versus elective biology courses that require first-year biology as a prerequisite.

Learning environments

Student perceptions of their learning environment influence how and to what extent they learn and retain knowledge. This is not unique to laboratory learning, and has been the impetus for classroom environment research for several decades. A three-part psychosocial construction of learning environments based on human interaction was developed by Moos (1987). This theoretical model examines learning environments through relationships, personal development, and systems maintenance/change. Relationship dimensions are those that relate to the nature and intensity of personal relationships. Personal development dimensions refer to the paths of the self-development progress. System maintenance and system change dimensions refer to the orderliness, clarity, control, and responsiveness to change in the environment (Moos 1987). This work was built on Walberg's research on psychosocial learning environments. This research explored the multidimensional nature of a psychological model of productivity. Factors in this model included the learner's age, ability, and motivation, the quantity/quality of instruction, and the psychosocial environment of home, classroom, peer group, and mass media (Quek et al. 2005).

Fraser later refined Moos's work to make it more appropriate, initially to describe classroom learning environments, and then science learning environments. Fraser's work with McRobbie and Giddings identified five aspects: Student cohesiveness describes how well students know each other, work well together, and support one another. Openendedness refers to students' opportunities to design their own research and pursue individual interests to enhance their personal constructions of scientific knowledge. The integration dimension characterizes how laboratory activities are connected to theoretical material taught in the lecture portion of the science classroom. Rule clarity is defined by how clearly structure and expectations are communicated and implemented in the laboratory. Material environment describes students' perceptions of the adequacy of their laboratory materials and equipment. The Science Laboratory Environment Inventory was developed as a measure of these aspects of science learning environments (Fraser et al. 1993).

Science Laboratory Environment Inventory validation

A comprehensive validation study was conducted in tandem with this study to examine each aspect of Messick's unified definition of validity (Messick 1989, 1995) through the application of confirmatory factor analysis and multidimensional Rasch analysis (Luketic et al. 2007). The dimensionality analysis revealed that a five-dimensional structure provided the best information and characterization. Removal of the 13 negatively worded items dramatically improved the reliability and validity of the measures of the model. Data were

scaled to a multidimensional random coefficients multinomial logit model. Item quality evaluation based on composite reliability (Raykov and Tomer 1991) resulted in fairly good point measure correlations (from 0.35 to 0.56). None of the items exhibited misfit. Item difficulties were consistent with the mean calibration by dimension. In addition, the reliability of the separation indices for the multidimensional model reflected internal consistency for each factor. Reliabilities ranged from 0.42 to 0.70. Group comparisons revealed no statistically significant differences in perceptions between genders or ethnic groupings. The authors of the SLEI conducted investigations of the psychometric properties of the instrument when it was initially developed (Fraser et al. 1993). Evidence of the external validity of these measures was collected through analysis of the responses within and between classrooms. Specifically, analyses revealed that students within each class held similar perceptions of the learning environment while between-classroom perceptions were differentiated. The analyses presented on the validity of the measures of SLEI support its use as an instrument useful in measuring student perceptions of their classroom environment.

The current study

The perceptions of high-school students of their science laboratory learning environment were examined through the research of this study. The research also examined the influence of classroom achievement levels and biology classroom experience. In consideration of this research focus, three related research questions were examined.

The first question examined student perception of the laboratory environment based on academic achievement. Classroom type was used as a proxy to characterize the different achievement levels. To understand this, the following question was asked: Are there differences between the perceptions of 'regular' and 'high-achieving' students? Regular classrooms were identified as those in high schools that were not specialized, pull-out programs, as well as those classrooms that were in the regular course of study as opposed to honours or further advanced courses. High-achieving classrooms were identified as advanced placement, international baccalaureate, honours, special elective, second-year biology, electives, and first-year biology classes from specialized schools.

The second research question examined student perceptions based on their experience with biology learning. This question was explored from two different perspectives: Are there differences in perceptions of the environment amongst students of different grade levels? And, do first-year biology students differ in their perceptions when compared with those beyond the initial biology class? First-year biology classes are those taught in the first year of secondary school, regardless of the type of school or achievement level of the classroom. 'Beyond' includes students enrolled in any class following the first year of biology, regardless of school or class.

Methodology

Sample

Students participating in two university-based precollege outreach/partnership programs were selected purposely to ensure a high rate of response from students who are completing some form of laboratory learning. Schools were chosen to ensure that there were responses from different grade levels, academic achievement levels, and biology classroom experiences. Specifically, schools were chosen from three states (Virginia, Arizona, Missouri) to represent private and public schools as well as the duration of the partnership with the university (1–4 years). Surveys were distributed to 900 students in 17 schools. A total of 355 students from 11 schools provided responses to the questionnaire. Student-to-teacher ratios ranged from 12.4 to 20.5 students per teacher. School size ranged from 300 to

4,000 students, and school settings included rural, urban fringe (small, medium, and large city), and small and large towns. The proportions of students receiving free or reduced-cost lunch at each school ranged from 3 to 40 %, and the racial minority population of the schools ranged from 10 to 40 % (NCES 2007). The sample of 355 students was 35 % male ($n = 123$) and 65 % female ($n = 226$). In addition, 68 % ($n = 236$) of the participants were European American while 32 % ($n = 107$) were from a racial or ethnic minority. The majority of students were enrolled in different types of biology courses.

Procedures

Students' perceptions of their classroom science laboratory environment were collected using a paper version of the Science Laboratory Environment Inventory (SLEI) during the 2006–2007 school year. Students completed the questionnaire during class-time. The SLEI contains 35 items (Fraser et al. 1993), measuring five dimensions comprising seven questions each. Responses were recorded on a five-point frequency scale (1 = almost never, 2 = seldom, 3 = sometimes, 4 = often, 5 = very often). Information about demographic indicators (i.e. grade in school, course of study, gender, and ethnicity) was collected using a one-page attachment to the SLEI.

Based on findings from a complementary study (Luketic et al. 2007), the negative items were removed from the dataset for the analysis (Marsh 1996). These negatively-worded items did not measure the dimensions in the same way as the other items; instead, they acted as an additional factor in the composition of the science classroom environment construct. The remaining 22 items were used to explore the research questions presented here.

Analyses of measure estimates

Differences in predicted response rates based on grade, course type, and science program type were investigated through analysis of the means and standard deviations of the Rasch measures for individuals and groups from the Actual form of the SLEI. Expected response rates across these subgroups were reviewed to determine if there were any meaningful differences. Rasch difficulty estimates were completed to compare responses across subgroups.

The grade variable was divided into the four high-school grade levels: 9th, 10th, 11th, and 12th. We expected to see differences in the estimates for these dimensions, with higher positive estimates for older, more advanced grades. One-way analysis of variance was undertaken for each of these variables for each of the five dimensions identified in the measures of this instrument. This analysis was completed to examine the Rasch measure estimates for significant differences between grade levels.

The data were analyzed for differences in perceptions based on achievement level, biology learning experience by grade level (i.e. 9th, 10th, 11th, and 12th), and experience by years of biology coursework completed (i.e. first year, and beyond). Multivariate analysis using the least-squares procedure was completed using JMP software (JMP 2006). Student perceptions based on grade and achievement level were examined with this modeling. In addition, the interaction of grade level, achievement, and years of biology course experience on the expected response rates was also studied.

Results

Associations between student perceptions and classroom achievement

Students in high-achieving courses had a more favourable perception of all aspects of their learning environment when compared with students in regular courses (Fig. 1). The

differences between regular and high-achieving students were statistically significant, although the effect sizes were small. Significant differences between achievement groups were found for Student Cohesiveness ($F = 26.86, p < 0.0001, \eta^2 = 0.071$), Integration ($F = 25.00, p < 0.0001, \eta^2 = 0.066$), and Rule Clarity ($F = 11.29, p = 0.0009, \eta^2 = 0.031$). The small effect sizes indicate that, while there are significant differences, probably there are several other factors influencing student perceptions.

Associations between student perceptions and biology class experience

Student perceptions of their laboratory could be influenced by the extent of students' experience in learning science (Fig. 2). Grade level was used as a proxy for experience, with 9th-graders having the least experience and 12th-graders having the most. Grade level differences in student perceptions were statistically significant ($p < 0.001$) across all five factors of the laboratory environment. Our analysis showed that ninth-graders tended to be more negative than students in other grades. The 10th-graders reported the most positive perception of all the students. Eleventh-graders were more positive than 12th-graders. Effect sizes ranged from 0.039 to 0.074.

The negative perceptions of ninth-graders could be attributable to their lack of experience in learning and applying science knowledge. To explore this further, first-year biology students were compared with those beyond their initial biology class experience (Fig. 3). Biology classroom experience influenced student perceptions between first-year students and those beyond the first year. Negative perceptions of the classroom environment were reported for first-year students. In contrast, students beyond the first year were found to have positive laboratory environment perceptions. The notable exception to this trend was in the Open-endedness dimension, for which first-year students were more positive. However, this difference between the first-year and all other students for the Open-endedness dimension was not statistically significant ($\mu = 0.04$ and $-0.02, SD = 0.40$). The most meaningful differences between the students in first year and all other classes were instead found for the dimensions Student Cohesiveness [$F(1, 351) = 5.78, p = 0.0008, \eta^2 = 0.02$], Integration [$F(1, 351) = 8.34, p = 0.0041, \eta^2 = 0.004$], and Material Environment [$F(1, 351) = 7.58, p = 0.0062, \eta^2 = 0.021$].

Differences in student perceptions based on grade and biology experience

Building upon the initial research questions, two additional research questions were investigated to assess grade level, achievement level, and biology experience as mitigating influences. The first question addressed whether students at the same grade level perceived their environment the same regardless of achievement or experience level. The second question considered whether students at the same achievement or experience level had similar perceptions of the laboratory regardless of grade level in school.

To determine whether differences observed by grade level could be attributable to biology learning experience versus experience in school, additional analysis was undertaken. The analysis revealed that differences in perception were consistent across academic achievement groups as well as experience level by first year and beyond (course level) rather than by grade level (Table 1). Perceptions were consistent amongst regular and high-achieving students regardless of grade level. In addition, student perceptions were consistent regardless of grade level (Table 2).

Discussion

The research presented here utilized the Actual form of the SLEI with a small sample of students to explore differences in their perceptions. This was a useful tool for furthering

understanding of these students and their learning environments. Higher-achieving students were found to be more positive in their viewpoint than students in the regular track. This highlights several interesting points. The first concerns the potential that regular-track students perceive their environment differently because of factors that could include science experience, academic achievement, and ability to make connections between theory and practice. The second interesting perspective highlighted here concerns the actual learning environments of regular versus high-achieving students. The possibility that there are common traits among 'regular' laboratories that make them different from 'high-achieving' laboratories is fascinating. Understanding these differences would enable a focused effort in the improvement of learning environments for many science students.

Biology experience in the classroom impacts student perceptions. Students in their first year of biology tended to be negative in their perceptions of the learning environment. This could be the result of several factors including cognitive maturity, as well as their overall high-school experience. Ninth-graders in our study had the most negative perceptions of their learning environment. Younger students could require more structure and more guided interaction with their peers. The classroom environment for older students could be changed through expanded use of independent work and group projects that advance the application of theory taught in the classroom.

These findings have several implications for teaching and practice. Understanding how regular and high-achieving students perceive their environment differently can enable teachers to focus their attention on critical areas. A very open-ended environment could be ideal for students in an honours laboratory, but could not be as ideal in the regular laboratory where students could still be struggling to connect theory with laboratory exercises. Students learn through applying what they are taught to their own experience and knowledge and then formulating new concepts (Bransford et al. 2001). Structuring laboratories differently based on the differing needs of students could enable learning to occur more successfully by allowing students to build on their knowledge from their own comfort level. In addition, further understanding of the influence of biology experience on perceptions of laboratories could help educators. Tenth-graders in our study were found to be the most positive about their laboratory environment. If this finding holds true across a larger sample, then the opportunity to capture and hold students could come as they transition from 10th to 11th grade. Directly addressing students' negative perceptions and assessing ways of positively changing the laboratory environment for older students could be a good way to keep older students interested and engaged.

Achievement levels and biology experience should be investigated at further depth to understand the broader impact of these factors on student perceptions and ultimately learning. It would be very useful to understand more about what makes certain groups of students more positive about their learning environment than others. Interviewing students who complete the SLEI and asking them why they perceive, for example, open-endedness in the way they do could advance the way laboratory environments are structured and the way students learn. Furthermore, observations of classes that report varied perceptions of their learning environments could enhance in-depth understanding of intrinsic differences.

Future research should include expanded administration of the SLEI to encompass a larger sample and also examination of the differences between actual and preferred environment scores available through the multiple forms of the instrument. Expanding the research findings with the SLEI through qualitative research could provide further evidence for curriculum formulation as well as for informing teacher understanding of the specific needs of the students in their classrooms. Teachers can use the student perceptions of their learning

environment to emphasize critical pedagogical approaches and modify other areas that could enable enhancement of the science laboratory learning environment.

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Fig. 1.
Differences between regular and high-achieving classrooms

Fig. 2.
Differences in perceptions by grade level

Fig. 3.
Differences in perceptions of the laboratory environment between first year classroom students and other students

Table 1
Differences in perceptions by dimension, grade level, and achievement and experience

Dimension and grade level	Achievement		Experience		Overall
	Regular	High	First year	Beyond	
Student cohesiveness					
10th grade	-0.35	0.42	0.03	0.43	0.17
11th grade	-0.12	0.19	-0.02	0.25	0.01
Total	-0.48	0.11	-0.18	0.09	
Open-endedness					
10th grade	0.00	0.33	0.19	0.07	0.12
11th grade	-0.14	0.02	0.08	0.05	0.12
Total	-0.05	0.01	0.04	0.02	
Integration					
10th grade	-0.34	0.50	0.07	0.59	0.22
11th grade	-0.17	0.11	0.20	0.20	0.02
Total	-0.51	0.10	-0.22	0.09	
Rule Clarity					
10th grade	-0.17	0.56	0.20	0.58	0.35
11th grade	-0.12	0.01	0.33	0.11	0.06
Total	-0.35	0.06	-0.14	0.04	
Material Environment					
10th grade	0.13	0.57	0.37	0.35	0.07
11th grade	-1.04	0.06	0.04	0.05	0.18
Total	-0.04	0.00	0.14	0.09	

Table 2

Statistical significance and effect size by academic grouping within grade

Dimension	Statistical significance			Effect size (where relevant)			
	Regular	High achieving	First year	Other	Regular	High achieving	First year
Student Cohesiveness	0.77	4.24 *	6.34 *	2.85	0.00	0.03	0.10
Open-endedness	0.41	16.37 **	7.75 **	2.53	0.00	0.11	0.12
Integration	0.98	4.15 *	6.63 *	2.11	0.00	0.03	0.10
Rule Clarity	1.16	5.72 **	7.04 **	1.55	0.00	0.04	0.11
Material Environment	1.99	17.14 **	6.21 *	4.04 *	0.00	0.11	0.10

* $p < 0.05$ ** $p < 0.001$