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Student Perceptions of Learning Data-Creation and Data-Analysis Skills in an Introductory College-Level Chemistry Course

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Abstract

This study examines how students perceive their learning of creating and analyzing data in an introductory inquiry chemistry course at a college level that features oral presentations in student-centered discussions. A student Participant Perception Indicator (PPI) survey was administered in order to obtain data on student perceptions with respect to their own data-creation and data-analysis skills, which skills are essential for learning and understanding science. These student perceptions regarding gaining knowledge were consistently higher than their perceptions regarding gaining confidence and experience; however, both the confidence and the experience measures increased significantly as a semester progressed. Further, significant differences in student perceptions were found to exist between students who made oral presentations and students who did not. This finding strongly supports the active learning theory, i.e., learning by doing, and strongly encourages student participation in knowledge creation. Findings were also analyzed according to student demographics (gender, school) to determine patterns for different populations within the groups of students. Such analysis is important for instructors and for course designers to enable them to adjust their manner of teaching based on student demographic information in their classes, and to adjust the provided feedback and guidance, as needed.

Keywords:

Undergraduate education/introductory level education, Data-Creation Skills, Data-Analysis Skills, Chemical Education Research, Student-Centered Learning

Introduction

Current reform efforts in college level undergraduate education in the USA are to develop pedagogical methods for facilitating student-centered classroom instruction. Student-centered instruction, a form of active learning, shifts the focus from the teacher to the student. One way to foster active learning in student-centered classrooms is to incorporate data-analysis tasks, such as lab finding presentations, in a guided discussion session. The Boyer Report (1998) *Reinventing Undergraduate Education: A Blueprint for America's Research Universities* recommends processes for teaching, rather than for content, that can be applied appropriately across disciplines. The report encourages the creative use of technology for educational processes, and links communication skills with course work. The report argues that undergraduate education should build on the freshman foundations, and suggests that the freshman year should offer numerous opportunities for both research-based and inquiry-based learning, Specifically, it argues that traditional classroom methods be replaced by inquiry methods. It strongly recommends that teacher-centered classrooms should become student centered, and that team-centered learning should replace individual competitive learning.

Other studies clearly address the need for changes in undergraduate education, and support a shift from instructor-centered learning to student-centered learning, particularly in introductory level classes (Francisco, Nicoll, & Trautmann, 1998; Slunt & Giancarlo, 2004). In the traditional classes, the teacher, rather than the student, becomes highly skilled by speaking, consulting, organizing, and solving problems. In contrast, student-centered teaching focuses on skills and cognitive development of students (Xu, 2003). In this teaching process, students no longer passively receive information, but actively participate in teaching, learning and thinking. Many reports argue that student-centered learning is a superior form of active learning (Felder & Brent, 1996; Lloyd & Spencer, 1994; Michael & Modell, 2003; Oliver-Hoyo, Allen, Hunt, Hutson, &

Pitts, 2004; Siebert & McIntosh, 2001; Yuretich, 2003). These studies indicate that critical

thinking involving student-centered activities are more effective when the activities require

student involvement in higher-order thinking tasks, such as analysis of data and application

results to new situations.

One way to implement active learning in student-centered classrooms is to incorporate

instructional technology, such as oral presentations of lab findings, in guided discussion sessions.

Oral presentations, in a science laboratory course, involves data-analysis, which reinforces the

development of high cognitive skills and problem solving, to enhance critical thinking (Kerner,

Black, Monson, & Meeuwenberg, 2002; Kovac, 1999; Mckeachie, 2002; Zoller, 1999).

Moreover, a presentation of data-analysis exposes students to thinking and to qualitative

reasoning processes, by which scientists organize data, develop principles, make predictions, and

design experiments.

This study describes a novel approach for teaching skills that are essential to the process of

learning and understanding chemistry and evaluates the effectiveness of that innovative practice.

More specifically the study examines how students perceive their learning of creating and

analyzing visual data in an introductory inquiry chemistry course at a college level. The

perceptions of student experiences are essential to the development of educational processes, in

addition to the assessment of academic achievements. By obtaining inputs from participants,

which might be missed or considered irrelevant by an external observer, the development and the

implementation of learning environments can be improved (Fraser, 1994, 1998). Thus, this study

investigates the perceptions of students regarding their ability to create and analyze data. The

participating students were enrolled in a large (745 students, 33 sections) introductory, guided-

inquiry chemistry course in a major research university. Results from this study are not limited to

chemistry students, but are broadly applicable to any area of science and engineering.

Research Question

The research question presented in this study is: Do students perceive that they are learning,

becoming more confident, and gaining experience regarding how to effectively create and

analyze data in an introductory inquiry chemistry course at the college level?

Literature Review: Why Data-Creation and Data-Analysis are Important in Chemistry Learning

The National Science Education Standards (National Research Council, 1996), the

Framework for K-12 Science Education (National Research Council, 2012), the Boyer Report

(1998), and other contemporary science education literature, emphasize inquiry as essential for

student learning, and support the use of inquiry for instruction (Bruck & Towns, 2009; Bybee,

Minstrell, & Van Zee, 2000; Hofstein & Lunetta, 2004; Krajcik et al., 1998; Lunetta, 1998;

Olson & Loucks-Horsley, 2000). The inquiry lab environment develops qualitative reasoning

skills for students, which scientists use to solve problems such as formulating hypotheses,

organizing data, making inferences, and designing experiments. The goal is to determine whether

students perceived learning from such an environment.

The interpretation of data, and the ability to construct graphs and tables, are essential for the

scientific process (Bowen & Roth, 2005). Graphs and tables are invaluable tools for representing

data and for finding relationships between variables, particularly for determining patterns,

properties and reactivity of matter. Such abilities are skills required by scientists for conducting

investigations, for analyzing data, for drawing conclusions, and for writing research studies

(Bowen & Roth, 2005).

The National Science Education Standards (National Research Council, 1996) and the

Framework for K-12 Science Education (National Research Council, 2012) emphasize data-

analysis skills. They state that students need to learn how to analyze evidence and data, and that

the evidence they analyze may be from their investigations, from other student investigations, or

from databases. The Standards also suggest data-related activities in which students ought to be

skilled, such skills include the ability to collect, organize, and describe data, to create tables and

graphs, and to analyze and interpret data to identify patterns, properties, and relationships.

Data-creation and data-analysis skills are not limited to the chemistry classroom, but are

becoming increasingly important also outside the classroom. One of the central skills required in

the 21st century is the ability to work with data, for instance, to make inferences from given data,

to find trends, to criticize data, and to use the data. In the current information era, students need

the ability to understand day-to-day medical results (e.g., growth-tracking charts and cholesterol

levels), as well as commercial advertisements and news media (e.g., political elections, sports,

and financial matters).

Educators call for practical programs that encourage the development of graphing and data-

analysis competence (Glazer, 2011; Roth & McGinn, 1997; Tobin, 1990). The programs should

provide opportunities to reflect on findings in the lab for clarifying understandings and

misunderstandings with peers (Tobin, 1990). Although inquiry and associated skills, such as data

analysis and data inference, are essential components in science learning, little is known about

the perceptions by students of their own cognitive capability and their confidence to implement

such skills. This paper enriches the literature with a study of student perceptions while learning

in a particular course designed to foster cognitive skills important for inquiry, such as data-

creation and data-analysis. This study is particularly valuable to high school and undergraduate

science instructors and curricula developers interested in implementing a student-centered

learning approach into their instruction in order to enhance data-creation and data-analysis skills.

Method

The Learning Environment

The current paper studies an introductory chemistry lab course in a major US research

university that implements student-centered learning. The course includes a team-based

collaborative inquiry lab, with technology-assisted data sharing, and technology-assisted data-

analysis. It includes a student-centered post lab discussion of oral presentations by students to

findings regarding specified questions that require analysis and/or application of lab data. The

course is non-traditional, in that there is a student-centered discussion following the completion

of collaborative inquiry lab investigations before moving on to a new lab topic. Usually, an

introduction to general college chemistry requires students to apply lecture material in weekly

labs. In the course featured in this study, the students were asked, before moving on to the next

topic, to organize and analyze the varying team data, and to orally present the findings in a one-

hour student-centered discussion. For example, when the students studied redox reactions, they

were asked to present their observation and conclusions regarding the reactivity of halogens

(oxidizing agents) and halides (reducing agents) and to explain if there is a correlation between

the reactivity of halogens and halides. In another question, also regarding redox, students were

asked to present their interpretations of the reaction between $Cu(NO_3)_2$ and NaI, to explain how

they identified the reacting species and any products formed, to explain the purpose of adding

Hexane, and to explain whether the Hexane is a reactant or not.

Course structure.

The course consists of a lecture given by a faculty member, and of a set of lab experiments

and discussion sessions, each including a plurality of sections of 20-24 students taught by

Teaching Assistants (TAs). The lab groups are broken down into teams of four students, where team members rotate roles in each experiment (team manager, recorder, technologist, and chemist/safety officer). The manager of the team is responsible for doing the presentations; thus, the role of the presenter is assumed by a different member for each experiment. Other team members are encouraged to help the presenter to prepare for the discussion. Since roles rotate after the completion of each topic, each student is assigned to be the presenter at least one time throughout the semester. Students taking this class are not chemistry majors and are usually enrolled in it because of distribution requirements. The students are primarily from the Engineering School or from the college of Literature, Science, and the Arts (LS&A). The LS&A is a liberal arts and sciences college within a large university. Students' majors can be in many different programs in three main areas of studies: social sciences, natural sciences, and humanities. Some common majors are Psychology, Economics, Political Science, Biology, English, Communications Studies, Mathematics, and History.

Students in the course made observation in laboratory experiments and recorded the observations as a team in a central database. Students then got problems that require organization and analysis of the collated class data and in the following week they presented their answers in a student centered discussion. The main topics that were taught in the course include precipitation reactions, solution color and spectroscopy, redox reaction, acid-bases, and Lewis acids- bases.

The Instrument

A student Participant Perception Indicator (PPI) survey was administered in order to obtain data on student perceptions of their own abilities. The PPI survey, which was introduced by Albert Bandura (Bandura, 1977) as a key component in social cognitive theory, consisted of a short web survey that measured perceptions of knowledge, experience and confidence in three to

five themes (factors) determined important for learning. The overall objective was to check

whether students perceived that they were learning, that they were becoming more confident, and

that they were gaining experience as a result of participating in the course, particularly when

asked to visualize results and to orally communicate findings in the student-centered discussions.

An IRB approval was obtained prior to the beginning of the data collection.

The PPI survey was developed to determine whether students perceived learning as a result

of attending the course described above. The survey queried responses by students to specified

perception statements as to whether they had acquired various discussion-related skills, such as

data-creation, data-analysis, and speaking in front of peers. In addition to the perception

statements, the survey included demographic questions, such as gender, school, section, and year

in the program. This information is important to examine, in case various groups of students

responded to course objectives in different ways.

The PPI survey for this study included 20 statements that related to several factors which

constituted broad objectives of the course, each addressed by a set of multiple (four or five)

statements to increase reliability. A factor analysis was then run in order to group the statements

into factors. The content of each statement was validated by a chemistry faculty member who

taught the course, and by a science educator who was experienced in creating and analyzing

surveys. For each perception statement, the students were asked to indicate how they perceived

their knowledge, experience and confidence levels according to a five-point Likert scale, similar

to the example in Figure 1 below.

Statement	Knowledge	Experience	Confidence
	Low ....high	low ....high	low ....high
1) Organize data into a table or graph	1 2 3 4 **5**	1 2 **3** 4 5	**1** 2 3 4 5
2)…..	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Figure 1. Sample PPI question

In the example above, response 5 in the knowledge category indicated the participant perceived that he/she had a great deal of knowledge about organizing data into a table or graph; response 3 in the experience category indicated the participant perceived that he/she had an average amount of experience about organizing data into a table or graph; and response 1 in the confidence category indicated the participant had no confidence about organizing data into a table or graph.

The Research Sample The PPI survey was administered via the web in three rounds during the semester (beginning, middle, and end) to approximately 700 students (33 sections) in the introductory chemistry course.. Overall, 1,194 responses (N) were received. In order to increase reliability, only sections (21 sections) with a high level of responses (i.e. sections where more than half of the students responded consistently all three times) were included in the study. The number of responses in these sections totaled 951 (N=951). Each round involved an average response rate of 60-75%; i.e., there were 291-360 responses out of 475 students. The first round (called Time 1) included 300 responses and was administered after the students had completed the first discussion; the second round (called Time 2) included 291 responses and was administered mid-semester; and the last round (called Timed 3) included 360 responses and was administered at the end of the semester.

The responses were primarily from Engineering School students (N=416), constituting 43.74% of the responses, and from Literature, Science, and Arts (LS&A) School students (N=493), constituting 51.84% of the responses. Most of the students were freshmen (N=810), constituting 85.17% of the responses, with 58% of the students being male (N=552) and 42% being female (N=399). Both presenters (N=329, 34.6% of the responses) and non-presenters

(N=622, 65.4% of the responses) responded to the survey. Students' demographic and survey

information are summarized in Table 1.

Table 1: Students' demographic and survey information

Demographic/survey info		N	Percentage (%)
School	LS&A	493	51.84%
	Engineering	416	43.74%
	Other	42	4.42%
Year in the program	Freshman	810	85.17%
	Sophomore	98	10.30%
	Junior	23	2.42%
	Senior	20	2.10%
Gender	Male	552	58.04%
	Female	399	41.96%
Student Role?	Presenters	329	34.60%
	Non-presenters	622	65.40%
When survey taken?	Time 1- Beginning	300	31.55%
	Time 2 - middle	291	30.60%
	Time 3 - end	360	37.85%
Total responses		951	100.00%

Results

The current research focuses on only one of the factors in the survey, namely whether

students perceived that they have acquired the skills associated with data-creation and data-

analysis. This factor is a combination of the following five individual perception statements:

1. State the main conclusion to the assigned question

2. Organize data into a table or graph

3. Use alternate methods to organize and visualize class data via tables or graphs

4. Create graphs/tables to visualize the data

5. Interpret relationships represented in the graphs/tables

A factor analysis was conducted to verify that the above five items could be reduced to one

factor and could be correlated. For each knowledge, experience, and confidence levels, all five

survey items (statements) were found to be correlated with no significant difference (all p-values

were less than .001). A reliability analysis confirmed that they fit well together (Cronbach's

Alpha for knowledge, experience, and confidence, being .851, .827, and .821, respectively).

Thus, all five items can be averaged for the analysis.

A data-analysis was then conducted to identify patterns over time, and patterns related to the

different knowledge, experience, and confidence levels. In the data-analysis, the data was also

analyzed to determine patterns for different populations within the group of students. Following

are the results of this data-analysis.

Analysis of Perception over Time

Figure 2 shows the mean of student perceptions in each round of the administered survey for

each of the knowledge, experience and confidence levels. Analysis of the ratings in Figure 2

shows the differences between the student perceptions regarding their knowledge, experience
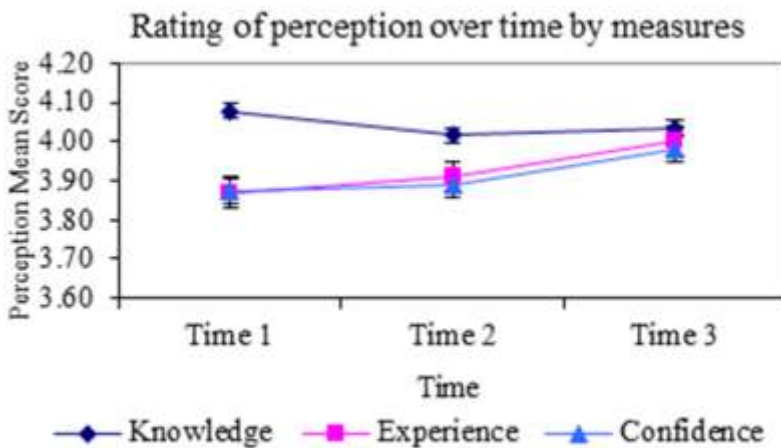
and confidence levels.

Figure 2. Rating of perception over time by measures

As shown in Figure 2, student perceptions of "knowledge" were at a higher level than their

perceptions of "confidence" and "experience" in all the rounds. Using an ANOVA test with a 5%

significance level (α) shows that as the semester progressed, there was no significant change

from Time 1 to Time 3 in student perceptions regarding their "knowledge" level (p-value=0.389),

but there was a significant increase regarding their "experience" level (p-value=0.014), and

almost significant increase regarding their "confidence" level (p-value=0.052).

Analysis of Perception Mean by Measures

Figure 3 shows the perception mean for each measure (knowledge, experience, and

confidence). The vertical lines in the graph are confidence intervals that represent the range of

responses within one standard deviation. Confidence interval length is related to the diversity of

responses, with longer confidence intervals indicating greater variation in responses. If

confidence intervals overlap, there is no significant difference between the groups/variables. If

confidence intervals do not overlap, there is a significant difference between the
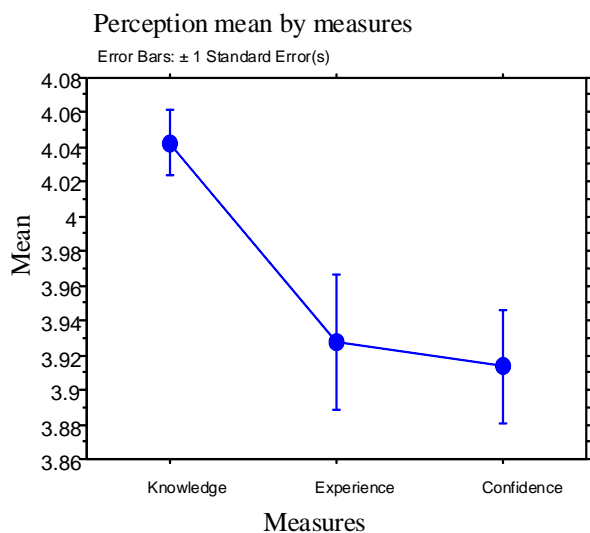
groups/variables.

Figure 3. Perception mean by measures

As can be seen in Figure 3, students had higher perceptions of having gained knowledge of

data-creation and data-analysis competence in comparison to gained confidence or gained

experience in those skills. Also, confidence intervals (vertical lines) of "experience" and

"confidence" overlap, but neither overlaps with the "knowledge" confidence intervals. Thus, the

responses by students of having gained knowledge are significantly different from their

responses of having gained confidence or experience. Furthermore, the "experience" and

"confidence" responses had greater variations (longer confidence intervals) in comparison to

"knowledge" responses.

Analysis by the Role of the Students

Figure 4 shows the perception mean for each measure in terms of the role of the students at

the particular time the survey was taken, irrespective of whether the students presented the data

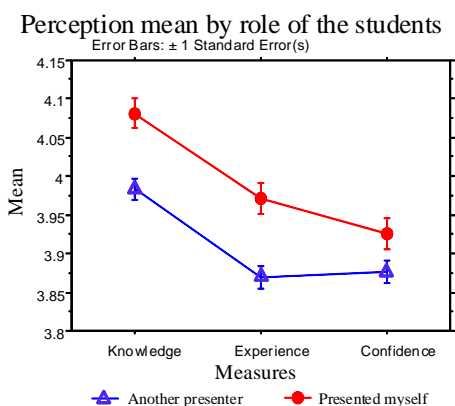by themselves, or whether another team member presented the data.

Figure 2. Perception mean by role of the students

As can be seen in Figure 4, there was a significant difference between students who orally

presented data, and those who did not. Thus, confidence intervals do not overlap between the two

groups of students; also, p-values for knowledge and experience are less than 0.001, and for

confidence are less than 0.05. The rates of perceptions by presenters were significantly higher

than those by non-presenters at the time the survey was taken. This strongly supports the active

learning theory, i.e., learning by doing. Students who were actively involved in a particular

assignment perceived themselves as having learned more and as having gained more experience

and confidence, in comparison to their teammates who were not in charge of doing the

presentation.

Analysis by Gender

Figure 5 shows an analysis of the perceptions by students of data-creation and data-analysis

competence according to their gender.

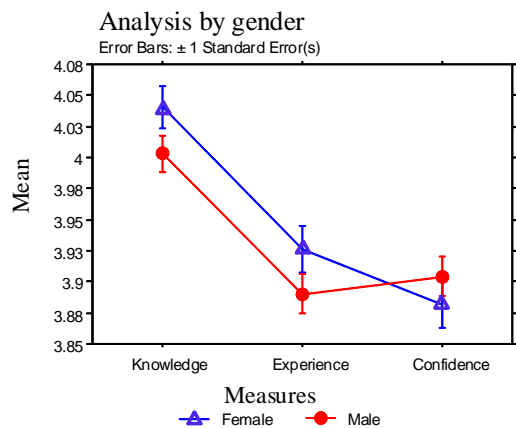Figure 3. Analysis by gender

As can be seen in Figure 5, there was no significant difference between males and females

regarding their perception of "experience" and "confidence". Thus, confidence intervals

overlap; also, p-values (0.123 and 0.086, respectively) were both more than 0.05. There was,

however, a difference regarding their perception of "knowledge" in that females perceived their

knowledge greater than the males, although not significantly greater (p-value=0.036).

Accordingly, it can be seen that the "knowledge" and "experience" perceptions in females are

higher than in males, but the "confidence" perception is lower.

Analysis by the School Affiliation

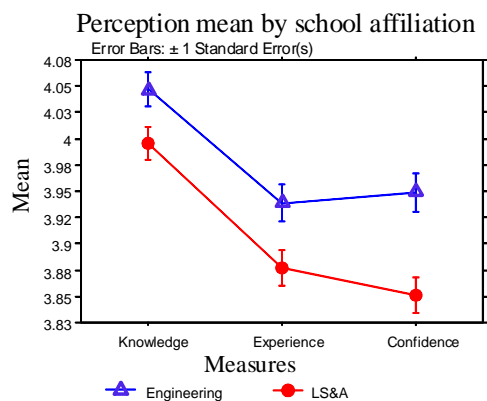Figure 6 shows the perception mean of students according to their school affiliation.

Figure 6. Perception mean by school affiliation

Figure 6 reveals a significant difference between LS&A students and engineering students regarding their perception of data-creation and data-analysis competence. Thus, confidence intervals did not overlap; also, p-values were less than 0.05. Accordingly, it can be seen that for all measures (knowledge, confidence, and experience), the perception by engineering students was higher than by LS&A students, the greatest difference being in their confidence level (p-value =0.0004).

Discussion

The overall objective was to check whether students perceived they were learning, becoming more confident, and gaining experience, regarding how to effectively create and analyze visualizations of data as a result of participating in an introductory college-level chemistry lab course, where they were asked to visualize results and orally communicate their findings in student-centered discussions. The results (Figure 2 and Figure 3) show that the responses by students regarding the gaining of knowledge were significantly different from those regarding the gaining of confidence or experience. As the semester progressed, there was no significant change in the perceptions by students of their "knowledge" regarding data-creation and data-

analysis; however, the students perceived gaining more confidence and experience in those skills.

Overall, the students indicated that they had a great deal of knowledge in their ability to effectively create and analyze data. At the beginning of the semester, they felt assured in their knowledge, but they did not feel confident and experienced in their data-creation and data-analysis. Data showed that students grew in confidence and experience regarding their perception of data-creation and data-analysis skills.

Confidence and experience are important for learning. Improving confidence increases the chances of success. When students are more confident, they are likely to take a task more seriously, challenge themselves more, and succeed more (Linnenbrink & Pintrich, 2003). Experience also has an important impact on learning since learning new skills takes time. However, practice is not enough to ensure that a skill will be acquired, since practice under appropriate instruction, and appropriate feedback, are also important (National Research Council, 2001).

Figure 4 shows that students who were active in a presentation, perceived learning more than their teammates who were less active. This finding supports the correlation between self-efficacy, engagement, and learning that had been presented in the model of Linnenbrink and Pintrich (2003). According to the National Science Education Standards, science is an active process in that "learning science is something that students do, not something that is done to them" (National Research Council, 1996, p. 20). This finding also provides an important feedback for the course designer, and suggests that more students need be actively engaged in future assignments.

Strengths and Limitations of Using Self-report Data and the Limitations of this Study

Higher education scholars and institutional researchers rely heavily on self-reported survey data in their work. Surveys have a number of advantages over other data collection methods. For example, they can be implemented with relative ease, quickly and at little cost. In addition, they can relatively easily survey large populations, particularly with the assistance of the current technology. Because developing objective tests of student learning and skills can be extremely time consuming and costly, the use of self-reported surveys is widespread.

Researchers generally agree that the use of self-reported estimates of learning is valid within limits (Anaya, 1999a; Gonyea, 2005). At the most basic level, there is a concern regarding the validity of self-report measures (Razavi, 2001). The literature indicates that student self-reports have only moderately positive correlations with objective measures when used in estimating the learning or skill of *individuals*. When aggregated to compare the performance of *groups*, the reliability of self-reported measures is quite high and is generally considered to be a valid measure of a real difference in learning between *groups* (Anaya, 1999b; Pascarella, 2001; Pike, 1995, 1996; Volkwein, 2005).

This study focuses on the perceptions by different groups of students, based on their demographic characteristics or their role in the task. Future studies should also consider comparing perceptions of students in different achievement levels in order to check a correlation between their perceptions of learning and of their achievement.

Implications

High-school and/or undergraduate science instructors, who are interested in implementing a student-centered learning approach in their instruction on data-creation and data-analysis skills, can benefit from the study. Before adopting any learning approach, it is useful to know if such approach is perceived as being valuable from the point of view of the students. The reactions of

students, and the perceptions of their experiences, are important parameters of the learning

environments; they can complement the assessment of academic achievement to give a complete

picture of the educational process (Fraser, 1994, 1998). Self-efficacy may also impact the

motivation of students and their desire to learn (Zusho, Pintrich, & Coppola, 2003), and may also

serve as an achievement barrier even among capable students (Linnenbrink & Pintrich, 2003;

Steele, 1997; Steele & Aronson, 1995).

The data was analyzed according to student demographics (gender, school) to determine

patterns for different populations within the groups of students. This analysis is important for

course designers to enable them to adjust their manner of teaching based on student demographic

information in their classes, and to adjust the provided feedback and guidance, as needed. To

maintain student efficacy, instructors can provide appropriate feedback in order to help them

develop self-confidence. The feedback should be specific to the task and relevant to the learning

skill to be acquired. The literature shows that perceptions by participants of one or more

measures (knowledge, confidence, experience) may decrease in the middle of the semester

(Berger et al., 1999). Finding such changes in the perceptions reinforces the need to provide

more feedback and guidance also during the middle of the semester.

In this study, there was no significant difference between male and female perceptions

(Figure 5) regarding how effectively they created and analyzed data. Using these results as a

guide for adjusting the manner of teaching suggests that gender is not a major overall concern in

tasks that require data-creation and data-analysis competence. The analysis of student

perceptions according to their school affiliation (Figure 6) shows a significant difference

between engineering students and LS&A students. Engineering student perceptions of their

knowledge, confidence, and experience measures are significantly higher than the perceptions of

LS&A students, the greatest difference being in their confidence. It is possible that engineering students had more opportunity to deal with data-analysis and data-presentation in their engineering courses. Perhaps LS&A students need more instruction on data-creation and data-analysis related tasks.

Findings from this study support the notion that active learning affects self-efficacy. There was a significant difference between students who orally presented data and those who did not, which strongly supports the active learning theory, i.e., learning by doing. This aspect of the course corresponds to a broader reform effort for introductory college level courses, which effort encourages student participation in the creation of knowledge.

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