Assessing Differences in Students' Experiences in Traditional versus Scientific Teaching-Based Biology Course

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Introduction
The Illinois Mathematics and Science Academy (IMSA), located in Aurora Illinois, is a public, three-year residential high school for students who are academically talented in mathematics and/or science. Students apply in their freshman year and are chosen based on test scores and grades as well as other accomplishments, such as extracurricular projects or performances. About 10-15% of the sophomore class enters IMSA from the eighth grade.

The sophomore program consists of three content-based, one-semester core courses in biology, chemistry, and physics, and one methods-in-science course. Sophomores take two science classes per semester. About 80% of the sophomores have had a previous biology course. We offer a placement test and approximately 9% place into a biology elective and the other 91% are enrolled in the Scientific Inquiries - Biology (SIB) course (Scheppler, Dosch, Styer, & Rogg, 2005).

The mission statement of IMSA is to "ignite and nurture creative, ethical, scientific minds that advance the human condition." This corresponds with the recent reform movements in science education that emphasize the development of scientific habits of mind through student engagement in the process of science (NRC, 1996).

One program that focuses on developing scientific habits of mind is Scientific Teaching (ST), developed by the Wisconsin Program for Scientific Teaching (Handelsman, Miller, & Pfund, 2007). Students learning science through ST parallel the practice of science. They are active in questioning, investigating, analyzing, and discovering.

When teaching focuses on scientific practices rather than facts, student learning and knowledge retention increases. ST also models the collaborative process of science by including a diversity of student perspectives and experiences that aid in solving problems. Engaging all students in the classroom produces better-educated graduates with more highly developed cognitive skills.

Regular feedback is another tenet of ST. Built into the lesson, teachers continually assess whether learning goals are achieved and if changes are needed to improve instruction. This feedback also allows students to gauge their own progress on a regular basis.

To replicate the practice of science in a classroom, an ST course is designed to give students an active part in their learning. Active leaning can take many forms, but ultimately requires students to be engaged through inquiry-based learning, cooperative learning, and student-centered learning. Whether taking a few minutes or an entire class period, learners develop new knowledge and understanding based on something they worked on.

This constructivist approach requires that students gain understanding by building their own knowledge (Treagust, Duit, & Fraser, 1996) and not merely acting as passive recipients. For example, instead of a class period focused on lecture only, students can be provided with some information and then asked to come up with questions, investigate by means of a lab or activity, or analyze data.

In a biology class, then, students might include puzzle through case studies and pedigrees, hypothesize about bacterial growth on different media, put complex cell processes in sequence, examine data to determine a causal relationship in gene regulation, or draw a concept map about diseases and their underlying causes.

Active learning can be done individually, in activities where students work alone and then put

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their ideas together, or in groups, all of which take advantage of the benefits of the diversity of experience and perspective of their classmates. Immediate feedback from each other and the teacher then help both the teacher and the students determine their progress and understanding.

One of our goals for the SIB course was to incorporate ST - active learning, diversity, and assessment - as much as possible. Students often say that the SIB course is different from any other class they were enrolled in before coming to IMSA. In addition, in the first semester, they are adjusting to the challenges of living away from home, having more homework, and being encouraged to learn more and think differently in class than they are used to.

We therefore wanted to take a closer look at what specific differences exist between students' experiences in previous science classes at their home schools and SIB at IMSA in order to identify factors that make SIB unique and to identify areas for change so that we can help make transitions easier.

Materials and Methods

To make our survey we chose 34 questions that were applicable to ST from the Constructivist Learning Environment Survey (CLES) (Fraser, 1998) and the Individualized Classroom Environment Questionnaire (ICEQ) (Fraser, 1990). The questions specifically examine active learning, diversity, assessment, and classroom environment and use Likert scale response categories from 1 to 5 (1 = never; 2 = almost never; 3 = sometimes; 4 = often; 5 = always). We categorized the 34 questions into four subsets: Active Learning, Assessment, Diversity, and Classroom Environment; some questions fell into two of these categories and those results are reported in both subsets. See Table 1 for the survey questions.

IMSA's Human and Animal Subjects Review Committee approved the survey process before it was administered to students. At the beginning of the fall semester, 126 sophomores enrolled in SIB completed the survey with respect to their last year's science course. At the end of the semester, 115 students responded with reference to SIB, with numbers differing due to attrition.

For analysis, we combined response categories 1-2 and 3-5, corresponding generally to rare vs. frequent occurrences, because we were looking for broad differences in the students' classroom experiences in their previous schools as compared to SIB.

Results and Discussion

A one-tailed Mann-Whitney U test was performed on the survey data. As shown in Table 1, responses for 31 questions about students' previous science courses were significantly different from their responses regarding SIB ($p < 0.05$), demonstrating that SIB has significantly more active learning, assessment, diversity, and student-centered classroom environment than what they had experienced before.

The differences in responses to questions on Active Learning in Table 1a show that the ST approach in our course is significantly different from students' previous experiences for all but one of the items. Students are asked to work closely with their peers and to use each other as resources for questions and explanations. Since ST puts some students out of their comfort zones, it may explain why some are reluctant to try constructing their own understanding or working with other students.

When comparing the results between "Students find out answers to questions from the text book rather than from investigations" and "Students discuss their work in class," we see that many students are experienced in discussing their work in class, but that fewer have used investigations to answer questions.

Assessments are a useful tool for teachers and students to determine if the necessary understandings have been acquired. As shown in Table 1b, there were significant differences between previous science courses and SIB. For example, students identified that they were asked questions and expected to explain meanings of statements and data more often in SIB than in their previous schools. Also, students responded that they more often helped the teacher assess their learning in SIB. While many of our students come from demographically diverse classrooms, the questions in Table 1c were directed towards diversity of appreciation and inclusion of varied perspectives, ideas, questions, and learning styles through the activities and general environment of the classroom, as is suggested in Scientific Teaching.

Significant differences were found in how often student ideas and suggestions were used in class, how often students talked with others, and how often they were told exactly how to do their work. Encouraging students to share their perspectives can contribute to a better understanding of the material for all learners involved. Students will be more likely to share their ideas and take risks to engage in discussion or unfamiliar activities if they feel their contributions are valued.

Questions related to student experiences in the classroom environment are shown in Table 1d. Students were less likely to be expected to do the same work at the same time in SIB compared to their previous experience. They were also less likely to choose their own seats or partners.

Because students are expected to construct their own knowledge in SIB, for example by working with data to draw conclusions, there is more flexibility in the pace and direction they take to accomplish the content goals.

ST not only requires redesigning the approach to what is done in the classroom but also redefining the interactions between class participants. Students reported that teachers in previous courses remained at the front of the room while this rarely happened in SIB. Also, students felt more comfortable complaining when activities were confusing and asking for the rationale behind learning certain material.

Implications for Our Teaching

The survey results have implications for our teaching since understanding the previous classroom experiences of our students helps us facilitate their transition and adjustment. Our results show that our students were accustomed to discussing their work in class but that they had little experience in drawing conclusions from data. Thus, if we find students are not communicating well, we know we need to help them make their conversations more productive.

Table 1

a. Questions on Active Learning

	P value
Students discuss their work in class	< 0.0001**
Students find out answers to questions from the textbooks rather than investigations	< 0.0001**
Students draw conclusions from information	< 0.0001**
Students carry out investigations to test ideas	< 0.0001**
Students find out the answers to questions and problems from the teacher rather than investigations	< 0.0001**
Students are asked to think about the evidence behind statements	< 0.0001**
Students are asked questions	< 0.0001**
Students carry out investigations to answer questions from class discussions	< 0.0001**
Students sit and listen to the teacher	< 0.0001**
Students explain the meaning of statements, diagrams, and graphs	< 0.0001**
Students learn that science cannot provide perfect answers to problems	< 0.0001**
Students learn that science has changed over time	0.4761
Students talk with other students about how to solve problems	< 0.0001**
Students explain their understanding to other students	< 0.0001**
As a student, you ask other students to explain their thoughts	< 0.0001**
As a student, you ask by other students to explain your ideas	.002*
The teacher lectures without students asking or answering questions	< 0.0001**

b. Questions on Assessment

	P value
Students are asked questions	< 0.0001**
Students explain the meaning of statements, diagrams, and graphs	< 0.0001**
The teacher uses tests to find out where each student needs help	0.0001*
As a student, you help the teacher to assess your learning	< 0.0001**

c. Questions on Diversity

	P value
Students discuss their work in class	< 0.0001**
Students work at their own speed	0.1131
Students choose their partners for group work	< 0.0001**
Most students take part in discussions	0.0001*
Students are told exactly how to do their work	< 0.0001**
Difference students do different work	< 0.0001**
Students' ideas and suggestions are used during classroom discussions	< 0.0001**
Students talk with other students about how to solve problems	< 0.0001**
Students explain their understanding to other students	< 0.0001**
As a student you are asked by other students to explain your ideas	< 0.0001**
As a student you ask other students to explain their thoughts	< 0.0001**

d. Questions on Classroom Environment

	P value
Students choose their own partners for group work	< 0.0001**
Students are told exactly how to do their work	< 0.0001**
Students feel it's ok to complain about anything that prevents them from learning	0.0307*
The teacher decides where students sit	< 0.0001**
The teacher talks to each student	< 0.0001**
The teacher talks rather than listens	< 0.0001**
The teacher helps each student who is having trouble with the work	0.0516
The teacher remains at the front of the class rather than moving about and talking with the students	< 0.0001**
As a student, it is ok to ask the teacher "why do I have to learn this?"	0.0001**
As a student, it is ok for you to complain about teaching activities that are	0.0002**

Questions modified from the ICEQ and CLES. Questions have been divided into four categories: a. Active Learning, b. Assessment, c. Diversity, and d. Classroom Environment. P values and significance are shown comparing two administrations of the survey.

The pre-survey showed us that students were unfamiliar with explaining meaning and assessing their own understanding, activities which occur frequently in SIB. This suggests we need to develop ways to encourage ownership of learning in SIB, taking responsibility to connect with their teachers, peers, and others for help as needed.

One SIB strategy is to have students to write down their understanding of a process and then to work with a partner to improve their work. Both students are actively engaged with the material, evaluating their current level of understanding and creating more meaningful explanations. While initially challenging, students soon take ownership of their progress. These types of formative assessments have been beneficial to the students and teachers to identify the level of understanding of the class, to correct misconceptions, and to promote different approaches to the material.

Some responses indicated that SIB offers more freedom and flexibility than students were used to – choosing seats, working with others, and contributing suggestions, and more likely to be told exactly how to do their work. Some students have trouble with this kind of freedom since they are responsible for what they contribute, how they work with a group, and even just what to do first. Guidelines and checkpoints can help students manage these processes. Allowing students to work in groups for 5 to 10 minutes and then bringing their conclusions and questions into a large class discussion helps keep groups on task.

Students indicated in that they interact with their teacher in SIB more than in their previous classes. This interaction is very important in an ST classroom, so students need guidance on the course content and on the transition and adjustment to our teaching style.

The knowledge we gained from these surveys and observations we and other teachers made inspired us to put explicit steps in place to help students struggling with the transition to SIB in terms of active learning, collaboration, and reflection. These students were identified by their grades on the first exam and through their work and activities in and outside of class.

We developed a Biology Progress Plan outlining specific steps that students were to follow: writing up current approaches to the class and studying, recording their analyses about what was successful and what was not, and creating a plan for future success. They were encouraged to write out explanations of material after each class period, do all available practice problems and activities, gain feedback on their explanations and practices, work with other students at help sessions, and see their teachers on a regular basis for questions and discussion. Full participation also included turning in practice writing and problems consistently, seeing the teacher frequently, attending all help sessions, and following through with all suggestions made.

In general, students who fully participated in the plan improved their subsequent quiz scores by better than 10%. This was larger than the increase (and sometimes decreases) of students who were encouraged to do the plan but did not participate fully. Even those who were not struggling were inspired by these improvements and decided to follow the plan as well. In later semesters we have presented the Progress Plan to all students at the beginning of SIB. While not all students follow through, it is now understood that these are steps to take to learn and do well with the material, and are not reserved as a "fix" intended for those who are struggling.

Since we believe even small changes in pedagogy and class design can help students be more engaged, we will continue to use the survey information to help our students benefit from our ST-based SIB course. These changes encourage students to be more invested in and excited about science because their experiences better reflect the inquiry, problem solving, and collaboration with diverse perspectives that represent science. Student interest and excitement, in addition to the accumulation of facts and knowledge, may even make them more likely to pursue science in the future (Handelsman et al. 2007).

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