Meeting the needs of the partner disciplines:
An initial look at mathematical abilities of students in the sciences and technology

David C. Wilson, Buffalo State College

There are calls for greater communication between mathematics departments and the various partner disciplines whose students require a strong foundation in mathematics from organizations including the MAA and Project Kaleidoscope (PKAL). Buffalo State, as part of a U.S. Department of Education Title III grant, has formed a working group comprised of mathematics, science, technology, and computer information systems faculty whose objectives are to gain understanding of the needs of the various partner disciplines, assess students' abilities in identified areas of need and share the findings with departments, and provide professional development for faculty. The resulting discussions should promote better understanding among departments and generation of ideas for the improvement of instruction and student learning. The focus of this report is on the development and administration of a draft assessment instrument. Analysis of initial pilot results are discussed along with implications for undergraduate mathematics courses serving students in the partner disciplines.

Background

Buffalo State College is the recipient of a five-year U.S. Department of Education Title III grant (#P031A050184) to strengthen the College's capacity to improve the teaching and learning of mathematics. Three workgroups were formed to focus on different elements of the student body–elementary mathematics teacher preparation, mathematics for the liberal arts student, and mathematics for students in client disciplines including science, technology, and computer information systems majors. This report focuses on the work done by the latter group in the first year and half of the grant. The partner discipline working group is made up of faculty from physics, biology, geology, engineering technology, computer information systems and mathematics.

In 1999, the MAA's Committee on Undergraduate Programs in Mathematics (CUPM) formed a subcommittee to gather information from the partner disciplines regarding students' mathematical preparation. From 1999 to 2001 a series of eleven workshops were held with various representatives of the partner disciplines and in late 2001 a final report was issued. The report (MAA, 2001) had summary recommendations that included focusing on problem solving, conceptual understanding, mathematical modeling, and communication. The report went further to suggest emphasizing depth over breadth and among other course shifts, replacing the traditional college algebra content with mathematical modeling, descriptive statistics, and applications in technical areas. Similarly, Project Kaleidoscope (PKAL,2006) called upon mathematics and science departments to begin "dissolving barriers that isolate disciplinary communities and building bridges that connect them, helping faculty make the kind of connections they hope their students can make." (¶ 1)

Method

Instrument

The process of improving cooperation and communication between departments and improving mathematics instruction to better meet the needs of the partner disciplines began with discussions of the mathematical needs of students in the respective disciplines. The resulting conversations provided several directions for the committee to follow. Prerequisite mathematics courses were notably absent within some disciplines and current mathematics course content was not necessarily aligned well with the needs of the disciplines. Conversations included anecdotal evidence of student weakness in mathematics, but the need for some baseline data on student abilities was recognized. It was also recognized that there was a need for specific examples of the types of problems students have difficulty with from the various disciplines and that the assessment instrument should be based on those types of problems. Solicitation of specific problems from faculty in disciplines represented in the working group as well as other disciplines including earth science, science education, chemistry, and fashion and textile technology, resulted in substantial feedback. Following several iterations of narrowing content and problem areas and soliciting feedback from faculty, a group of skill areas were identified and led to the taxonomy of mathematical needs shown in Table 1.

Table 1.
Taxonomy of Mathematical Needs

Topic	Problem Area
Units and scales of measurement	Metric/SI system Angular measurement (angles, time, latitude/longitude) Significant figures, accuracy, precision, estimation. Number line problems – arithmetic with integers Dimensional analysis.
Logarithms and exponential relationships	Common and natural logarithms The exponential function Logarithmic scales (pH, etc.) Scientific notation
Proportional reasoning	Simple percentage problems (discounts, weight change, relative frequencies) Dilution problems Density problems (e.g. number of items per unit area or volume)
Geometrical and spatial reasoning	Understanding that irregular figures (e.g. leaves) have areas Trigonometry problems in stratigraphy, design, physics Map reading and preparation Calculus: areas and definite integrals
Mathematical thinking	Recognizing/accepting mathematical models as representations of reality. Interpreting slopes, rates, etc. Multi-step problems: stamina, trusting intermediate results. Verifying reasonableness of answers. Knowing when to apply arithmetical operators.
Graphs (of data, not functions)	Reading (verbalizing) complex graphs Producing graphs (scales, tick marks, labels, symbols) from data

The assessment instrument was then developed as specific examples of problems reflective of the categories were written and discussed. The input from all departments was consistent in terms of the necessity for students to be able to read and interpret the mathematics with given situations and thus it was decided that all questions would be written in context. Items from national and international assessments in mathematics and science were considered including the National Assessment of Educational Progress (NAEP), the Third International Mathematics and Science Study (TIMSS), and the Programme for International Student Assessment (PISA). The written and selected assessment problems were then discussed with faculty members within the related disciplines. Lastly, the assessment instrument was analyzed with respect to State University of New York Math and Quantitative Reasoning outcomes and NAEP ability categories of procedural knowledge, conceptual understanding, and problem solving. Nearly half the problems emphasized conceptual understanding with another one-third addressing problem solving and the remainder focusing on procedural tasks. The need for varied response formats was agreed upon and thus the instrument has a mix of multiple choice and constructed response items. The final draft reflects refinements based on these analyses and revisions based on feedback from the working group. A parallel assessment was also developed for purposes of reliability. The following paragraphs discuss only the initial assessment draft and not the parallel assessment results.

Participants

The assessment was administered to several classes of students in the various disciplines including mathematics. The sample included a total of 65 students from two upper division biology classes– Genetics and Ecology; two technology classes– Engineering Technology (upper division) and Fashion and Textile Technology; two College Algebra classes, and University Physics I, a calculus-based physics class. Table 2 displays the sample size for each class and a summary of the mathematical background of the students. The sample size is small in some cases due to administering two forms of the assessment and thus having data for only half the class discussed in this report.

Table 2

Participating Classes and Student Background

Course	N	Mathematical Background
BIO 303: Genetics	12	Calculus (8 of 12)
BIO 315: Ecology	6	Calculus (all)
ETT 461: Control Systems I	6	Calculus (all)
FTT 250:Fashion Buying and Merchandising Principles	7	College Algebra (6), Calculus (1)
MAT 110: College Algebra	15	High School mathematics
Physics 111: University Physics	19	Calculus (all)

The classes were selected based on the willingness of the instructor to participate in the process following requests from the faculty involved in the project. Students were allowed to use calculators and some of the questions required the assistance of a calculator.

Scoring Procedures

The assessment contained multiple-choice, short-response and constructed-response items as shown in Table 3. Four multiple-choice were enhanced to include explanation of the choice but most problems required a short response in that the student had to set up and solve a problem.

Table 3

Assessment Composition

Item Type	Number of Items
Multiple Choice	2
Extended Multiple Choice	4
Short Response	7
Extended Response	2
Total	15

The problems varied in difficulty and were valued accordingly. Problems that were simple multiple-choice or that required minimal work were scored out of 1. The extended multiple-choice and two of the short-response were scored out of 2 and the extended-response items were worth 3 points each for a total of 25 points.

Results

The results on the assessment varied greatly across the various courses ranging from a low of 35% correct to a high of 78% correct. Table 4 displays the means and standard deviations of the scores within each course.

Table 4

Summary Data

Course	N	Mean Raw Score	Std. Deviation	Mean %
BIO 303	12	15.17	3.76	61
BIO 315	6	16.00	5.87	64
ENT 461	6	19.50	2.95	78
FTT 250	7	8.86	5.70	35
MAT 110	15	11.95	5.21	48
PHY 111	19	16.95	4.73	68

While overall performance was poor on the assessment there were some items that a large percentage of students responded to correctly. One of these dealt with subtraction of integers in the context of temperature and another dealt with percentages. Students correctly answered these questions 92% and 88% of the time respectively. It was discussed that both contexts and problems were too elementary to illuminate differences in student ability. The percentage question was fairly straightforward with a two-digit percentage (e.g., 45%) and involved simply calculating the percent of a total number. Suggestions for revision included using a rational percentage (e.g., 9.5%) as well as "nesting" the percentage task. That is, students have greater difficulty in responding to a problem that involves x % of group A and of those, y % have a certain trait.

Three other problems that were successfully completed involved selection of the data set that would considered more reliable when both have the same mean (80%), number sense and the ability to recognize a given mean isn't appropriate given the set of data (80%), and calculation of a missing angle in a right triangle (75%). These problems are under review in terms of their value in gathering baseline data for purposes of future evaluations.

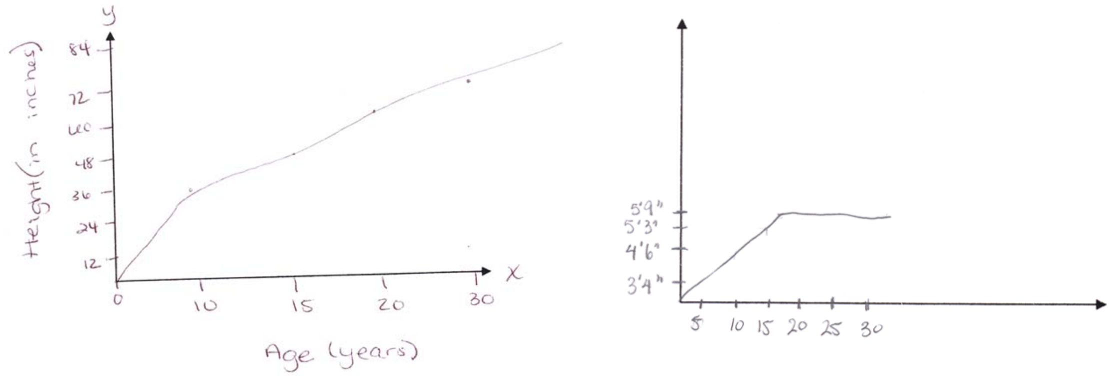
Many problems had a very low correct response rate and the students' work often revealed interesting patterns regarding their thinking. There were two items that were designed to assess understanding of logarithms. The first asked students to evaluate the $\log_2(8)$ and provided the solution to $\log_{10}(100)$ as an example. Only 38% of the students correctly responded with the vast majority of those coming from the physics and engineering technology courses. The second involved setting up and solving a logarithmic equation. Students often simply omitted the item with only 25% completing the problem and again, most of those were from the same two classes. Analysis of student work revealed a common error that involved students' willingness to solve for R in $6= 10\log_{10}(R)$ by dividing both sides by $10\log_{10}$. They used their calculator to determine the value of 10log(10) and thus arrived at .6 for an answer.

Another item that had a low correct response rate, but was attempted by almost all, involved estimation of the size of a crowd at a sold out concert given the dimensions of the rectangular field all were standing on[1]. The field had an area of 5000 m^2 and choices for attendance were provided of 2000; 5000; 20,000; 50,000; and 100,000. Only 28% of the students correctly responded with 20,000 people based on 4 people per square meter. It may be that the students understanding of the size of a square meter is poor or that they believe a sold out concert would allow 1 person per square meter which was the most common incorrect response. It was discussed the next assessment might include an item that assess student's estimation of a meter to differentiate among the incorrect responses.

The item that had the lowest correct response rate involved students constructing a graph of the

[1] This item is from the 2003 PISA available at http://nces.ed.gov/surveys/pisa/

height of a person from birth to age 30[2]. Only 12% were able to completely correctly respond to the item though 66% provided a partially correct response. Figure 1 displays two sample responses that illustrate the typical errors students made in constructing the graphs.



(a) (b)

Figure 1. Student responses to the task of constructing a graph of height to age 30

Figure 1a. exemplifies the two most common errors in students' responses in that the graph begins at the origin and displays a steadily increasing height over the given domain. Figure 1b. reflects two other errors including the all to common lack of consistent scaling on the y-axis scale as well as the less frequent representation of growth as strictly linear to a certain point and then constant.

A second item that was used to assess understanding of some of the same concepts as the height-age graph above involved students selecting the graph which best modeled the height-time relationship of liquid in a container as it is being poured in at a constant rate[3]. Figure 2 displays the container and graph choices. The results for this question were better than the height-age graph with 35% responding with a completely correct response. In order to receive full credit students had to justify their selection. If students who received partial credit (correct selection

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[2] This item is from the 1995TIMSS available at http://timss.bc.edu/timss1995i/SiteIndex.html
[3] This item is from the 2003 PISA available at http://nces.ed.gov/surveys/pisa/

but not acceptable justification) are included the correct response rate rises to 52%.

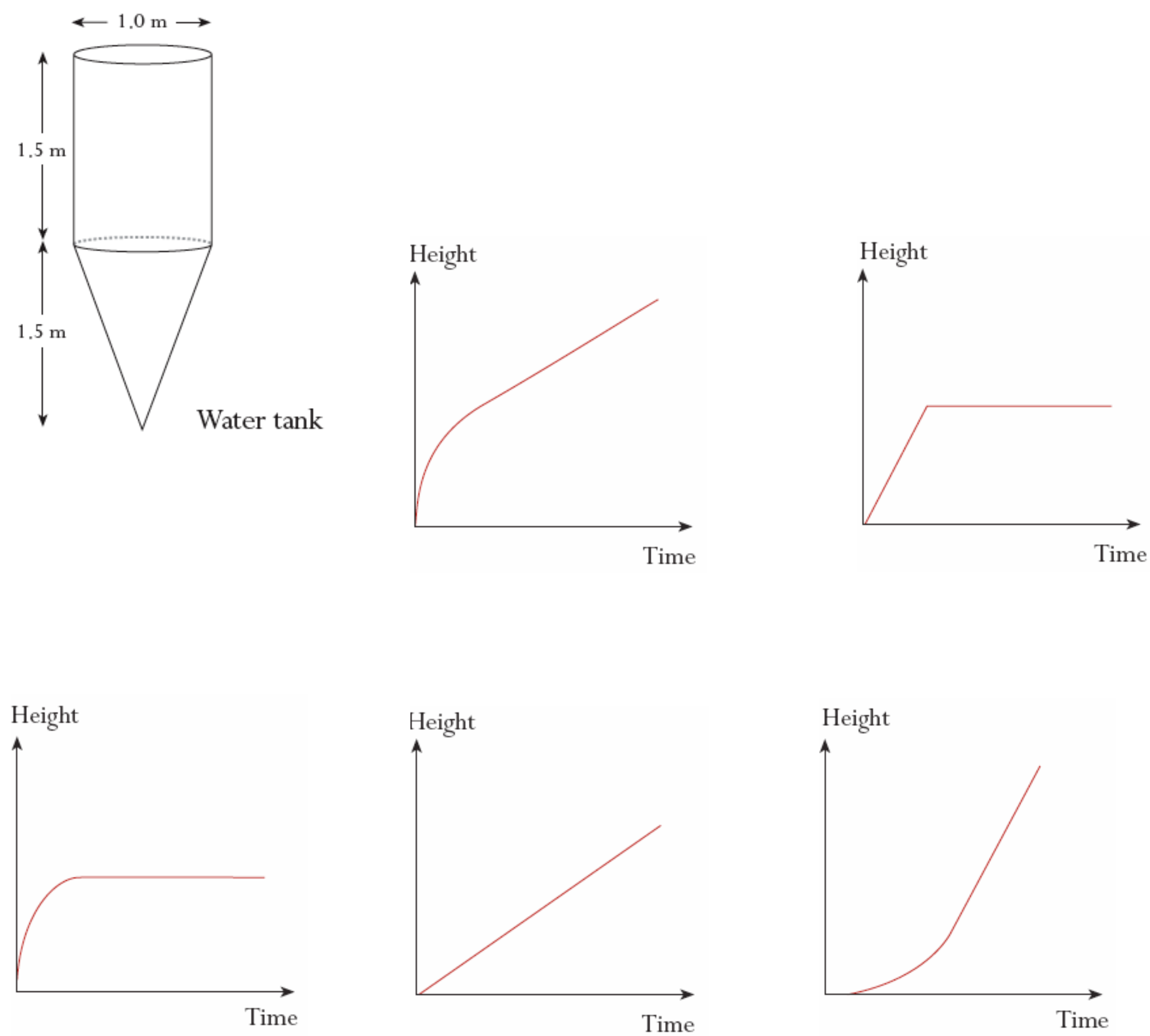

Figure 2. Graph of height of liquid in tank during filling at a constant rate

Students' explanations generally did not address the varying height rate within the cone portion of the tank. In other words, it was difficult to understand why a student would choose the last graph as opposed to the first graph based on their descriptions.

Conclusions

The purpose in administering the assessment was to provide some baseline data on students in areas that were identified as in need of attention by faculty in the partner disciplines and to promote discussions between the mathematics faculty and the partner disciplines. In addition, the feedback on the assessment from the various departments will be used to modify the instrument for future administrations.

The discussions that have followed the presentation of results have provided several avenues for the working group to follow. One involves editing or removal of some items in favor of others that may target additional significant areas including dimensional analysis and interpretation of data presented in a graphic representation. Discussions have also noted the need for more detail on what prerequisites the various programs and courses have to determine whether the expectations are aligned with the requirements. The courses that students take from the mathematics department that feed into the partner disciplines including college algebra are being examined for possible revision particularly in light of the latest recommendations from the MAA/CUPM (2007) subcommittee Curriculum Renewal Across the First Two Years (CRAFTY) and the specific goal of meeting the needs of the partner disciplines. Other outcomes include examining options to improve student readiness for mathematics courses and providing greater opportunities for additional assistance in mathematics courses are also being discussed across disciplinary boundaries. These conversations hopefully are the beginning of the process described by PKAL above– to dissolve disciplinary barriers and build bridges that allow for a better experience for our students.

References

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