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Succeeding in Introduction to Physical Science: Is Mathematics Background Important?

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Abstract

Most college students complete courses in physical and life science as general education requirements. Although the level of difficulty of these survey courses is relatively low compared to upper-level science courses, a number of students still struggle to pass them. The purpose of this research was to investigate (a) the nature of mathematics background of students enrolling in physical science courses; (b) the change in mathematics ability of students at the end of the semester; and (c) what is the relationship between mathematics background and course completion and success. A 15-item test of basic mathematics skills was administered as a pre-test and post-test to students in two sections of Introduction to Physical Science at Arkansas Tech University. Results show that more than half of the students performed deficiently or failed the pre-test, that students who finished the course did not gain any significant knowledge in mathematics, that students who eventually withdrew from the course performed worst in the pre-test than students who persisted, and that there is a statistically significant relationship between pre- and post-test scores and students' final grades in the course.

Introduction

Most students complete several courses in science as general education requirements for their institutions. In some cases, both a life science and a physical science course are required. Although the level of difficulty of these survey courses is relatively low compared to upper-level courses in science, a number of students still struggle to pass them. In the case of physical science courses, it is argued that the mathematical ability of the students is an important factor in their success or failure. This is consistent with research which shows that mathematics knowledge is a significant variable in passing courses in a variety of physical science classes, including engineering (Levin and Wychoff, 1987), college chemistry (Sánchez and Betkouski, 1986), and introductory college physics (Hart and Cottle, 1993; Crooks, 1980; Hudson and McIntire, 1977).

Although students who have not mastered the basic mathematical skills do seem to have more problems with physics or physical science courses, this is not to say that they are inexorably condemned to failure nor that mathematically literate students will automatically perform better in physical science (Hudson and McIntire, 1977):

[Mathematics skill] is more of a predictor of failure than a predictor of success. This is consistent with the idea that a highly motivated student can overcome a deficiency in the prerequisite material. It is also consistent with the presupposition that mathematical skill is only one of several factors necessary to physics, and a high score on a mathematics test is no guarantee of success in physics.

Although students who have completed courses in algebra and trigonometry (and even pre-calculus and calculus in some high schools) are assumed to be capable of handling college level physical science courses, a mathematics skills pre-test could be a good method to explore students’ real knowledge in this area. A pre-test of this type would also allow students to know early on in the semester that they might be at risk of failing the physical science course.

The purpose of this paper is to share some results from a pre-test and post-test of basic mathematics skills that the author considered important for success in a general education physical science class. The test was administered to two groups of Introduction to Physical Science students at Arkansas Tech University during the spring semester of 2003. According to the university catalog, this course is “an introduction to the natural laws governing the physical world, with emphasis upon the development of these laws and their effect upon man. Specific topics are selected from disciplines of physics, chemistry, astronomy, geology, and meteorology” (Arkansas Tech University, 2003). In particular, four research questions guided this inquiry:

- What mathematical knowledge do students have at the beginning of the course?
- Is there a gain in mathematics knowledge at the end of the semester?
- Does lack of mathematics knowledge contribute to students withdrawing from the course?
- Does possession of mathematics knowledge contribute to success in the course?
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Table 1. Descriptive data for pre-test (n = 95) and post-test (n = 64).

<table>
<thead>
<tr>
<th>Item</th>
<th>% correct on pre-test</th>
<th>% correct on post-test</th>
<th>Item</th>
<th>% correct on pre-test</th>
<th>% correct on post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75.79 %</td>
<td>76.56 %</td>
<td>9</td>
<td>70.53 %</td>
<td>73.44 %</td>
</tr>
<tr>
<td>2</td>
<td>65.26 %</td>
<td>68.75 %</td>
<td>10</td>
<td>44.21 %</td>
<td>42.19 %</td>
</tr>
<tr>
<td>3</td>
<td>78.95 %</td>
<td>82.81 %</td>
<td>11</td>
<td>40.00 %</td>
<td>48.44 %</td>
</tr>
<tr>
<td>4</td>
<td>86.34 %</td>
<td>93.75 %</td>
<td>12</td>
<td>57.89 %</td>
<td>59.38 %</td>
</tr>
<tr>
<td>5</td>
<td>78.95 %</td>
<td>78.13 %</td>
<td>13</td>
<td>71.58 %</td>
<td>76.56 %</td>
</tr>
<tr>
<td>6</td>
<td>78.95 %</td>
<td>85.94 %</td>
<td>14</td>
<td>51.58 %</td>
<td>51.56 %</td>
</tr>
<tr>
<td>7</td>
<td>52.63 %</td>
<td>50.00 %</td>
<td>15</td>
<td>54.74 %</td>
<td>62.50 %</td>
</tr>
</tbody>
</table>

Methods

A 15-item multiple-choice test was designed based on a close examination of the mathematics skills needed to understand derivations of equations and to solve general problems both in class and as homework (Crooks, 1980). It included concepts such as conversion between regular and scientific notation, substitution of numbers in a formula to obtain a result, solution of numerical equations, simple and complex fractions, ratios, and solution of equations for a given variable.

The reliability of the test was measured based on the descriptive statistics of the pre-test administration. The reliability coefficient based on Kuder-Richardson's procedure (Thorndike and Hagen, 1961) was established as 0.63. Although this reliability coefficient is not as high as generally recommended by the literature (0.75 or more) it is still within an acceptable range, considering the low number of items on the test (in general, more items contribute to a higher reliability coefficient) and the heterogeneity of item difficulty (tests with items of homogeneous difficulty contribute to a higher reliability coefficient). The full test is available upon request.

During the first class, the instructor discussed the course's syllabus with the students and administered the mathematics pre-test. Although it was first labeled a diagnostic test, the instructor informed the 95 students present that their scores would be added as bonus points to their final grades. This was intended to raise the students' motivation to take the test seriously. Students who were not present during the first class were not included in this study.

As part of the course's final examination, the same mathematics assessment was administered again as a post-test. The 64 students who took the final test were informed that their score would also be considered as bonus points. Due to the nature of the test items, students were not allowed to use calculators for either the pre-test or the post-test.

Each student's item response was aggregated into an Excel file. Then, a new Excel file was created and students were subdivided based on whether they finished the semester and took both the pre-test and post-test (n = 64) and those who only took the pre-test (n = 31) but withdrew from the course before the end of the semester. Descriptive statistical analysis was performed in Excel, and inferential statistics were performed with free online statistical tests available at http://members.aol.com/johnp71/javastat.html.

Results and Discussion

The results from the aggregated pre-test data show some remarkable findings in terms of the mathematical knowledge students have at the beginning of the course. Although all students took high school courses in algebra, and most students take college algebra as a prerequisite to Introduction to Physical Science, there were significant weaknesses in the students' basic mathematics knowledge.

The average score for the pre-test was 9.94 out of 15, or 66.3%, which means that more than half of the participants performed deficiently or failed the test. (Table 1) The highest percentage of correct answers, about 86%, came from items four and eight, which dealt with scientific notation and simple numerical equations. Students performed the poorest (less than 60%) on items 7 and 10 (finding numerical values for a variable on fractional equations), item 11 (simplifying complex fractions), item 12 (application of ratios), and items 14 and 15 (solving equations for a given variable).

To determine whether there is a gain in mathematics knowledge by the end of a semester of physical science, pre-test and post-test results were compared. It was found that 8 students (13.11%) obtained the same score on both tests, 35 students (57.38%) obtained a higher score on the post-test, and the remaining 18 students (29.51%) obtained a lower score on the post-test.

Although the positive gain looks noteworthy, a statistical analysis is needed to determine whether it is significant. A t-test comparing pre-test and post-test scores for students who completed the course (n = 64) found no
statistically significant increase between scores \( t = 0.97, P = 0.3357 \).

To examine the results on an item basis, a statistical analysis was performed using the McNemar test available at http://www.fon.hum.uva.nl/Service/Statistics/McNemars_test.html. According to this website, this test determines whether a difference in response (right-wrong and wrong-right) could be by chance or not. This test assumed nominal data and matched pairs and was used instead of a t-test, although for \( n > 30 \), a t-test was suggested. To perform this test, the data must be classified into four categories: (Table 2):

- Number of students who answered correctly on both test administrations
- Number of students who answered incorrectly on both test administrations
- Number of students who answered incorrectly first and correctly the second time
- Number of students who answered correctly first and incorrectly the second time

No statistically significant difference per item between the pre-test and post-test was found, providing more evidence that completing the physical science course has no significant effect on students’ mathematics knowledge.

A comparison was made between the pre-test results for the 64 students who finished the class and the 31 students who withdrew to determine whether lack of mathematics knowledge might be a contributing factor in students leaving the course. (Table 3) A t-test was used to determine if the difference between the mean proportion of correct answers for students who finished the class \( \text{correct/total} = 0.6948 \) and for those who withdrew \( \text{correct/total} = 0.5979 \) was statistically significant at the 0.05 level \( t = 2.4591; P = 0.0158 \).

A detailed analysis of each item showed that students who withdrew from the physical science course had significantly lower scores on item 4 (change from scientific notation to regular notation, item 6 (number substitution into equation), item 8 (finding numerical values for a variable on an equation), item 11 (simplifying a complex fraction) and item 15 (solving an equation for a given variable).

To investigate whether mathematics knowledge might be related to different degrees of success, measured by the students’ final percentage score in the class, a Pearson correlation coefficient was calculated using pre-test data (Fig. 1). The correlation coefficient was found to be 0.4004. A statistical analysis to determine whether the coefficient is different from zero was found to be significant \( t = 3.44, P < 0.001 \).

A stronger correlation coefficient of 0.4958 was found between the students’ final percentage score in physical science and their post-test results (Fig. 2). This correlation coefficient is also significantly different from zero \( t = 4.6031 \) and \( P < 0.001 \), demonstrating a positive relationship between mathematical knowledge and final academic achievement in physical science.

Although physical science instructors create their own beliefs about mathematics knowledge and student achievement in their courses based on personal and anecdotal evidence (Hart and Cottle, 1993), it is important to confirm this information based on research data. The results from this study are in line both with anecdotal evidence and with results found by other scholars, especially Hart and Cottle (1993), Crooks (1980), and

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Table 2. Pre-test and post-test performance per item.

<table>
<thead>
<tr>
<th>item</th>
<th>right-right</th>
<th>wrong-wrong</th>
<th>wrong-right</th>
<th>right-wrong</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>5</td>
<td>10</td>
<td>13</td>
<td>0.678</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>6</td>
<td>14</td>
<td>8</td>
<td>0.286</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>1</td>
<td>10</td>
<td>6</td>
<td>0.454</td>
</tr>
<tr>
<td>4</td>
<td>52</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>0.388</td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>51</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>0.388</td>
</tr>
<tr>
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<td>17</td>
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<td>17</td>
<td>15</td>
<td>0.860</td>
</tr>
<tr>
<td>8</td>
<td>51</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>0.388</td>
</tr>
<tr>
<td>9</td>
<td>32</td>
<td>9</td>
<td>8</td>
<td>14</td>
<td>0.286</td>
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<td>14</td>
<td>18</td>
<td>19</td>
<td>13</td>
<td>0.377</td>
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<td>19</td>
<td>14</td>
<td>13</td>
<td>1.000</td>
</tr>
<tr>
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<td>27</td>
<td>11</td>
<td>15</td>
<td>11</td>
<td>0.557</td>
</tr>
<tr>
<td>13</td>
<td>42</td>
<td>2</td>
<td>13</td>
<td>7</td>
<td>0.263</td>
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<td>13</td>
<td>16</td>
<td>0.711</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
<td>9</td>
<td>15</td>
<td>10</td>
<td>0.424</td>
</tr>
</tbody>
</table>
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Hudson and McIntire (1977). In general, the more mathematics knowledge a student has, the better are his or her chances of completing Introduction to Physical Science with a good grade.

It was somewhat surprising that college students who took several mathematics courses in high school and also took college algebra as a prerequisite for the Introduction to Physical Science course scored so low on a relatively simple mathematics test, especially in items similar to physics problems. If the test is really measuring their mathematics knowledge, there are significant deficiencies in some areas.

An unexpected but important observation is that after about 10 weeks of solving mostly physics problems, students did not gain significant mathematical knowledge. A possible reason for that result might be the way the course is structured. During the first ten weeks, topics such as kinematics, dynamics, thermodynamics, electricity, structure of the atom, and nuclear physics are covered. During the last five weeks, the emphasis shifts to a more conceptual study of astronomy, meteorology, and geology. It is possible that during this period of time students "forget" most of the mathematics they used during the first ten weeks. Another possible explanation is that they did not learn mathematics, that is, they cannot make the connection between mostly pure mathematical problems as presented on the test and the applied mathematics used for solving problems during regular lecture sessions. Regardless of the explanation, it is important to address whether the instructional methodology, the relevance of the course to the students' experiences and background, and its interconnections with other subject areas such as mathematics could be made more effective to improve students' understanding of physical science.

Of particular interest is the interpretation of the correct and incorrect items on both tests as portrayed on Table 2. If we assume that students did not have other math classes during that semester, common sense tells us that the column "right-right" could be interpreted as students who already knew the material on the item; the column "wrong-wrong" could be interpreted as students who never understood the concept, even after the class; and the column "right-wrong" could be interpreted as student who learned the concept during instruction. Is it appropriate to interpret the "right-wrong" column as students who knew the correct mathematical concept at the beginning of the course but forgot it after instruction? Is the physical science class creating the unintended result of confusing some students? Could it be that some students never knew the correct answer but guessed right the first time and guessed wrong the second time? Furthermore, is it possible that students

Table 3. Comparison of the proportion "correct/total" for items where students who withdrew from physical science (n = 31) performed significantly worst than students who finished the course (n = 64).

<table>
<thead>
<tr>
<th>item</th>
<th>c/t finished</th>
<th>c/t withdrew</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.9375</td>
<td>0.7188</td>
<td>0.0029</td>
</tr>
<tr>
<td>6</td>
<td>0.8594</td>
<td>0.6563</td>
<td>0.0208</td>
</tr>
<tr>
<td>8</td>
<td>0.9219</td>
<td>0.7500</td>
<td>0.0202</td>
</tr>
<tr>
<td>11</td>
<td>0.4844</td>
<td>0.2500</td>
<td>0.0274</td>
</tr>
<tr>
<td>15</td>
<td>0.6250</td>
<td>0.3750</td>
<td>0.0203</td>
</tr>
</tbody>
</table>

Fig. 1. Final grade (percentage) in physical science as a function of pre-test scores in mathematics test.

Fig. 2. Final grade (percentage) in physical science as a function of post-test scores in mathematics test.
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took a mathematics course concurrently with Introduction to Physical Science, and there might be additional variables that were not considered in this study?

Another variable that is worth mentioning because of its potential effect on the interpretation of findings is the students’ apparent overdependence on calculators. Since the test used a multiple-choice format, it is possible that some students knew the procedure for some items but failed when doing the computations manually. Others might have felt more anxious knowing that they could not use a calculator. A possible extension of this study might be to create a better assessment instrument that would provide reliable results for the same mathematical concepts and that could be completed by using a calculator.

The finding that students who withdrew from the course had less mathematics knowledge than those students who persisted has some important implications for student advising. Although students tend to complete the Introduction to Physical Science course during their freshman year, advisors should recommend that students adhere to the following guidelines:

- If possible, take the Introduction to Physical Science course during their sophomore year. This might provide students additional time to develop good study habits, especially if they need to review some mathematical concepts.
- Complete all or most of their mathematics requirements before taking the course. This might provide students with more confidence when facing word problems in physics. Advisors might even suggest students repeat college algebra if they passed this course with a D before attempting an Introduction to Physical Science course.
- Develop study groups or other peer-originated academic support early in the semester.
- Establish a close relationship with the course instructor and discuss concepts and/or exercises during the instructor’s office hours. Even if students are not performing well in physical science, they rarely take advantage of office hours.

For these suggestions to be implemented, the results of research such as this should be shared with campus advisors, especially those who advise first year students.

Due to several limitations of this study, the previous findings must be interpreted with caution. For example, results might be more conclusive with a larger sample size, if the participants are selected from several sections with different instructors, if the study is replicated over a number of semesters, or if other sections of physical science (chemistry, physical geology, astronomy) are included.

Conclusions

Why do students fail to learn basic mathematics skills in the physics classroom, as suggested by this study? A possible explanation might be that the traditionally large lecture sessions are not effective in promoting an active learning environment. Research in physics education has shown that many students who take introductory physics courses in the standard lecture-recitation format do not develop a real understanding of physics concepts, despite the instructor’s informed lectures and reinforcing demonstrations (González-Espada, 2003). Could the answer be smaller class sizes, or does the problem go beyond that, to the very core of how general education physical science courses are taught at the college level?

Literature Cited


