Assessing the Use of Technology and Using Technology to Assess

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Abstract. The Department of Mathematical Sciences at the United States Military Academy (USMA) is fostering an environment where students and faculty become confident and competent problem solvers. This assessment will reevaluate and update the math core curriculum,s program goals to incorporate the laptop computer, enabling exploration, experimentation, and discovery of mathematical and scientific concepts.

Background and goals

Technology has made a dramatic impact on both education and the role of the educator. Graphing calculators and computer algebra systems have provided the means for students to quickly and easily visualize the mathematics that once took effort, skill, and valuable classroom time. The Calculus Reform movement sought to improve instruction, in part, by taking advantage of these technological resources. Mathematical solutions could now be represented analytically, numerically, and graphically. The shift in pedagogy went from teaching mathematics to teaching mathematical modeling, problem solving, and critical thinking. Ideally the problem solving experiences that students encountered in the classroom were interdisciplinary in nature. Mathematics has truly become the process of transforming a problem into another form in order to gain valuable insight about the original problem.

Portable notebook computers provide an even greater technological resource that has led us to once again reexamine our goals for education. Storage and organization coupled with powerful graphical, analytical, and numerical capabilities allow students to transfer their learning across time and discipline.

The Department of Mathematical Sciences at USMA is committed to providing a dynamic learning environment for both students and faculty to develop self-confidence in their abilities to explore, discover, and apply mathematics in their personal and professional lives. The core math program attempts to expose the importance of mathematics, providing opportunities to solve complex problems. The program is ideally suited and committed to employing emerging technologies to enhance the problem solving process. Since 1986, all students at USMA have been issued desktop computers with a standard suite of software; this year the incoming class of students (class of 2006) will be issued laptop computers with a standard suite of software. The focus of this assessment is to reevaluate the program goals of the math core curriculum and update these goals to incorporate the ability of the laptop computer to not only explore, experiment, and discover mathematical and scientific concepts in the classroom, but also provide a useful medium to build and store a progressive library of their analytical and communicative abilities.

Description

The general educational goal of the United States Military Academy is "to enable its graduates to anticipate and to respond effectively to the uncertainties of a changing technological, social, political, and economic world." The core math program at USMA supports this general educational goal by stressing the need for students to think and act creatively and by developing the skills required to understand and apply mathematical, physical, and computer sciences to reason scientifically, solve quantitative problems, and use technology effectively.

Cadets who successfully complete the core mathematics program should understand the fundamental principles and underlying thought processes of discrete and continuous mathematics, linear and nonlinear mathematics, and deterministic and stochastic mathematics. The core program consists of four semesters of mathematics that every student must study during his/her first two years at USMA. The first course in the core is Discrete Dynamical Systems and an Introduction to Calculus (4.0 credit-hours). The second course is Calculus I and an Introduction to Differential Equations (4.5 CH). The sophomore year's first course is Calculus II (4.5 CH), and the final core course is Probability and Statistics (3 CH). Five learning thread objectives have been established for each core course. They are: Mathematical Modeling, Mathematical Reasoning, Scientific Computing, Communicating Mathematics, and the History of Mathematics. Each core course builds upon these threads in a progressive yet integrated fashion.

The assessment focuses on the following aspects of our core math program:

1. Innovative curriculum, instructional, and assessment strategies brought on by the integration of the laptop computer.
2. Student attainment of departmental goals.

Innovative curriculum and assessment strategies

Projects: In-class problem solving labs serve as a chance for the students to synthesize the material covered in the course over the previous week or two. Students use technology to explore, discover, analyze, and understand the behavior of a mathematical model of a real world phenomenon. Following the classroom experience, students will be given an extension to the problem in which they are required to adapt their model and prepare a written analysis of the extension. Students are given approximately seven to ten days to complete the project. For the most part, these out-of-class projects will be accomplished in groups of two or three. An example of a project is provided in Appendix A. To add realism to the scenario, we create interaction between the model's components by means of extensions that force the students to adapt their model and prepare a written analysis.

Two-day Exams: Assessment of student understanding and problem-solving skills will take place over the course of two days. Paramount in this process is determining what concepts and/or skills we want our students to learn in our core program. We understand that "what you test is what we you get"; therefore, we have adapted our exams to assess these desired concepts and skills. The first day of the exam will be a traditional in-class exam in which students do not have access to technology (calculator or laptop computer). This exam portion focuses on basic fundamental skills and concepts associated with the core mathematics program. Students are also expected to develop mathematical models of real world situations. Upon completion of this portion, students are given a take-home scenario that outlines a real world problem. They have the opportunity to explore the scenario on their own or in groups. Upon arrival in the classroom the next day, the scenario is adapted to allow students to apply their problem-solving skills in a changing environment. An example of a take-home scenario and the adapted scenario is provided in Appendix B of our report on the SAUM website.[1]

Modeling and Inquiry Problems: To continue to develop competent and confident problem solvers, students are not given traditional examinations in the second core mathematics course. Instead, they are assessed with Modeling and Inquiry Problems (MIPs). Each MIP is designed as an in-class "word problem" scenario to engage the student for about 45 minutes in solving an applied problem with differentiable or integral calculus or differential equation methods. The student must effectively communicate the situation, the solution, and then discuss any follow-on scenarios, similar to the Day Two portion outlined above, all in a report format. As an example, a MIP may involve using differential calculus to solve a related rates problem.

The "Situation" portion of the MIP involves transforming the words into a mathematical model that can be solved, by drawing a picture, defining variables with units, determining what information is pertinent, what assumptions should be made, and most importantly, what needs to be found. Finally, the Situation ends with the student stating which method (related rates in this case) will be used to solve the problem. The "Solution" portion involves writing the step-by-step details of the problem and determining what is needed to be found. Any asides or effects of assumptions can be written in as work progresses, and this portion

[1] www.maa.org/saum/cases/USMA.html

ends with some numerical value, to include appropriate units. For example, "the rate at which the oil slick approaches the shore is two meters per minute."

The MIP itself has a second paragraph that asks follow-on questions. "Suppose the volume of the oil slick is now doubled. How does that affect your rate?" Or "what is the exact rate the moment the slick reaches the shore?" These follow-on questions prod the student to go back to the method and rework the problem with new information.

The final portion of the MIP write-up is the "Inquiry/Discussion" section. The MIP write-up must be coherent and logical in its flow. Students must tie together the work and stress the solution back in the context of the problem. The Inquiry section is vital in student understanding of the problem. Students do not stop once they determine a numerical answer. They must continue and communicate how that answer relates to the problem, and more importantly, if the answer passes the common sense test.

As of the time of this writing, the third core course has also incorporated MIPs, in addition to traditional exams. The probability and statistics course is considering the use of MIPs in future years. An example of a MIP (focusing on a differential equations problem) is provided in Appendix C of our report on the SAUM website.

Electronic Portfolio: The notebook computer provides a tremendous resource for storage and organization of information. This resource avails the opportunity for students to transfer learning across time and between courses. In the novel, *Harry Potter and the Goblet of Fire*, Dumbledore refers to this capability as a "pensieve."

"At these times," says Dumbledore, indicating the stone basin, "I use the Pensieve. One simply siphons the excess thoughts from one's mind, pours them into a basin, and examines them at one's leisure. It becomes easier to spot patterns and links, you understand, when they are in this form." The portable notebook computer provides the resource for students to create their own pensieve. Creative exercises offer the student exposure to mathematical concepts with the ability to explore their properties, determining patterns and connections which facilitate the process of constructing understanding. Thorough understanding is feasible in either a controlled learning environment or at the student's leisure. Instructors will provide early guidance to incoming students on organizational strategies and file-naming protocol. Informal assessments of a student's electronic portfolio will provide information regarding the ability to understand relationships between mathematical concepts.

Attitude and Perceptions Survey: One tool that will be used to assess if students are confident and competent problem solvers in a rapidly changing world is a longitudinal attitude and perceptions survey. Students will be given a series of sixteen common questions upon their arrival at the Academy and as part of a department survey at the conclusion of each of the four core math courses. A comparison of their confidence, attitudes, and perceptions will be made against those students who in prior years took the core math sequence without a laptop computer. The questions used in the survey are provided in Figure 1. Students responded on a Likert-Scale from 1 (strongly disagree) to 5 (strongly agree).

1. An understanding of mathematics is useful in my everyday life.
2. I believe that mathematics involves exploration and experimentation.
3. I believe that mathematics involves curiosity.
4. I can structure (model) problems mathematically.
5. I am confident in my ability to solve problems using mathematics.
6. Mathematics helps me to think logically.
7. There are many different ways to solve most mathematics problems.
8. I am confident in my ability to communicate mathematics orally.
9. I am confident in my ability to communicate mathematics in writing.
10. I am confident in my ability to transform a word problem into a mathematical expression.
11. I am confident in my ability to transform a mathematical expression into my own words.
12. I believe that mathematics is a language which can be used to describe the world around us.
13. Learning mathematics is an individual responsibility.
14. Mathematics is useful in my other courses.
15. I can use numerical and tabular displays of data to solve problems.
16. I can use graphs and their properties to solve problems.

Figure 1. Questions used in Attitude and Perceptions Survey

Revisions Based on Initial Experience

The assessment began in the Fall of 2002 and will track students over a period of four semesters. A pilot study was run in the Spring of 2002 and the following lessons were learned.

Student use of computers on exams: In the initial implementation of the two-day exam, students were allowed to use the computer on both days. Many students used their computers as electronic "crib sheets." This problem may be further exacerbated when student computers in the classroom have access to a wireless network. The Day One portion of the exam has been reengineered to assess skills and concepts that do not require technology of any sort.

Electronic imprints of exams: Core math courses are all taught in the first four hours of the day. The students' dorms are all networked and word travels very quickly. It is currently against our policy to prohibit students from talking about exams with students who have not yet taken the exam. Enabling the use of laptops on exams creates a situation in which an imprint of the exam is on some cadet's computer following the first hour of classes. The Day Two portion of the exam, which is designed to test the students' ability to explore mathematics concepts using technology, will be given to all students at the same time, during a common lab period after lunch.

Power: Computer reliability, particularly in the areas of power is an area of concern. Students will be issued a backup battery for their laptops. It is forecasted that an exchange facility will be available in the academic building for cadets who experience battery problems in the middle of a test.

Findings

Projects: Students overwhelmingly stated that the course projects helped to integrate the material that was taught in the course. The students, ability to incorporate the problem-solving process (i.e., modeling) increased with each successive project.

Two-Day Exams: The two-day exams provided a thorough assessment of the course objectives. Course-end surveys revealed that the students felt that these two-day examinations were fair assessments of the concepts of the course. The technology portion (Day Two) magnified the separation between those who demonstrated proficiency in solving problems using technology and those who didn't; there was no significant in-between group of students.

Electronic Portfolios: Assessment of the electronic portfolios consisted of individual meetings of all students with their individual instructors. The results of these meetings brought out the point that students needed assistance in determining what material should be retained and how it should be kept. Students realized that material in this course would be needed in follow-on courses, so file naming would be key. Guidance was given to students to incorporate a file management system for later use, but no universal scheme was provided; in this manner, students could best determine their own system.

Additional Findings: Unless assessed (tested), the students did not take the opportunity to learn how to effectively use the computer algebra system *Mathematica*. Students embraced the use of the graphing calculator (TI-89) as the preferred problem-solving tool; they overwhelmingly reported that the laptop computer was a hindrance to their learning.

Use of the Findings

Projects: We will continue to use group projects to assess knowledge; however, we will phase the submission of the projects to provide greater feedback and opportunity for growth in problem-solving and communication skills. Our plan is to have students submit the projects as each portion (Introduction, Facts and Assumptions, Analysis, and Recommendations and Conclusions) is completed.

Two-Day Exams: Content on the Day-One (non-technology) portion needs to be more straightforward, emphasizing the concepts we want students to internalize and understand without needing technology. For the Day-Two (technology) portion, questions should be asked to get students to outline and explain their thought processes, identifying possible errant methods. We need to keep in mind that problems with syntax should not lead to severe grade penalties.

Additional Use of the Findings: We are going to introduce graded homework sets designed to demonstrate the advantage of the computer algebra system and the laptop as a problem-solving tool. Use of the graphing calculator will be limited to avoid confusion and overwhelming students with too many technology options. We plan to review course content and remove unessential material, thus providing more lessons for exploration and self-discovery.

Next Steps and Recommendations

The assessment cycle will continue as we implement the changes outlined above into the first course. The majority of students will enter the second core course, Calculus I which will continue the use of laptops. Six Modeling and Inquiry Problems and one project will be used to assess the progress of our students, problem-solving capabilities.

Acknowledgements. We would like to thank the leaders of the Supporting Assessment in Undergraduate Mathematics (SAUM) for their guidance and support. In particular, our team leader, Bernie Madison, has been instrumental in keeping our efforts focused.

References

1. USMA Academic Board and Office of the Dean Staff (1998), *Educating Army Leaders for the 21st Century*, West Point, New York.
2. J. K. Rowling, *Harry Potter and the Goblet of Fire* (Scholastic Trade Publishing, New York, 2000).

Appendix A. A Sample Project

Humanitarian De-mining

Background. The country of Bosnia-Herzegovina has approximately 750,000 land mines that remain in the ground after their war ended in November 1995. The United Nations (UN) has decided to establish a Mine Action Center (MAC) to coordinate efforts to remove the mines. You are serving as a U.S. military liaison to the director of the UN-MAC.

The UN-MAC will initially have 1000 trained humanitarian de-miners working in country. Each of these trained personnel can remove 65 mines per week during normal operations. Unfortunately, there is a rebel force of about 8,000 soldiers that opposes the UN-MAC's efforts to support the legitimate government of Bosnia-Herzegovina. They conduct two major activities to oppose the UN-MAC: killing the de-miners and emplacing more mines. They terrorize the de-miners, killing 1 de-miner for every 1,000 rebels each week. However, due to poor training and funding, each of these soldiers can only emplace an average of 5 additional mines per week.

Meanwhile, the accidental destruction of the mines maim and kill some of both the de-miners and the rebel forces. For every 1,000,000 mines, 1 de-miner is permanently disabled or killed each week. The mines have the exact same quantitative impact on the rebel forces.

Modeling and Analysis. Your current goal is to determine the outcome of the UN-MAC's efforts, given the current resources and operational environment.

1. Model the strength of the de-mining organization, the rebels, and the number of mines in the ground. Ensure you define your variables and domain and state any initial conditions and assumptions.
2. Write the system of equations in matrix form
   $A(n+1) = R * A(n)$.
3. If the interaction between the rebels and de-miners as well as their respective efforts to affect the minefields remain constant, what happens during the first five years of operations?
4. Graphically display your results. Ensure you display your results for each of the three entities you model.
5. What is the equilibrium vector, D or Ae, for this system? Is it realistic?
6. The General and Particular Solution for the new system of DDS's using eigenvalue and eigenvector decomposition.

Extensions

Better estimate on casualties. Suppose we receive more accurate data on the casualties due to mines; it may (or may not) change part of your model. Better estimates show that for every 100,000 mines, 2 de-miners are permanently disabled or killed each week. The mines have the exact same quantitative impact on the rebel forces.

Other minefield losses. Other factors take their toll on the number of emplaced mines as well. Weather and terrain cause some of the mines to self-destruct, and civilians occasionally detonate mines. Approximately 1% of the mines are lost to these other factors each week.

Natural attrition of forces. Due to other medical problems, infighting, and desertion, the rebel forces lose 4% of their force from one week to the next. The de-miners have a higher attrition due to morale problems; they lose 5% of their personnel from one week to the next.

Recruiting efforts. Both the rebel forces and the de-miners recruit others to help. Each week, the rebels are able to recruit an additional 10 soldiers. Meanwhile, the UN-MAC is less successful. They only manage to recruit an additional 5 de-miners each week.

Project Report

For the project, your report should address the following at a minimum:

1. Executive Summary in memo format that summarizes your research.
2. The purpose of the report.
3. Facts bearing on the problem.
4. Assumptions made in your model, as well as the viability of these assumptions.

5. An analysis detailing:
   a. The equilibrium vector, *D* or *Ae*, for the system and discuss its relevance.
   b. The General and Particular Solution for the new system of DDS's using eigenvalue and eigenvector decomposition.
   c. A description of what is happening to each of the entities being modeled during the first five years of operations.
6. The director of the UN-MAC also wants your recommendation on the following:
   a. If the de-mining effort is going to be successful within the first five years, when will it succeed in eradicating all mines? If the de-mining effort is not going to be successful, determine the minimum number of weekly de-mining recruits needed to remove all mines within five years of operations.
   b. Describe at least one other strategy the UN-MAC can employ to improve its efforts to eradicate all of the mines. Quantify this strategy within a mathematical model and show the improvement (graphically, numerically, analytically, etc.).
7. Discussion of the results.
   a. Reflect on your assumptions and discuss what might happen if one or more of the assumptions were not valid.
   b. Integrate graphs and tables into your report, discuss them, and be sure to label them correctly.
8. Conclusion and Recommendations.