TAKING MATH OUTSIDE OF THE CLASSROOM: MATH IN THE CITY

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Abstract: Math in the City is an interdisciplinary mathematics course offered at University of Nebraska-Lincoln in which students engage in a real world experience to understand current major societal issues of local and national interest. The course is run in collaboration with local businesses, research centers, and government organizations, that provide data and act as consultants throughout the course. We provide a brief description of the course with examples of projects offered over the years. We emphasize service learning aspects of the program, as well as benefits to students and business collaborators.

Keywords: interdisciplinary course, hands-on learning, project-based learning

I liked the fact that we didn't know what we were capable of doing until we did it. (Math in the City student)

The cold morning of December 2, 2011 did not get much notice from the students of Math in the City, who were getting ready to talk about their work and results on the semester long projects. The early days of setting up the data, then creating mathematical models and analyzing them, the long hours put into preparing the final reports and presentations were all behind them. In their interview attires they were showing their enthusiasm and excitement of participating in this rewarding experience.

These student presentations were given at the yearly Math in the City workshop, where instructors from varied institutions across the United

States came to learn about an interdisciplinary project-based course. In this program students work with local businesses to set up and analyze models based on data and activities related to issues of local and national interest. Some of these professors have heard of or participated in similar endeavors, while others were considering it as a new model to teach mathematics. This course came as a solution for many of them in response to the challenge for STEM teachers to prepare the new student generation with a range of skills that will help them enter and rapidly adjust in the workplace after graduation.

The three groups of students took turns talking about their projects that in the Fall 2011 were done in collaboration with Lincoln's Finance Department. In the audience there were undergraduates, graduate students, faculty members, and also, math teachers that were preparing to take the course in Spring 2012 as part of their training in the Noyce Program at UNL. In this mostly academic group, the "outsiders" were some of the business collaborators that have worked with the course over the years, by providing data and guidance for the student projects. The students' great performance illustrated that they learned more than math in this class; their newly gained abilities to showcase their work have greatly improved their employability skills.

The audience was impressed by the student performances and asked questions about why certain decisions were taken along the research. Why was the data chosen this way? How did they decide on the approach to use? The audience also wanted to know more about the student experience (what was the most difficult part? what was the most valuable thing you learned? how long did it take to do the research and how long did it take to write the report?). The business partners commented on the value of their results to the community. Math faculty and students asked and made comments about the mathematical background and hypotheses. The overall agreement in the room was that such an experience is extremely beneficial to students, so departments, and communities likewise need to learn how to support similar endeavors.

These presentations marked the end of the fifth offering of the course

at UNL, with 13 projects so far and counting. The course is now one of the math capstone courses for students at UNL, but since the background requirements are relatively minimal (two of the three courses: Differential Equations, Matrix Theory, or Intro to Statistics) students with varied mathematical training (such as non-math majors in their second or third year) had successful experiences. The Mathematics Department strives to offer the course every year, so all students have the opportunity to take it at least once during their time at UNL.

1 Why Math in the City? What is Math in the City?

A strong body of evidence suggests that project-based instruction that includes hands-on learning is an outstanding way to prepare our students for the 21st Century (see [11]). Mathematicians, pure and applied, know that teaching mathematics in an interdisciplinary context provides not only the motivation for studying the material that students need to know, but it immediately connects students with the outside world [5]:

> We believe that studying applied math, like learning living languages, provides both useable knowledge and abstract skills. In math, what we need is quantitative literacy, the ability to make quantitative connections whenever life requires (as when we are confronted with conflicting medical test results but need to decide whether to undergo a further procedure) and mathematical modeling, the ability to move between everyday problems and mathematical formulations (as when we decide whether it is better to buy or lease a new car). It is through real-life applications that mathematics emerged in the past, has flourished for centuries and connects to our culture now.

While this quote comes from an article published in 2011, I started having similar thoughts after teaching my first courses as a newly minted assistant professor at UNL in 2005. In courses such as Differential Equations, I would observe how students struggle with putting word problems into equations and with creating a mathematical model when a set of

data was given (I learned during my graduate studies the importance of understanding a mathematical model, see [12]). Thus, in 2006 I created a pilot version of the course Math in the City, which received strong support from the department and university, as well as from business representatives around the Lincoln area. I taught the course several times before my colleague, Stephen Hartke, and I partnered to address further development and sustainability issues; these efforts received NSF support in the form of a TUES (former CCLI) grant. This support enabled us to create additional course materials, as well as organize a yearly workshop to disseminate the course to other institutions.

Math in the City provides a real world experience in which students engage in hands-on learning and use mathematical modeling to understand current major societal issues of local and national interest. To obtain data and guidance during investigations we seek collaborators among local businesses, research centers, and government organizations, thus creating strong connections between our department (and university) and industry. Throughout the semester students develop mathematical models based on real data and realistic assumptions, so they experience first hand the applicability of mathematics in society.

Since the first course offering in Spring 2006, we have worked with a wide array of businesses and research centers. Some of the course collaborators have been:

- University of Nebraska Medical Center in Omaha – on a project identifying risk factors in heart disease;
- Nebraska Department of Natural Recources – to analyze water levels in the largest lake in Nebraska, Lake McCounaghy, during a seven year drought;
- The Schemmer Associates (Lincoln) – who provided data and guidance for a project related to traffic in the city;
- Lancaster County Assessor (Lincoln) – for a statistical analysis of the housing market during the national housing bubble;
- The Architectural Partnership (Lincoln) – to evaluate costs vs. benefits in sustainable design;

- The City of Lincoln Recycling, Recycling Enterprises, and Von Busch and Sons – to find optimal routes for the recycling trucks;
- The City of Lincoln Finance Department – to perform an analysis of the city's financial activities.

The following project description (from Fall 2008) exemplifies the type and scope of work done in the course; more information on each of the projects can be found at [9].

Sustainable design. Three groups of students analyzed costs vs. savings in sustainable design at two LEED certified buildings: the Nature Center at Pioneers Park in Lincoln, NE, and the Prairie Hill Learning Center in Roca, NE. These buildings feature green energy and water saving features such as: strawbale walls, geothermal HVAC system, a wind turbine, solar panels, energy efficient windows and appliances, low VOC emitting paints, cool metal roofs, low flush toilets, sink aerators etc. One group of students focused on the impact that these buildings have on the environment by optimizing costs while minimizing emission of carbon dioxide and other pollutants. All three projects used linear programming as the main mathematical tool. In each project, students set up cost savings functions which included as variables the items or the units corresponding to a green feature, and the coefficients were taken to be the savings generated by the particular green feature per unit over a fixed period of time. The students looked at the best green features in which to invest so that the total premium cost paid by the builder would be less than a given amount. For longer periods of time (30 years or more) students also incorporated financial factors such as inflation, increases in energy and water prices, and rate of return for the money, and then analyzed the model under different scenarios for these factors.

Over the years the students presented their results obtained at two well attended, yearly events - the University of Nebraska-Lincoln Undergraduate Research Fair and the Nebraska Research Expo, a conference organized in collaboration with local businesses from Nebraska. The students' work has been applauded by professors in different disciplines as well as business representatives.

The course was very well received by the local businesses with which we worked; in fact, there have been more businesses interested in working with this program than has been possible to accommodate. As a classroom instructor in academia it has also been very rewarding to know that two students found jobs after completing the course as a result of their work in this class. One of the students received an internship followed by a job offer from the collaborating institution. A second student used the Math in the City experience to apply for a job that did similar type of analysis as the one done during the course; the company hired her after hearing about the work that she had done in Math in the City.

Math in the City is designed as an interdisciplinary program that allows students to see how mathematics is used outside academia, thus illustrating the importance of studying mathematics in college. Indeed, as it is pointed out in [2] (which cites [4]) failure to establish relevance is one of the worst ten mistakes in teaching, since "students learn best when they clearly perceive the relevance of course content to their interests and career goals. The "trust me" approach to education ... doesn't inspire students with a burning desire to learn, and those who do learn tend to be motivated only by grades." A growing body of academic research supports the use of project-based learning in schools with technology employed in a meaningful way as a mechanism to engage students, cut absenteeism, boost cooperative learning skills, and improve test scores; using open-ended projects versus the traditional, direct instruction is far more beneficial [1, 3].

As it has become obvious to teachers of all levels, it is important to connect problems to practice and the keys to success of this process is to choose a good problem, implement it well, and verify the results. In Math in the City this three-step process is done in collaboration with our business consultants. It is important to recognize that, in the learning process that takes place, students need to make conjectures, justify them, and check their validity. This is more important than "knowing" the answer because of the thinking process in which they are involved. Math in the City is a hands-on learning experience that makes the transition from the traditional lecturing style and from the

"procedure ...procedure ...procedure ..." teaching approach to effective and efficient teaching in which the students are actively involved.

In Math in the City the focus is on the project and the application of the material; the mathematics is learned and *performed* in order to solve the problems. This is in contrast with a standard textbook approach in education, where the applications are often secondary and a sequel to the main material. We believe that solid mathematical education should include both; depending on student's future careers this blend may be in different proportions, but we believe that all will benefit from seeing applications first hand. Also, the course provides a bridge between the textbook information learned in other courses with real life problems of national interest.

2 Civic engagement through Math in the City

" Service-learning is a teaching strategy through which students identify, research and address real community challenges, using knowledge and skills learned in the classroom." [8]

The course offers an excellent opportunity for students (and more largely, for academia) to get connected with the community around them. Newspaper articles and TV news become real when students access the data and the information behind the news. This awareness is usually followed by the students' motivation to understand and tackle the issues that they see as most important. There are several aspects that we believe speak of the civic engagement of the course:

2.1 Connection with the community and the environment.

Students learn during the very first week of classes about the topics and goals of their projects; in fact, we invite the collaborators to give a presentation (or two) about their work and its significance during that first week. As part of the real world aspect of the course, students also visit the collaborators' workplace. When working on routing problems for the recycling companies in Fall 2010, we scheduled a visit to a recycling site, and also visited the Lincoln's landfill. It was the volume of recycled

(or discarded) material that made a lasting impression on the students, but maybe even more so, the amount of work and planning that went into these processes. Most of us did not know that a landfill site needs a team of engineers and a multi-layered process that goes into designing and maintaining a landfill site. At the end of these trips everyone was committed to the 3 Rs: Reduce, Reuse, Recycle.

2.2 Connection in space.

Student campuses are mini-universes where the new generations are formed. In these spaces, educators in all disciplines share the belief that we are all connected; we know that our students of today will be our doctors and engineers of tomorrow. We have learned that collaborating with our peers will contribute to the progress and development of the outside world. The students in a class, however, don't always experience this sense that we are all weaving the same piece. They wonder: what does my homework have to do with hers? Anyway, not until the instructor assigns us to do something together. In Math in the City students choose the project, and in this way they choose each other. I found that in this way students are involved with each other and their work at a deeper level; having a common interest is more motivating to them than choosing their teammates based on looks during that first class they have together (something that people at Match.com also figured out!). Once students have a group, they start gaining the confidence that they can do something significant together; by the end of the project [they gain] " experience working with a group on a much larger project than what could be done by an individual" (again, anonymous quote from a Math in the City student).

I believe that this connectedness is the first level of civic engagement. The projects selected from around the city were some that captured the attention of the local community, or they were the topic in a national front page article. We looked at water issues in Spring 2006 at a time when Nebraska was going through a seven year drought; we analyzed the housing market in Lincoln in Fall 2006 when the nation was identi-

fying a housing bubble; when the "going green" and sustainable design movements started to gain traction in Nebraska we looked at sustainable design (projects of Fall 2008); recycling was the theme when the city started considering a city service for its residents. For these large projects students had to identify the issues that mattered, the data that was needed, the analysis that would be useful to the collaborator. During Fall 2011 students worked with the City of Lincoln County Assessor to learn about the city's financial situation. As we designed the course we expected students to look at interest rates and prioritizing expenses, but one group of students chose to look at the efficiency of police stations. When asked why they decided this, they gave several reasons that exemplified their clear understanding of the data, showed the preliminary research they did (quite a large undertaking in itself), and the feeling of ownership for their project. First, they noticed that this was the largest expense of the city (it took more than half of the budget); second, they took a look at the police stations and they were a little surprised at their locations throughout the city. They investigated the efficiency of these locations and the possibility of adding a fourth location based not only on financial reasons, but also considering safety aspects for citizens. It was a proud moment for us instructors to see how far students can go without any instructor guidance: they contacted over a dozen police stations around the country to assess the efficiency vs. staffing of police stations in cities of similar sizes; they made contact with a local police representative and set up meetings to discuss these issues (they followed up with her throughout the semester). When I first designed this course, I never dreamed that students would have this level of initiative to carry out a project.

Throughout these projects, students learned to use their communication skills to solve community problems. They learned that in order to approach a large scale problem they need to be involved and communicate not only with their peers, but also with instructors, business collaborators, and as we mentioned they often find resources outside their immediate community. This continuous exchange of information between the students, the business and the community ultimately ben-

efits all parties.

2.3 Connection in time.

There is also a connection of our students through time. First we identify this connection as students of a past project will inform future students' work through their results, analysis, so further investigations (or different ones) could be carried out. There is a difference between a former student saying: plan ahead and an instructor advising the same thing. Students' perception of an instructor may be altered by the anxiety that comes with someone that assigns grades, so we are incorporating more ways in which students can learn from past experiences of students from previous years. We are currently working on a student handbook that will be handed out to students at the beginning of a semester. This handbook will contain information on how to best plan and divide the work, how to deal with challenges, and how to have the best performance in the course. The best section, however, may be the one containing advice from previous students. These are some of the comments that we have received so far which clearly show the variety of things that students took from the course:

- " Set goals and map out all of your work for this course as much as possible because if you don't do this the work will creep up on you quickly and it will be easy to get overwhelmed."
- " Especially in the beginning it might be nice to set up a weekly sort of meeting for your group outside of class even just for 30 minutes so that you all can touch base and regroup. It is easy to all get going in different directions and it really helps to have a time where you can all get back on the same page, focus, decide what remains to be done in the project and figure out how you are going to accomplish it as a group. "
- " Start early and add to the report little by little so when it comes time to the making the final report you have a good start."
- " Leaving yourself enough time to prepare for writing your report presentations is crucial."

- " Make sure you have time to meet outside of class and start doing so as soon as possible. The project is going to take you much more time than you think it will. Also, don't give in when you want a question answered. If your group doesn't want to answer it together it is okay for you to work and answer it on your own and then work to add that to the project as well. You won't always get along and many times you will have different ideas, but it's the work that matters."

2.4 Deep Learning and Big Dreaming

An important facet of Math in the City is that it promotes deep learning, essential in forming the minds, work skills and attitudes of tomorrow's citizens. Thus, an undergraduate degree should be conferred to a student confident in her abilities, so that the importance is not placed on "knowing everything", but knowing the important ideas and how to go about building on those skills and ideas.

" [Faculty] must teach for deep learning, realizing that no one can go deep in all areas of content. It is important, therefore, to identify what Wiggins and McTighe (2005) call enduring understanding, those key aspects of a discipline that students MUST learn in order to succeed in the next course or, more importantly, in the profession or as citizens. Deep learning not surface learning is thus essential for mastering key concepts and skills in virtually all disciplines." [10]

What students learn in the classroom today is what they will build tomorrow. More importantly, what they dream today is what they will raise tomorrow. If we do not allow students to dream, to practice in the classroom, how much risk will they take when they leave the classroom, enter the workforce and have to be accountable for every decision they make? There is not much room for error afterwards and not learning to trust their instincts and follow their dreams will be a failure for the education we provided. The safety net provided by the classroom, teachers, and peers alike will not exist after graduation. There will be orders to fill, plans to execute, and often that may happen with little assistance

from supervisors or colleagues. Students experiencing group work on a real project in college will learn two things: the importance of building a network of experts and colleagues that you can rely on; and, it is all right to dream and to make (some) errors along the way. For those of us believing that every challenge is an opportunity for growth, this will be a natural follow-up thought. There is a wonderful freedom that comes with the acceptance that mistakes are part of the process; Yo-Yo Ma said that " your attitude has to be, "I welcome that first mistake because now I'm free" " (read the story behind this quote at [7]).

3 Impact of Math in the City

We measure course success through the impact that it has on students, who recognize the challenges that the course brings, as well as its benefits. These are some end-of-semester comments that they had (collected anonymously by the Bureau of Sociological Research at UNL):

- " Have fun and enjoy the experience because although at times the course may seem stressful or like a lot, in the end it really pays off and is a great experience and something totally different from anything you've ever done in a course before. Being able to get up there and present at the workshop and feel confident in your results and your project is the best feeling ever."
- " How to value different raw data is one of the most important skills I learned. I also gained some skills to pick and choose goals that are reachable from goals that cannot be finished. "
- " No specific answer to the problems. Instead of like a normal textbook, you just open up the back to see if you got it right, in this course you have to decide if you think it is right or not. "
- " It made you think. A lot. "
- " This is one of the most challenging and most rewarding classes I've ever taken. I plan on taking it again next year if possible."

3.1 Benefits to the students

We summarize here some of the educational and personal benefits that the program brings to the students. From the beginning, the course was designed so that it enables students to translate a complex real-life situation into a mathematical model. Throughout the semester students develop better communication skills in writing and for oral presentations through many ways: they write weekly in their journals, they turn in memos to give updates on their work, they give slide and poster presentations at the end of the semester, and of course, they turn in a manuscript containing their results and analysis, in a format that resembles an honors thesis. These written manuscripts are first turned in as drafts for which students receive feedback from the instructors, after which they turn in their final write-ups that will be graded. Guidelines for grading for each course offering are available on the program's website at [9].

For every course offering, students worked with some mathematical software, so they learned SPSS, Maple, Sage, as well as typesetting software such as LyX and LaTeX. A key aspect remains the exposure to workplaces outside academia (they can show off and improve their "employable skills"). On the personal level students learn how to deal with setbacks, how to manage their time so they can meet deadlines. They learn how to work in groups, and learn to take initiative as instructors have often witnessed it. The entire experience leads to increased self-confidence and sense of achievement – a great way to start preparing for the job market. When the average time an employer spends on a resume is about six seconds [6], an experience such as Math in the City will make the student's application stand out and increase her chances of being hired.

3.2 Other benefits

The instructors of this class have all noticed how their perspective on teaching has changed by the end of the semester; this class showed them how applying hands-on learning methods increases students' involvement, so they started applying the same techniques in other courses

they teach. Personally, after seeing the benefits of writing and oral presentations, I started assigning more essays, in lower level classes, such as Differential Equations, as well as in advanced graduate courses. I can think of a few ways to increase a graduate student's employability, but probably none is faster done than asking students to give oral presentations and training them to showcase their work. A graduate student in the department spent a good portion of her successful job interview talking about Math in the City, sparking interest from the hiring institution.

Finally, but not of least importance, we mention the benefits that the course brings to the sponsor. Our collaborators have found that the course is a great avenue to advertise to the public some of their programs. Since the students often end up giving presentations on their work, a potentially large number of people find out information about these activities (for example recycling, sustainable design, city's efforts to maintain financial stability). Students often found ways to improve or optimize the activities of the business collaborator; they found better ways for the routing of recycling trucks, they studied and made suggestions to improve the efficiency of the police stations, they formed models to predict water levels in Lake McCounaghy given weather and precipitation conditions.

The course is all in all a win-win-win situation for students, instructors, and collaborators.

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BIOGRAPHICAL SKETCHES

Petronela Radu received her PhD from Carnegie Mellon University, Pittsburgh, PA in 2004. She is now an Associate Professor in the Department of Mathematics at University of Nebraska Lincoln, where she is conducting research in applied mathematics and engaging students in solving problems with applications in the real world.