involve
a journal of mathematics

Experiences of working with undergraduate students on research during an academic year

Jobby Jacob

msp

2014 vol. 7, no. 3

INVOLVE 7:3 (2014)
dx.doi.org/10.2140/involve.2014.7.363

Experiences of working with undergraduate students on research during an academic year

Jobby Jacob

(Communicated by Darren A. Narayan)

Over the last three years, I have worked with four undergraduate students on research during the academic year in addition to mentoring undergraduate students at the REU at Rochester Institute of Technology. All four of these students had taken proof-based classes with me. These students had a high level of mathematical maturity with excellent motivation and work ethic. In this paper, I share my experiences working with them during the academic year and share my principles in mentoring undergraduate students.

1. Introduction

I joined the School of Mathematical Sciences at the Rochester Institute of Technology as an Assistant Professor in Fall 2009, after finishing my PhD from Clemson University. At Clemson, I was fortunate to serve as a graduate student mentor for three undergraduate students participating in the Clemson REU. As an undergraduate, I never had an opportunity to experience undergraduate research. I enjoyed the experience of mentoring undergraduate students at the Clemson REU, and decided that as a faculty member I wanted to work with undergraduate students in research as well.

My area of research is graph theory, and in particular, graph labeling. I was assigned to teach proof-based courses (discrete mathematics and graph theory) at the Rochester Institute of Technology (RIT) during my first three years. All four of my students — Ryan Held, Samuel Kennedy, Christopher Wood and Shamalie Peiris — were in these classes. These students had a high level of mathematical maturity with excellent motivation and work ethic. From our work, we were able to submit and publish multiple manuscripts in refereed journals. Currently, two of these students are applying to graduate school, one of them is working in industry, and the other student is looking for a job in industry.

MSC2010: primary 97-02, 00A99, 97C99, 97A99; secondary 97K30.
Keywords: undergraduate research, student mentoring, $L(2, 1)$ coloring, ranking.

In this paper, I share my experiences working with these students during the academic year. I describe how I met these students, the problems I selected for them, and the principles I used while mentoring them in research.

2. Finding students and selecting problems

I mentored four undergraduate students in research over the last three years during the school year. I met all these students in my classes. Some of them approached me looking for a faculty to work with them in research, while others I approached to work with me. All four of these students took at least one proof-based course, like discrete mathematics or graph theory, from me. One of the main advantages of finding students from classes you have taught is that you get a first hand sense of their mathematical maturity and work ethic.

My first student was Ryan Held who was in my discrete mathematics course. He approached me to ask if I can help him to find a research opportunity for that summer. While I was not able to find him an opportunity for that summer, I asked him if he would like to work with me during the next academic year. Ryan worked with me for two years, and we were able to publish two papers in peer-reviewed journals as coauthors [Held and Jacob 2011; 2012].

I had Sam Kennedy in my graph theory class during Spring 2011, and he applied to participate in the RIT REU in the summer of 2011. We accepted Sam into our REU program without hesitation knowing that this could lead to successful collaboration beyond that summer. I mentored Sam and another student during the REU. After the REU, I asked Sam if he would like to continue working on the problem with me during the academic year, and he is still working with me on research. We submitted our results [Dobosh et al. 2013] to a refereed journal.

Chris Wood was in my graph theory class in the fall of 2011. He approached me toward the end of the quarter to ask me if I could offer advanced graph theory as an independent course. He was not a math major; however, he had a good appetite for mathematics. I agreed, but, suggested that he register for undergraduate research instead of independent study, because I knew he was capable of doing research. He was thrilled that I made the suggestion, and worked with me for a year on research. We submitted two papers for publication in peer-reviewed journals [Wood and Jacob 2013a; 2013b].

The fourth student, Shamalie Peiris, was in my graph theory class in Spring 2012. She did extremely well in class, and her attention to detail was extraordinary. I asked her if she was working on research with anyone, and when she said that she was not, I offered to mentor her in research. She was very interested, and we started working on a problem in the fall of 2012 and made significant progress.

To each of the students, I gave different problems, even though there was some overlap. I was not convinced that working on the same problems with them in a group would be a good idea, and I am glad that I did not give them the same problem. This way, they made significant progress on the problem I gave them. In general, I did not give them a set of problems to work on, but rather had them each focus on a single problem. To each one, I presented the problem and gave a simple question or two to look at, and asked them to come back the following week with their results. I also reminded them that if they found the problem uninteresting or too hard, then we would change the problem. However, I stayed away from giving them a choice of problems in the beginning.

The problems I gave them were in graph labelings, my area of research. I asked Ryan to look at the irreducible no-hole $L(2, 1)$ coloring of some graphs. He was thrilled about the problem, and he generalized his ideas to $L(h, k)$ labeling. Sam continued his problem from the REU — to find the rank number of some classes of graphs. He was able to find rank numbers of many classes of graphs that are Cartesian products of some graph with a complete graph.

Chris was not a math major; he was a computer science and software engineering major. While he was very good at proofs, I figured problems that involve computational components might suit him better. I asked him to study a 20-year-old conjecture on the $L(2, 1)$ span of trees, suggesting that he consider the conjecture from a computational angle. He "ran with it" using a program called Nauty to generate large numbers of trees, and combed through those trees using the subroutines he developed. While I was confident that he would have been successful with a problem that did not involve a lot of programming, this problem suited him well as we were able to use his programming experience as an asset.

Shamalie started working on a ranking problem. She was able to come up with solutions to the questions I asked her. However, the next level of problems I gave her was a little too hard. She tried hard, and looked at solving the problem from different angles, but we were not able to make progress and were running out of ideas. So I decided to change the problem to finding a parameter called the *azero-forcing number* of some graphs. She is making good progress on the problem. I was able to change the problem at the right time and keep her interest in research.

3. Working with the students during the school year

Typically, I meet with the students once a week to discuss their progress and suggest some ideas. As a graduate student, I served as a mentor for three undergraduate students during the Clemson University REU. One lesson I learned there was that it is better, if possible, to let the students identify issues through their own efforts rather than tell them how to proceed. That approach has worked well for me so far.

When I meet with my students, I ask them about their progress. Usually each of the students has made progress on the problem, and has ideas on how to proceed. There are times when I feel that their ideas are not going to be successful; however, I almost never tell them that. For me, this approach has many advantages. One is that the students come to see the issues themselves, and understand the shortcomings of a given approach much better than if I point them out. I feel that it is part of the research process to get stuck on ideas, and to go back to the drawing board, and I constantly remind them that this is part of the process. The added advantage of this approach is that when I am wrong about their ideas not working out, I don't have to eat my words. However, if it turns out that I am wrong in the beginning about their ideas not working out, then once they succeed, I tell them that I was not convinced in the beginning about their ideas. This approach allows me to convey to the students that just because I am a faculty member, I am not always right about which ideas will work out. The best way to find that out is to run with the ideas.

One of the challenges I face, at least in the beginning, is making sure that the students understand the difference between doing research and doing coursework. I convince them that the main difference is that the problems I give them for research might not be solvable, and that I certainly do not have solutions to them. I tell them that just like them, I am working on this and don't know how to solve the problems. So they know that when I make a suggestion, that does not mean that it would work out. One piece of great advice I received as a graduate student is that research is about making baby steps. Very rarely does someone take a giant step in research. I make sure to tell my students this, especially when they think that they are not making progress. I remind them about the progress they made since they started working on the problem, and usually that makes them feel better, and rightly so.

I meet with these four students separately, usually in my office. However, sometimes we meet in a different room with larger white board space. For example, Chris likes to talk about his research by explaining on the white board, so when I meet with him I usually meet in a room with plenty such space. The duration of meeting times varies: it can be anywhere from 15 minutes to 2 hours. Meetings with Chris, for example, tend to take an hour, but have occasionally gone to two hours or more. During the meetings, the students explain their progress on the problem. If they are looking for ideas on how to proceed then I may give them a couple of suggestions. I usually remind them that these ideas may not work. Also, to make them feel comfortable, I usually ask them a few questions about their interests and classes.

Apart from working on the problems, there are two rules I ask them to follow. If, for any reason, they have to cancel a meeting, then they should send me an email message so that I know about it. The other one is that they should write down or type up their research every week, even if the proofs or results are not correct. I

encourage them to keep a research notebook, and encourage them to carry it with them as much as possible. I strongly suggest to them that they work on research in the notebook, so that they have a record of all the work. I am happy to say that these four students have exceeded my expectations in every way.

4. Conclusion

I enjoy working with undergraduate students in research. The students I worked with were motivated and had a good work ethic. Even though most of these students approached me to do research, in some sense I was able to select them from my classes and knew about their mathematical maturity and work ethic before I started working with them. We were able to submit and publish multiple manuscripts as coauthors. These students told me that these experiences were helpful to them, and, more importantly, that they enjoyed them too.

As an undergraduate student, I did not have any opportunity to do research, and in fact, I did not even know about research until I was a graduate student. As a faculty member, I enjoy mentoring undergraduate students in research. These experiences undoubtedly are some of the highlights of my career so far. And as a byproduct, mentoring and publishing papers with undergraduate students are excellent line items on my resume. I am looking forward to my future years working with undergraduate students on research.

References

[Dobosh et al. 2013] K. Dobosh, S. Kennedy, and J. Jacob, "On the rank number of the Cartesian product $K_m \square K_n$", *submitted* (2013).

[Held and Jacob 2011] R. Held and J. Jacob, "On the graphs whose $L(2,1)$-span is the same as their inh $L(2,1)$-span", *Congr. Numer.* **210** (2011), 169–179. MR 2856362 Zbl 1247.05080

[Held and Jacob 2012] R. Held and J. Jacob, "On the irreducible no-hole $L(h,k)$ coloring of graphs", *Congr. Numer.* **214** (2012), 155–166. MR 3024454

[Wood and Jacob 2013a] C. Wood and J. Jacob, "Forbidden subtree construction techniques for trees under the $L(2,1)$-labeling problem", *submitted* (2013).

[Wood and Jacob 2013b] C. Wood and J. Jacob, "$L(2,1)$ span of trees of order up to 20 vertices", *submitted* (2013).

Received: 2013-01-19 Revised: 2013-10-18 Accepted: 2013-11-19

jobby.jacob@rit.edu *School of Mathematical Sciences, Rochester Institute of Technology, Rochester, NY 14623, United States*

involve

msp.org/involve

See inside back cover or msp.org/involve for submission instructions. The subscription price for 2014 is US $120/year for the electronic version, and $165/year (+$35, if shipping outside the US) for print and electronic. Subscriptions, requests for back issues from the last three years and changes of subscribers address should be sent to MSP.

Involve (ISSN 1944-4184 electronic, 1944-4176 printed) at Mathematical Sciences Publishers, 798 Evans Hall #3840, c/o University of California, Berkeley, CA 94720-3840, is published continuously online. Periodical rate postage paid at Berkeley, CA 94704, and additional mailing offices.

Involve peer review and production are managed by EditFLOW® from Mathematical Sciences Publishers.

PUBLISHED BY

mathematical sciences publishers

nonprofit scientific publishing

http://msp.org/

involve
2014 vol. 7 no. 3