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Undergraduate research in mathematics with deaf and hard-of-hearing students: four perspectives

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Involving more deaf and hard-of-hearing students in undergraduate research is a step toward getting more such students into STEM (science, technology, engineering and mathematics) careers. Since evidence exists that undergraduate research improves retention, especially for some underrepresented groups that have low retention rates — as, for example, deaf and hard-of-hearing STEM majors — it is a particularly pertinent step to keep interested students in these career paths. Nunes and Moreno have suggested that deaf and hard-of-hearing students have the potential to pursue mathematics, but lack the resources. By involving more such individuals in undergraduate mathematics research, we can improve their success rates and promote mathematics research within the Deaf community.

Here we describe our experiences working both *with* and *as* deaf or hard-of-hearing students in research, as well as advice that stems from these experiences. Each of the authors is a faculty member at the National Technical Institute for the Deaf, a college of Rochester Institute of Technology, and holds a PhD in a scientific field. Three of the authors are deaf, and one (Jacob) is hearing. While this paper describes the experiences and opinions of individuals, and is not meant to be an all-inclusive handbook on how to do research with any deaf or hard-of-hearing student, we hope that it will be a helpful resource.

1. Introduction

Why we need deaf and hard-of-hearing undergraduates in mathematics research. Perhaps for many mathematicians, the question of why we should encourage more deaf and hard-of-hearing students to pursue mathematics is unnecessary to consider. The benefits are too obvious: first, math is great fun and good for the brain, so we should share it with everyone, and second, deaf and hard-of-hearing students have talent and perspectives that can further add to the existing body of mathematics literature.

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However, we would like to pause to describe some potential benefits. We argue that there are, in fact, especially strong arguments for involving deaf and hard-of-hearing undergraduates students in mathematics research. Certainly, an undergraduate research experience can help not only mathematics majors, but also other STEM majors in their future careers, both by simply appearing on the student's resume, and also by developing the student's research skills. In addition, there is evidence that for some underrepresented groups, undergraduate research experiences actually reduce attrition [UROP 2012] and increase the likelihood of students in those groups pursuing graduate school [Hathaway et al. 2002].

While there are examples of highly successful deaf and hard-of-hearing individuals in STEM fields, there are few deaf and hard-of-hearing mathematicians, leaving deaf and hard-of-hearing students few role models and potential mentors. Deaf students, starting in secondary school, are steered towards vocational or applied fields due to the belief that they cannot succeed in more rigorous, abstract fields. By including deaf and hard-of-hearing students in research, we will not only promote the individuals' careers, but also potentially influence the Deaf community by increasing awareness that mathematics research is an option, and that there are deaf and hard-of-hearing mathematicians out there. In the future, there will hopefully be deaf and hard-of-hearing mathematicians in all areas of mathematics, available to serve as mentors and role models to deaf and hard-of-hearing students who seek them; however, at this point there are few deaf and hard-of-hearing mathematicians, meaning that hearing mathematicians need to take on the roles of mentor and role model for deaf and hard-of-hearing students, to the best of our abilities.

For two of the deaf authors of this paper, a central reason that the authors ended up in academic research careers is because of hearing researchers who sought them out. Often, areas of research that are related to hearing loss, deafness, or accessibility for deaf people attract deaf and hard-of-hearing researchers, in part because researchers in these fields think to look for deaf and hard-of-hearing talent. As mathematicians, we should be motivated to look for deaf and hard-of-hearing talent as well.

Finally, we believe that deaf and hard-of-hearing students will be more likely to participate in mathematics research if they understand the benefits. The second author, who currently does mathematics research with undergraduate students, has found that curiosity draws many students to mathematics, but it is also a good idea to express to students how mathematics research can positively impact their future. Particularly for deaf and hard-of-hearing students in computer-related majors, of which there are many at RIT, mathematics research can be attractive to future employers and graduate school admissions. Depending on a faculty member's research interest and a student's major and career goals, explicitly describing the potential benefits of the research problem to the student's career may be a good move.

Description of this paper. In this paper, our goal is first to encourage faculty to pursue research with deaf and hard-of-hearing students, and second, to give some general advice for each part of the research process, including selecting students, in-person as well as written communication, supporting students at conferences, and potential pitfalls. To illustrate our suggestions, we include our own experiences, both from our own student research experiences and our experiences in leading student research.

A recurring theme in this paper is the fact that deaf and hard-of-hearing students are individuals. While we attempt to give helpful advice, each student is different. Faculty members will encounter deaf and hard-of-hearing students who are exceptions to each generalization we describe here, and to whom none of this advice applies. It is essential to keep this idea in mind when reading this paper and interacting with students. We hope, however, that we can provide some general advice to get started and to allow faculty to build a better working relationship between themselves and their deaf and hard-of-hearing students.

Three of the authors in this paper are deaf or hard-of-hearing faculty in scientific fields, while one, Bonnie Jacob, is a hearing mathematics faculty. We write the paper as a group, but in sections where one of us describes his or her personal experience, we will use the author's name along with italics to indicate that these are the words of one specific author.

2. Before research: recruiting your student and finding problems

Bonnie: *When we look for students for mathematics research, one important consideration is whether the student has the background to understand the question and to make any progress. As I've sought students to work on problems, however, I've realized that there is a great deal of talent at a lower course level than I would ordinarily look. While I recruited one rare deaf mathematics major who had already had some advanced courses such as abstract algebra, I now keep my eyes open for students who have had as little as a semester in elementary calculus or a single course in discrete mathematics. My current pair of students are just that: one has had two quarters of nontheoretical discrete mathematics, while the other has had two quarters of basic calculus.*

The reason that I started considering students with less course preparation than I would normally consider is simple: numbers. There are very few deaf and hard-of-hearing students taking upper-level mathematics courses, even here at NTID/RIT. However, quickly it became apparent that this approach has an added benefit: there is a great deal of undiscovered talent, I believe, in the beginning stages of college mathematics. I like to think of many of the students I encounter as "diamonds in the rough."

Many deaf students have not had the exposure to the possibility of going far in mathematics. First, deaf and hard-of-hearing students are often steered toward more applied rather than theoretical fields, under the often mistaken assumption that they do not have the aptitude to succeed in theoretical fields, and that these majors will not lead to viable careers for deaf students. This means that students with potential to look at more abstract problems have been kept in more applied, lower-level courses. Second, the Deaf community is a cultural group, whose members share values and exchange information. Since there are currently relatively few mathematicians who are also members of the Deaf community, there is a lack of influence from this perspective as well.

Bonnie: *When I consider whether a student would be a good fit for doing mathematics research with me, I look at a few factors. First, at this point I only consider students who have had at least one course in calculus or discrete mathematics, and who have done well in these courses. I also look at their basic mathematics skills such as manipulation of fractions and algebraic expressions. Many mathematics faculty may consider these abilities a given in their students, but when I'm picking students from a lower course level, I need to consider whether the student has these basic skills or not. The student also needs to be responsible, with a good work ethic: I will not consider a student who breaks appointments or shows up late. A strong sense of mathematical curiosity is essential: even among students with a good work ethic, some students are interested in simply getting a good grade, while others show interest in the problems. I look for students with evidence of being in the latter group. Finally, while this last criterion is somewhat intangible, I look for students who will work well in a group. Normally, students I have met with the other necessary characteristics satisfy this one as well, but I need to make sure that the student will make the meetings pleasant for everyone.*

My list of criteria for students is, of course, tied in with my research interests. One area I work on is graph theory. While it is not my main area of research, I enjoy it, and I find that it works well for students in a variety of levels. Students with less background can understand a problem if I choose it carefully; students with computer skills can write programs related to our problems; students with more background can often work on aspects of the problem that may be inaccessible to other students. When I worked with a mathematics major, however, we worked on a totally different problem. I had worked with Tyler Swob on material from an abstract algebra course, and found that, while abstract algebra is not his favorite topic, Tyler showed a high level of responsibility, motivation, and mathematical curiosity. I decided to seize the opportunity to work with Tyler, since deaf mathematics majors are uncommon, even at RIT. For Tyler, I chose a completely different sort of problem:

applications of wavelets to finance, because finance is a particular interest of Tyler's.

Since Tyler is a rare deaf mathematics major, with a tremendous number of interests, talents and activities, I hesitated to ask him about research, because I assumed he would already be doing research if he was interested. This was another learning moment for me: on a whim, I finally just asked, and Tyler jumped at the chance. No one had ever asked him to do research. In fact, he had approached one professor, but the faculty member could not work with him at the time, so Tyler stopped looking for a research mentor. The lesson here, I believe, is to be willing to jump in and ask any student you think would be a good fit to do research with you. Now, I do, and I'm surprised by how many students are interested.

The experience with Tyler was quite positive, I believe both for him and for myself as well. However, it was not sustainable: I could not wait for deaf or hard-of-hearing math majors to come along, select those who were a good fit, and design an entirely new project for each one. When I realized this, I changed my approach, and started looking at my pool of students who were taking discrete mathematics or calculus. If I find students who are a good fit, I approach them either by email or in person. Some do not respond at all, or are not interested. However, three of my students did respond positively.

While working with deaf and hard-of-hearing students on mathematics research can be a great experience, and we encourage mathematics faculty to just jump in, it is essential that you recruit students that you can believe in.

Henry: *In my case, there was Mrs. Lois Holland, my fourth grade teacher at the Lexington School for the Deaf, who believed that I would succeed in mainstreaming from that school to the New York public school system, in spite of the fact that everyone else at the school believed I would fail. There was Dr. Daniel Albert, an ophthalmologist who believed in me and hired me as a research technician at the Massachusetts Eye and Ear Infirmary. Then there was Dr. James Saunders, who was my PhD advisor at the University of Pennsylvania (UPenn).*

If we pick deaf students who are not a good fit for a research group or the project itself, we could be hurting more than we help.

Kim: *Often, deaf people feel like they are "tokens" in research projects — they need to feel like they are respected for their academic work.*

Therefore, while we should think outside the box and seek out students who may not have the course background we would normally expect, we need to limit our search to students who have the potential to succeed at research. A group from the City University of New York that involved high school and undergraduate deaf students in research describes multiple resources that they had that led to

their successful collaboration, but mentions that research among deaf and hearing individuals can be successful without all of these resources, if certain important characteristics are present [Huenerfauth 2010]. Specifically, they describe, "The key elements that we feel are the most important are that the students feel they are making a real contribution to the project and that they feel that they have full access to the communication environment of the laboratory." We discuss communication in Section 3.

3. Doing research together

Just jump in. Bonnie: *I've been pleased by how well students have done once we start working. With Tyler Swob, the mathematics major, I spent a great deal of time planning the project, and preparing materials. This was primarily because we worked on the problem as more of an independent study than straight research, but also because the problem was from outside of my area. As the quarter progressed, I adjusted content as necessary, and we developed the project together, which involved a good deal of Matlab programming.*

I asked Katherine Fetcie to do research together after working with her on content from her second quarter of calculus. A sustainability major, Katherine is very pleasant to work with and highly motivated, always showing up prepared to work together. I soon noticed that she solved problems from her course quickly and easily, and is adept at seeing patterns. While Katherine and I tended to talk in English, she also showed an enthusiasm for learning American Sign Language (ASL), which is another important characteristic I look for in my students: a desire to communicate better with their peers. Katherine and I started working together one-on-one in the fall. The graph theory project I initially chose was a concept I thought was completely new, but turned out to be explored in the literature. Katherine managed to find some early results, but because much of the groundwork had already been done on the problem, I switched problems when we began work again in the winter quarter, this time with an additional student.

Daniel Saavedra is an information technology major who showed a strong work ethic and ability to grasp mathematical concepts when we worked on material from his discrete mathematics course. I asked him to join Katherine and me. While I would have liked the students to work individually, and had some concerns about disrupting the balance Katherine and I had, I chose to pair Daniel and Katherine together for a few reasons. First, I had no time specifically in my schedule to work with students on research, so managing two different problems and two different meetings each week would be more than I could reasonably manage. Also, both students are pleasant to work with, and I felt could benefit from each other's presence. Further, communication is smooth, because Katherine speaks English

and has worked at her ASL; Daniel is strong at both. I have also observed both students making concerted efforts to communicate with peers who have different communication styles.

With both Katherine and Daniel, I gave a very basic introduction to the problem, which is related to zero forcing in graphs. I only define what is absolutely necessary, and then start asking them questions. This has been reasonably successful. However, around the same time I recruited Daniel and Katherine, I found another student who showed strong potential for research, and asked him if he would like to try a problem. We met only once before the student quit. The problem I showed to this student is also related to zero forcing, but in my preparation to talk with the student, I was not careful in figuring out how to succinctly describe some basic ideas. I suspect that the student struggled to understand the problem, which led to him not wanting to return. While I regret this, it was a good learning experience because it helped me better prepare for explaining zero forcing to Katherine and Daniel. I've learned that with students who have less mathematics background, providing the least information possible in the simplest manner possible is key.

To be successful in mentoring deaf and hard-of-hearing undergraduates in research, mentors need to be ready to take a risk and jump in, but setting up clear expectations with the student from the beginning is critical.

Henry: *Devastating consequences can occur if neither mentor nor student gets a good understanding of the other. For example, before arriving at UPenn, I was rejected by one medical school because the person who interviewed me wrongly thought that I only wanted to work with deaf patients. This last point emphasizes the importance of having a good understanding not only between the interviewer and interviewee but also between the mentor and his or her student, regardless of disability.*

Asking good questions. A recurring theme in this paper is that deaf and hard-of-hearing students are all different, that there is no way to generalize what any particular deaf or hard-of-hearing student's needs are. Because of this, it is important that faculty mentors are ready to ask questions. Even faculty who are deaf or hard-of-hearing themselves, or have worked extensively with deaf and hard-of-hearing students, may not know exactly what works for a particular student.

If you believe that knowing the answer to a particular question will help make research a more positive experience for the deaf or hard-of-hearing student, then by all means, ask. Of course there are rude questions, but common sense can be a good guide.

Bonnie: *One important piece of advice came from an ASL teacher, who explained to me that asking whether a deaf or hard-of-hearing person can lipread may be considered offensive. At the beginning, I respected this statement, but I didn't*

understand it. Recently, when I asked her to explain more, she pointed out that asking someone, "Do you lipread?" is a question that appraises the person who is being asked. Rather than putting the burden on the person being asked, it would be more polite to ask, "Is my communication clear to you?" or "Is my speech clear?" This puts the focus on effective communication, rather than on a deaf or hard-of-hearing person's ability or lack of ability to speech read.

It is important to realize that you will make mistakes. However, if you ask what you do not know, and keep in mind that deaf and hard-of-hearing students are experts when it comes to working with them because they experience the frustrations of working with hearing people every day, you will certainly have a better experience than if you try to make all the decisions yourself without input from the student.

Communication.

In-person communication. Specific strategies for communicating effectively in person with a deaf or hard-of-hearing student depend on the student's communication style. We present some general advice as well as advice for specific situations here.

Kim: *One recommendation I have is that there should be an interpreter present anytime a hearing faculty wants to do research with deaf students who use sign language. Taking notes is not the same. Naturally, some deaf students may struggle with their English skills. Not everyone is bilingual – some deaf students may be stronger in one language than the other language. Some may be weak in both languages and some may be strong in both languages.*

We again return to the theme that deaf and hard-of-hearing students are all individuals, that there is no one-size-fits-all approach. Some students use ASL and never use their voices, while others don't sign at all; some can do both skillfully; some students are comfortable using their voices in certain situations and not others. No matter what your student's preferred communication mode is, it is important to have a plan for communication during meetings.

Some faculty members actually jump in and take ASL courses themselves, which is a wonderful step, but it is important to remember that ASL is a full language, and it will take a lot of time and effort (undoubtedly more time than it takes your student to complete a research paper) to learn ASL. Further, even if you become skilled at ASL, it is impossible to both function effectively as an interpreter for a student and participate in the meeting at the same time. Therefore, if you are planning on working with a manual student (a deaf student who primarily signs) on mathematics research, you will probably need an interpreter. There are instances when an interpreter does not show up, or is unavailable, or an unexpected meeting happens. In those cases, often writing back and forth, or using computers or cell

phones to type back and forth, can be a temporary substitute, but this sort of communication is time-consuming, and is generally not a good long-term solution.

One-on-one meetings between a research mentor and deaf student are valuable, and a mentor's creativity and ability to express concepts visually can also be critical.

Henry: *In my opinion, the most meaningful means of support at either scholarly or professional level is not note-taking or sign language interpreting but one-to-one discussions, that is, one teacher to one student (or one employer to one employee) discussions. I do appreciate such support when it comes to discussion with my superiors, colleagues, and students. This is because it allows excellent opportunities for each to make sure that they have a good understanding of what the other is expected to learn or know, and what he or she is supposed to do. I can give a good example of such an opportunity — it came from a hearing medical student when we were working on a research project at UPenn. He used a simple visual gesture showing the relationship between the tectorial membrane and hair cell stereocilia, and this gave me a much needed comprehension of how the ear works.*

To facilitate communication no matter what mode of communication — ASL, spoken English, or something else — your student uses, meeting in a room that allows all group members to see each other clearly is a good idea. Also, incorporating as many visual examples as possible can also be beneficial, as can writing down frequently occurring specialized vocabulary or names as they turn up. The environment in these meetings is critical: no matter how good a student is at mathematics, if he cannot follow the meeting, it will be much more cumbersome for him to contribute substantially to the group.

Raja: *I loved reading while growing up so I was able to become fluent in English. Although I did not receive formal deaf-related accommodations in high school, my parents took steps to mitigate barriers. These steps included enrolling me in a small laboratory school that was attached to a teacher's college. My class cohort was small at around fifteen students, and did not change. I saw the same teachers throughout, so they were familiar, and I was able to speech read fairly well.*

For my undergraduate degree, I enrolled in a large university, and this was too abrupt a change. Although I got accommodations such as note takers and oral interpreters, I missed a lot of information and struggled. I moved to a small university with smaller classes, which immediately made a huge difference in classroom learning and inclusion. I started to learn sign language. For my masters, I enrolled at RIT and made sure to enroll in small, inclusive classes to maximize my learning and outcomes.

Written communication. Writing can be a great communication tool when a hearing faculty member is working with a deaf or hard-of-hearing student. It is essential to keep in mind, however, that for many deaf and hard-of-hearing students, English

is not a first language; additionally, deaf and hard-of-hearing students do not have the benefit of hearing it every day, in contrast to their hearing peers. Written communication such as email between faculty and students is an important part of staying in touch in research; keeping emails succinct may be the best way to ensure that communication is clear. Beyond simple email communication, however, writing is major part of the research process, and may be one of the more difficult parts for many undergraduate students.

Henry: *I have never forgotten how ruthlessly my PhD advisor, Dr. James Saunders, criticized my first lab report with lots of comments about 24 years ago. I still have my original lab report, and yet it pains me to even remember that paper, much less look at it, but it has certainly inspired me to write well.*

The aforementioned lab report brings up another lesson that is relevant to mentoring deaf and hard-of-hearing students in mathematics. Mentors must show extra patience and willingness to teach their deaf or hard-of-hearing students how to write a paper properly. This simply cannot be learned overnight. The student must learn to act as though he or she were someone else reading the paper; and must make sure that it is simple and understandable enough so that an external reader could replicate the results without much help.

Therefore, providing extensive feedback on write-ups will probably be part of the territory when preparing for publication with your student. For most hearing students, of course, this is the case as well, since most of them have not experienced writing an article for submission in a peer-reviewed journal; for deaf students, however, the difficulty may be magnified.

Naturally, this is one more area where we cannot generalize: many deaf students, regardless of which communication mode they prefer, are quite comfortable with written English, and thoroughly enjoy writing. Some deaf and hard-of-hearing students have better writing skills than have most of their hearing peers. There are many students, however, who have the ability to do mathematics research, but will require much more intensive support with regard to their writing. A possible suggestion, for faculty members who can find the time, is to work specifically on reading journal articles with the student to expose her to the kind of language used in journal articles.

Kim: *One of the most successful strategies I found was a weekly journal club hosted by my research mentor. She would pick out a peer-reviewed article, have me read it and we would meet to discuss that article. She helped me develop critique skills, that is, the ability to recognize what was good about that research project and what that research project could have done to improve the results.*

While many faculty will not be able to start a formal journal club, assigning specific, manageable amounts of reading to students on a regular basis may potentially be helpful as students prepare to write up their results.

Issues beyond communication: fully supporting your student. When working with a deaf or hard-of-hearing student, overcoming the hurdle of communication alone is not sufficient to guarantee success. There is also the issue of managing attention.

Raja: *Though academic support can go a long way in improving deaf students' graduation rates, it is not sufficient, because classroom accommodations by themselves do not equalize access to information. Deaf students have to learn to effectively "manage and shift attention" among multiple information sources (e.g., interpreter, instructor, blackboard, slides), which remains an elusive goal. When this attention is poorly managed, loss of information is likely to occur, and cognitive effort is shifted towards managing lower level attention management at the expense of higher order thinking skills* [Mayer and Moreno 1998].

The cognitive effort that is focused on managing attention rather than learning can potentially result in poorer performance in academics and results in deaf students' withdrawal. This tends to decrease the overall number of deaf students. The ability to effectively engage, disengage and shift attention is important not just for learning in the classroom, but for working in technical and scientific jobs where deaf employees are expected to participate in meetings and group projects that involve dialogues. Deaf students must compete with hearing counterparts and be able to capture as well as understand high-level information during the lecture, thereby being able to engage in cognitive activities that would otherwise be out of their reach.

Most of us pick strong students to involve in research. Strong students — hearing or deaf — have developed strategies that work for them in the classroom. If you recruit a deaf student to work together on research, the student has undoubtedly found effective strategies for managing in the classroom. These same strategies may not be as effective during research.

Raja: *I did not have any problems with my professional coursework, as the same strategies in high school, undergraduate and graduate school worked. But these strategies did not work for my doctoral studies, which had two distinct phases. The first phase, to pass core courses and comprehensive exams with the aim of showing academic knowledge breadth, was a continuation of previous education. The second phase, becoming an independent researcher, was much harder. For a long time, I was the only deaf individual in my studies and work place, and became accustomed to working on my own with less collaboration with others.*

Although it was somewhat difficult to follow group conversations and many one-to-one conversations, I learned compensating strategies that served me well, such as mini-support groups and explicitly learning unwritten codes.

While these strategies served well in the work place and courses, they did not serve well towards the goal of becoming an independent researcher. The main reason was that for the first five years I did not meet any peers or mentors in my field who were deaf or could sign. Without peers or mentors, I was unable to transition from passing my classes to becoming an independent researcher, which is a core expectation in PhD studies.

While we cannot develop strategies on behalf of students to ensure their success in research, and we also cannot — as hearing faculty — replace a network of deaf and hard-of-hearing peers or mentors, we can be aware of these potential pitfalls and do what we can to make the transition easier. For example, during a research meeting, making the environment as deaf-friendly as possible will allow the student to manage his or her attention better; also, spending time mentoring the student one-on-one, and making contact with other deaf and hard-of-hearing mathematicians, or with mathematicians who can sign may alleviate some of the isolation or frustration a student may experience. In the next section, we will discuss strategies for helping students to develop the tools they will need outside their research group meetings to grow in research.

4. Outside the research meeting

A note on deaf culture. While many people are aware of sign languages such as American Sign Language, many of us have never heard of Deaf culture. A thorough description of Deaf culture, the American Deaf community, and other topics related to the difference between "deaf" and "Deaf" are beyond the scope of this paper. We refer interested readers to [Cohen 1994; Holcomb 2012; Padden and Humphries 2006] as a starting point.

However, being aware of the existence of Deaf culture may help avoid misunderstandings during research-related interactions. For example, if a faculty member sits in his office with the door closed, and does not have any kind of uncovered window between the hallway and the office, a deaf or hard-of-hearing student may have difficulty. Even if the student knocks, he may not be able to hear whether there is an answer or not. Therefore, uncovering a window on one's office door (if such a window exists), or leaving the door open whenever a student may visit can help the student have equal access to you.

Also, if a student depends on looking at you for communication, certain seating arrangements may be uncomfortable. It is better to sit in a way that allows the student to clearly see your face. If you sit side-by-side with the student rather than

facing her, or with your back to a window that gives off a glare, the student may not be as comfortable.

The second author, as a hearing faculty member newly among deaf students, experienced culture shock in her first year working with deaf and hard-of-hearing students.

Bonnie: *At the beginning, I was surprised by students who would walk right into my office without hesitation, sometimes shutting the door behind them. One or two students even sat down in my chair on occasion, which, frankly, shocked me a bit, or hung their coats up on top of mine on the single hook on my wall. Of course, there are many students who do not do these things, but as a hearing person, I tend to notice the students whose habits differ from hearing etiquette.*

On one occasion, I was working in my office with a student who needed help on a calculus problem. He closed the door behind him when he entered, which was normal for him. However, when his friend tried to open the door to join us, the door did not open, because I have it set to automatically lock when I close it. The student sitting at the table in my office got up to let her in, but also changed my lock setting so that it would not automatically lock. I was actually somewhat alarmed at this, because if I hadn't noticed, I would have closed my door later and unknowingly failed to lock it. I asked the student to change it back, and not change my lock settings in the future. He complied quite pleasantly, and we moved on.

It is important to realize that Deaf culture differs from hearing culture in many ways. Be ready for some potential surprises, as well as flexible and understanding of ways you can benefit the student; however, if there are situations that you feel compromise your security or comfort, you should discuss your discomfort directly with the student.

Before and during conferences. Many of us attended our first mathematics conference as graduate students, and may have found the experience daunting. Undergraduates, of course, may be even less prepared, and a deaf or hard-of-hearing student often has more concerns. First, even if you normally work one-on-one with a hard-of-hearing student who seems to communicate fine with you in your office, there is a good chance that your student will require accommodations of some sort at a conference, whether captioning or an interpreter. Conferences can be noisy, a speaker may be very quiet or difficult to see, and the room layout is unpredictable. In particular, if your student is giving a talk or a poster, it is essential to plan ahead and make sure the student has the necessary tools.

In addition, for many mathematicians, the important part of the conference is the interactions we have with other mathematicians in hallways between or after talks. It would be a good idea to address your student's communication needs in these

situations as well, whether it means having an interpreter available or choosing quiet, well-lit spaces for social events.

Grundy and McGinn [2008] describe the graduate research experience of the first author, Annabelle Grundy, who is hard-of-hearing. One topic that the authors discuss is Grundy's experience at conferences, pointing out that smaller conferences provided intimate settings that allowed Grundy to get to know speakers, who would then make their talks more inclusive, but larger conferences were overwhelming. When Grundy gave her thesis defense, the group selected a room with "strong lighting, close seating, and minimal background noise," and the committee was asked to write their questions on cards in addition to asking the questions orally. Taking such relevant steps based on a student's needs will reduce the student's stress during the talk, and increase the chance that the student will give a successful presentation.

Networking and the water coolers. As with the aspect of writing, deaf and hard-of-hearing undergraduate students will gain considerably from the research experience if faculty mentors devote conscious effort to helping their students develop a support network. Many undergraduates, including hearing undergraduates, struggle with networking, but for many deaf and hard-of-hearing students, this is one hurdle that is more daunting because of the inherent communication barrier.

Kim: *One of the most successful strategies I learned, as a young researcher, was to network as much as possible. This was a critical part that I didn't realize was very important especially as a professional. My mentor introduced me to some "big names" in our field at workshops, conferences, etc. Some of those introductions led to professional working relationships with these professionals and researchers which have been maintained to this day.*

Having a network of peers and mentors will increase the chances that students will find out about relevant conferences, fellowship or scholarship opportunities, and research opportunities. Simple knowledge of these opportunities can be the difference between a successful research experience and an unsuccessful one.

Raja: *In retrospect, during my early years of doctoral studies, being the first deaf student in the program inadvertently delayed my dissertation progress. My initial dissertation environment involved working in two labs at different universities. This arrangement made it hard to obtain interpreting services outside of my institution. In addition to my own work, I had to learn the ABCs involved in networking in both biomedicine and computer science. The reduced accessibility resulted in loss of valuable information in lab meetings as well as outside, such as informal chats by the water coolers. I was unaware of doctoral fellowship grants that were available to students in underserved populations. I was also unaware of*

which conferences I would benefit from attending related to my research work. It was a blessing in disguise that the external lab's closure forced me to change advisors. My advisor explained which conferences were relevant and their unwritten expectations. I also learned how to maximize networking opportunities at these conferences. This resulted in successful conference submissions and subsequent research collaborations.

Leading the student's research is not the only way that you can ensure that a deaf or hard-of-hearing student has a chance to experience research. You may not have the time to work with a deaf student, or your research interests may not match the talents and interests of the student. In this case, it's a great idea to inform the student about different REUs, conferences, or programs that may be a good fit. Many undergraduates, hearing and deaf, are unaware of the research opportunities available for them, but a deaf mathematics major may be even less aware.

Bonnie: *In one case, I encountered a deaf mathematics major who was thinking about a summer research experience. I did not have the time or resources to do research with the student at that point, and her interests did not overlap mine. Further, since the student was an international student, she faced an additional constraint. I looked into programs that would accept international students. What struck me was that the student was surprised when I gave her a list of programs. "Why are you helping me?" she asked. It never occurred to her that a faculty member would be interested in helping her to find research opportunities.*

In many cases, students are surprised when I suggest research. Many students have no idea that these opportunities exist, or that they can get paid to participate in research.

Kim: *One day, I was working as a student development educator in the department of human development at the National Technical Institute for the Deaf (NTID); a faculty member approached me and told me about a summer internship opportunity at a research hospital. That faculty also happened to know the person who was coordinating the summer research internship program for deaf and hard-of-hearing students. What was also appealing about that summer program was that it was right in my home state! It was a great opportunity to participate in that program and at the same time, be with my family during the summer time. After I was convinced, I decided to apply to the summer internship program. A couple of months later, I learned that I had been accepted. Prior to beginning work in that summer internship program, I had no idea whether I would be interested in a research career or not.*

It is essential that we educate all deaf and hard-of-hearing mathematics students about the research opportunities that are available.

5. Further reading

We recommend resources for readers interested in particular topics that were mentioned in this article. These references represent only a starting point for further reading.

For general background information about Deaf culture, we refer readers to [Cohen 1994; Holcomb 2012; Padden and Humphries 2006]. For background about deaf and hard-of-hearing children and the learning of mathematics, see [Kritzer 2009; Lang and Pagliaro 2007; Nunes and Moreno 2002]. A reference on the education of deaf and hard-of-hearing children in general is [Marschark et al. 2001]. The articles [Lang et al. 1993] and [Marschark et al. 2008] present research into how deaf college students learn and perceptions among deaf college students and faculty, respectively. For reports on deaf students' transition from high school through employment, see [Walter 2010]. For a detailed synopsis on scientists with hearing loss from the 16th century to the early 1990s, see [Lang 1994].

A handful of articles describe involvement of deaf or hard-of-hearing students in research. [Grundy and McGinn 2008] describes a hard-of-hearing graduate student's experience; [Huenerfauth 2010] describes the experience of a group that involved deaf undergraduate and high school students in ASL animation research through the City University of New York; [MacDonald et al. 2002] describes James Madison University's undergraduate research program in chemistry, which involves deaf and hard-of-hearing students. Finally, for a description of some of the benefits that have been shown for members of underrepresented groups who do undergraduate research, see [UROP 2012; Hathaway et al. 2002].

6. Conclusion

The goal of this paper is to encourage mathematics faculty not only to seek out opportunities to work with deaf and hard-of-hearing students in research, but to become mentors for deaf and hard-of-hearing students in mathematics as well. We have presented recommendations based on our own experiences of working with deaf and hard-of-hearing undergraduates, and of being ourselves onetime deaf student researchers (as is the case with three of us).

There is, as we have mentioned, evidence to suggest that deaf and hard-of-hearing students will benefit tremendously from undergraduate research experiences in mathematics. As opportunities arise, we hope that faculty will become mentors and advocates for deaf and hard-of-hearing undergraduates in mathematics, and that the advice that we have presented here will make this process a more positive experience for students as well as faculty.

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