The Perceived vs. Actual Use of Mathematics in Medicine According to Pre-Medicine Students and Practicing Physicians

1. Introduction

This research was conducted to discover the perceived use of mathematics in the medical field according to undergraduate pre-medicine students versus the actual use of mathematics in the medical field according to practicing physicians. In particular, the researchers intended to discover the discrepancies between using mathematics in medicine and pre-medicine students' readiness to utilize mathematics in medicine. Therefore, the research question considered was: What is the actual use of mathematics in the medical field according to physicians and how does this compare with current pre-medical students' beliefs about the use of mathematics? Six current pre-medicine students and three practicing physicians were interviewed. The overall results were that physicians and pre-med students believe that mathematics is important in the field, but the physicians stated that higher-level mathematics such as calculus will be helpful for pre-med students, contrary to some pre-med students' answers. The results from this research may inform how mathematics education, particularly the requirements of mathematics courses, for future physicians can be improved.

2. Background Literature

Scientific theories and experiments are often built upon mathematical processes. Since the medical field revolves around the sciences, the intertwining of mathematics and medicine has been investigated in some particular areas. In the nursing field, Newton, Harris, Pittilgio, and Moore (2009) stated that "One of the skills most frequently used by RNs in clinical practice is mathematics" (p. 83).

Consequently, the use of mathematics within the nursing field has been largely investigated. A literature review done by Hunter, Revell, and McCurry (2013) found that there were common themes in 51 articles in nursing education that pertained to mathematics. According to the authors, there is a prevalence in the literature that students had "inadequate pre-college math preparation, inability to comprehend problem-solving approaches, test anxiety, and lack of contextual understanding" (p. 1353). Other studies question the mathematical preparation of nurses (e.g., Brown, 2006; Newton, Harris, Pittilgio, & Moore, 2009; Bagnasco, Galaverna, Aleo, Grugnetti, Rosa, & Sasso, 2016). There is also fatigue in mathematical preparedness when in the practice of nursing. Melius (2012) investigated the amount of hours nurses worked per week, their self-efficacy in mathematics, mathematics anxiety, and mathematics performance. According to the author, through statistical correlation it appeared that the more nurses worked, the greater the mathematical anxiety and the less accuracy in mathematics of dosage calculations (Melius, 2012).

Finally, there have been programs initiated to address these difficulties by pre-nursing students. The University of Massachusetts Nursing school is now using WebCT to examine if their students are at the proper level of mathematics before entering into the clinical nursing fields (Cunningham, 2001). The studies of mathematics errors in the nursing field and what causes the errors allow a better indication of how to improve nursing education in mathematics (Hodge, 1999). In particular, Hunter, Revell & McCurry (2013) stated that personal response system (PRS) technology (such as "clickers") "fosters active learning, and increases student interaction and participation" (p. 1355), and cited other articles with the same conclusion (e.g., Berry, 2009).

Though the use of mathematics in the nursing sector of the medical field differs from the use of mathematics by physicians, it is apparent that mathematics is prevalent in all aspects of medicine. Pre-medicine students are encouraged to enroll in as many upper-division science courses as their schedule allows, with the intention that they may have as much science experience as possible before entering medical school. For example, Richardson, Mulvihill, and Latz (2014) stated that there are pre-requisites and additional courses suggested for admission to medical school: "certain preparation in humanities and social sciences, in addition to 'hard science' course pre-requisites [general chemistry, organic chemistry, biology, and physics], such as introductory coursework in psychology, sociology, philosophy, or ethics" (p. 223). With that in mind, there has been research conducted about the benefits and situations of pre-medicine students in courses such as physics (e.g., Mylott, Kutschera, Dunlap, Christensen & Widenhorn, 2016) and chemistry (e.g., Barr, Matsui, Wanat & Gonzalez, 2010). However, with the lens of pre-medicine, mathematics is a subject that has had little research dedicated to it.

Nusbaum (2006) attempted to discover if a certain level of mathematics is necessary for pre-medicine students. Arguing against a calculus requirement for medical students, the author stated that there are four "core mathematical skills most important to most future physicians":

1. Basic mathematical knowledge sufficient to calculate drug doses, concentrations, and the like, similar to what one would expect nurses to master to safely care for patients and for much the same reasons

2. An understanding of the core statistical concepts most commonly represented in the medical literature

3. Knowledge of algebra to understand calculations of acid–base status and the like

4. Perhaps most fundamental is a sense of numeracy so as to be able to appreciate whether results are mathematically implausible. (Nusbaum, 2006, p. 167)

It is also noted that different specialties in the medical field require different levels of mathematics; however Nusbaum (2006) advocated that overall mathematics requirements for pre-medicine students should not focus on the specific specialties but look at the best route for future physicians in general.

Some universities understand the confusion about requirements for pre-medicine students and desire that their students receive the best education for their particular studies. Currently, Benedictine University has added a calculus lab course designed as a supplemental course for pre-medicine students. Originally, the separate bio-calculus course and labs were created so the pre-medical students, especially those majoring in biology, would have "an emphasis on the mathematics necessary to understand and model applications that occur frequently in biology" (Comar & Townsley, 2006, p. 55). However, the purpose of the course now includes ways to demonstrate the various uses of mathematics in students' futures in medicine (Comar, 2004). This additional course for pre-medicine students allows the students to truly understand why calculus is necessary to their futures. Comar and Townsley (2006) noted the success of calculus labs for pre-medicine, biology, and traditional calculus students.

The focus on biology and calculus integration has been used at other universities and textbook companies as well (e.g., Hoppensteadt, 1992; Mahaffy, 2001; Cornette, 2002; Neuhauser, 2004). Cornell University encourages their biology and pre-medicine students to enroll in not only beginning calculus but also in linear algebra and multivariable calculus: "A biologist or medical professional must be able to think mathematically (analyze graphs, interpret

quantitative information, use clear logical patterns). An early decision to get a strong mathematical background…and computer programming, will multiply a student's career options" (Math for the Biology Major or Pre-Med Student, n.d.). Though there are differences on mathematics requirements for pre-medicine students across institutions, an important faction to consider in developing those requirements is practicing physicians. This qualitative research study aims to consider physicians' perceptions on mathematics education and medicine, addressing a gap in the previous literature. The researchers take the study one step further to uncover the perceptions of pre-medicine students about mathematics education, and their (sometimes accurate) views of utility in practicing medicine.

3. Methodology

Nine participants were specifically recruited, carefully attending to diversity in gender, school level, and the physician's specialty. All of the demographic information is located in Table 1. They were recruited individually in person and by email using pre-written recruitment scripts. Six undergraduate pre-medicine (S) students and three practicing physicians (PH) were interviewed. All the pre-medicine students attended the same Midwestern research-intensive university at the time. After being recruited and agreeing to participate, the students were interviewed in person while being recorded on the researcher's iPad. The physicians, after agreeing, were interviewed via a phone call, while also being recorded.

Table 1: Demographic information of all participants

Name	Gender	Major	Level
Student 1 (S1)	Female	Chemical Engineering	Sophomore
Student 2 (S2)	Male	Biology	Junior
Student 3 (S3)	Female	Psychology	Junior
Student 4 (S4)	Male	Psychology	Junior
Student 5 (S5)	Male	Psychology	Junior
Student 6 (S6)	Female	Biology	Freshman

Name	Gender	Specialty
Physician 1 (PH1)	Female	Emergency Medicine
Physician 2 (PH2)	Male	Radiology
Physician 3 (PH3)	Female	Family Medicine- Geriatrics

The interviews were carried out with a semi-structured interview with both predetermined and impromptu questions, mostly to allow the participant to clarify their previous statements. The questions asked during the interviews are fully stated in Appendix A and Appendix B.

4. Results

4.1 Definition of Mathematics

All nine of the participants mentioned a definition of mathematics as manipulating numbers using common operations (addition, subtraction, multiplication, division); however, some students acknowledged mathematics modeling of situations. Examples of these definitions are written below:

> PH3: "Mathematics is the use of numbers to solve problems."
>
> S1: "Personally, I think it's a way of solving problems through numbers and through variables and through different processes."
>
> S4: "I'd say using numerical methods, equations, or statistical figures to either draw conclusions or analyze data."

Two physicians and four students referred to the use of "physics math," meaning physics was combined into the definition of mathematics. Almost all participants mentioned the subject "physics" at some point during their interview.

> PH2: "You have radiation physics, which is a certain part of your boards, and if you don't pass radiation physics, which had to do with a lot of calculus, and physical radiation decay formulas… you don't get board certified…"
>
> PH3: "Flow dynamics. I have a guy whose bypass grafts are shutting down and they think it's because of the flow dynamics… I think so because when I said, flow dynamics, weight bearing, those type of things are, some of those are physics more than they are simple math."

S2: “I did take Physics 2 a year ago, and that has a lot of math too. I feel like you had to really understand the theory behind it in order to be able to solve the problem, not just plug in numbers… I think [mathematics] is not just numbers, it’s more theory.”

4.2 How often mathematics is used in medical field

The physicians generally came to the same consensus about the amount of mathematics (according to their definition of mathematics) used in medicine, though the type of mathematics used varied among specialties. The students had a large range of beliefs about the use of mathematics in medicine. Half of them believed mathematics is extremely important in the medical field and the other half believed the opposite. The physicians’ answers to “How often do you use mathematics in your medical career?” and students’ answers to “How prevalent do you believe mathematics will be in the medical field?” are included below:

PH2: “I mean, on a daily basis now, not that much other than simple dose calculations, but it was absolutely, for me to be a board certified radiologist, it was crucial.”

PH3: “Probably like once every hour.”

S2: “I mean, it probably won’t be a big part of it, but I feel like enough is necessary…”

S3: “I feel like you won’t think about it all of the time, but it’s going to kind of be there every day. You’re going to use it most of the time, but you just won’t be thinking about it a whole lot.”

S4: “I wouldn’t imagine it to be too heavy of a feature.”

S5: “You definitely need to know how to use math in regards to measuring how much medicine you want to give a person, the dosage. If for surgery, in regards to an anesthesiologist, he needs to know a lot of math…. I think it’s becoming a lot more involved…”

Much like the nursing literature and some answers above, there were two physicians and two students who mentioned the importance of unit conversions in medicine. The participants that mentioned conversions believed them to be important in many aspects of medicine/science.

PH1: “If you have a 20 kilo kid and they needed 0.1 mg/kg of a certain drug, you have to do that math to come up with they need 2 kg… for drip rates… you have to know how many micro per milli and then how many micros per kilogram you want to run it at.”

S1: “[It’s] just a simple way to convert any kind of units to start from one concentration of anything and convert to a whole different value using reactions and everything in one simple math process.”

Though the students were unsure exactly how mathematics would be applied in the medical field, all students and physicians mentioned that having a “strong mathematics background” is beneficial to working in the medical field. The following are answers to “Do you believe mathematics education is important for the students entering into the Medical field?”

PH2: “I think it is. You don’t necessarily know where you’re going to go when you get to med school, so for me… it was my math background that allowed me to excel at that (Radiation Physics board exam) without even having to really

try… The people that I was with that didn't have the background struggled on that."

S1: "Math is definitely a strong foundation of my education. When I step foot in any science course, if I can establish a math foundation, it is beneficial to me."

S3: "Yes. I feel like it's essential for chemistry and biochemistry ... and so it's a huge part of the medical field. If we have to use chemistry, we have to use math."

Two of three of the physicians noted how technology is improving in the medical field and how the use of mathematics is affected. Two of the students were aware of the technological advances and conjecture how that will affect their use of mathematics in the future.

PH3: Discussing a medical phone app, and the necessity of medical students to understand mathematics, "I still think they have to understand…If someone plugs in the wrong number and says, 'Okay, Doctor, I've been giving them 225 ccs an hour to bring his sodium down 1.5 mil equivalents every 4 hours', I'm like, 'No this doesn't make sense'… so you have to understand the theory to be able to recognize, 'no you've miscalculated some number. You did not plug in the correct number somewhere.'"

S5: "I think it [mathematics] is becoming a lot more involved, especially with the advances in technology… so we can understand how it works and we can go back and do it ourselves to ensure the values the technology gives us are accurate and reliable."

4.3 Suggestions for Math Education and Pre-Medicine students

Two physicians and two students suggested more applications for mathematics and how it is used in medicine. This is motivated so that the students understand how they will use the specific mathematics techniques in their careers. The physicians thought the improvements could come through the amount of mathematics used in science courses.

> PH1: "I think if anything, I would potentially change how much mathematics you're asked to do in chemistry because… that is more consistent on what we look at. Not only are you dealing with numbers and trying to solve for a certain number, but you're dealing with the things I talked about, unit conversions."
>
> S1: "Having math courses that are more deemed towards what I'll be using them for."
>
> S5: "Make us take more advanced math classes and relate it to the medical field in some sense."

5. Discussions

The three physicians all mentioned mathematics as imperative for their careers, though the necessary mathematics mostly included basic concepts such as ratio/proportional calculations and unit conversions. They also agreed that though basic mathematics is more often used in their field than upper-division mathematics concepts, it is still important for pre-medicine students to have experience in these higher level mathematics courses, including calculus, because they cover the bases and knowledge necessary for some specialties in the medical field. Though not all specialties heavily involve calculus, the pre-medicine students do not know the particular specialty they will practice one day. For example, PH2 recognized that he did not know when his

calculus background could help, and he stated that it did with his Radiation Physics board exam. Therefore, calculus and statistics courses are suggested to be contained in the education for pre-medical students, which is different from Nusbaum's (2006) suggestion.

However, the definition of mathematics given by the physicians is different than the mathematics practiced and defined by mathematicians, which can make for confusion in discussion of mathematics education. For example, many mathematicians discuss mathematics as finding patterns and generalizing or expanding on those patterns (Devlin, 1996), which is an "action" definition, while mathematics is also used to cite "content" such as calculus (for example, someone could ask a student, "Did you do your *math* homework?"). Both the physicians and students did not mention "patterns" once, and only briefly discussed patterns as it related to dosage.

Though the basic mathematics concepts are more commonly used in the medical field, according to the physicians, the higher levels of mathematics are present and should not be ignored. There are aspects of many sciences, physics for example, where calculus and theory-based mathematics are the underlying methods. PH3 stated that she had to think about flow dynamics (a multivariable calculus topic) when analyzing bypass grafts. Calculus and theory-based courses may be important for future physicians so they have the venue to understand the theoretical concepts behind some of their practices. Through the interviews, this theme of underlying mathematics was common, yet not always recognized by the physicians and students.

The six students all acknowledged that mathematics will be present in their futures in medicine. However, none of the students were able to confidently answer how mathematics would be used in the medical field. The lack of understanding by students about the use of mathematics in medicine may be from a lack of application of mathematics directly to medicine,

perhaps little to no experience in medicine. Though mathematics is used throughout certain science courses, its application is not entirely present as well. The education for pre-medicine students may be improved by including specific examples from the medical field in the science courses required for these students. An instructor can also create open-ended projects that they can ask the students. This would allow the students to understand the purpose of their mathematics education and the importance that it plays for their futures without adding more requirements to their schedules. A suggestion similar to this was advocated for by Nusbaum (2006).

The physicians stated that there is a presence of continuously improving technology that is involved in medicine and how helpful it is towards the advancement of medical practice. Technological advances in medicine allow an increase in the speed of daily duties in a physician's life. However, they also noted a background in mathematics and its applications can be extremely vital as technology improves, since technology provides an answer, but that answer needs interpretation. For this reason, it is still important for students to know and truly understand the mathematical concepts behind the answers provided by technology in order to accurately apply the results to patients with differing needs, some that are not taken into consideration by this technology. This can also improve the accuracy of the programs they apply and improve confidence in using technology.

There was an interesting dissonance between male and female participants in the pre-med students. Though this research did not include a discussion of gender based answers, it has been noted that there is potentially a gender biased belief in the use of mathematics. It appeared that the women pursuing degrees in medicine believed mathematics is used more than the men

believed this. The gender bias in mathematics and medicine should be discovered in separate future research.

Conclusion

The researchers attempted to discover the perceived vs. actual use of undergraduate mathematics education according to pre-medicine students and practicing physicians. There has not been much previous research on mathematics and medicine in regards to student confidence and understanding of what will be expected of them upon entering the medical field. It was found that mathematics is important to the success of the medical field, regardless of the specialty. According to the physicians, it is important for students entering the medical field to understand how the mathematics is specifically applied. Though no other courses should be added to the already full pre-medicine track, more mathematics application questions/projects may be added to existing science courses. This could inspire confidence in their futures and desire to truly learn and understand the mathematics concepts that will be used. There is a general consensus that calculus is, in fact, a necessary course for pre-medicine students though calculus is not used as often as other areas of mathematics.

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Appendix A

Interview Questions Pre-Medicine Students

1. What is your definition of mathematics?
    a. Which field/course of mathematics do you believe has been most beneficial to you?
    b. How has this idea (this definition) changed with your higher education in mathematics?
2. How often do you use your mathematics education in your pre-medicine course track?
    a. Can you give me an example of this (often or not often)?
    b. In what non-math courses have you used mathematics the most?
    c. What math problem solving skills have helped you the most and how?

3. Do you believe your mathematics education is important for your future in the Medical field?
    a. Why/Why not?
    b. How prevalent do you believe mathematics is (will-be) in the Medical field?
4. What would you improve in mathematics education for pre-medicine students?
    a. Why do you believe these would be necessary improvements for pre-medicine students?
5. How does your understanding of mathematics techniques influence your approach to your other required courses?
    a. Would you further your mathematics education?
    b. Are there any techniques that are math based that you are surprised you have continued using?
6. What is “creative” in your pre-medicine courses?
    a. How does mathematics play into that?

Appendix B

Interview Questions Physicians

1. What is your definition of mathematics?
    a. Do you remember which course of mathematics do you believe has been most beneficial to you and why?
        i. If negative: is there a positive side to that?
    b. How has this definition of mathematics changed with your higher education / career?
2. How often do you use your mathematics education in your Medical career?

    a. In what ways do you use your mathematics education?
    b. What math skills have helped you the most and how?
3. Do you believe mathematics education is important for the students entering into the Medical field?
    a. Why/Why not?
    b. How prevalent do you feel mathematics is in the Medical field?
4. What would you improve in mathematics education for pre-medicine students?
    a. Why do you believe these would be necessary improvements for pre-medicine students?
5. How does your understanding of mathematics techniques influence your approach to your career?
    a. Would you have further your mathematics education if you could?
    b. Are there any techniques that are math based that you are surprised you have continued using?
6. What is “creative” in the Medical field?
    a. How does mathematics play into that?