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Title: Manifesto on Integration of Mathematical thinking into my Biology Curriculum

In investigating mathematical thinking and data literacies intersection with my curriculum I have come to realize that mathematical thinking is represented but in a disorganized and non-deliberate fashion. While it is true that I ask my students to work with data on a regular basis and I emphasize interaction with data when I consider the selection and development of my Biology curriculum. It is also true that there is no continuity in the arc of acquisition of data literacy skills and we do not dwell long enough at the moments that enrich mathematical thinking. The underlying reasons include a lack of awareness to the mathematical and data literacy skills that are already there and rigidity to sticking to my discipline, Biology, and leaving the math for math class. I also recognize that I have content and pedagogical gaps that do not allow for the richest teaching in concert the mathematical skills and the biology content in an integrated fashion. I accept the important of pulling more mathematical thinking into my classroom in order to produce a more complete picture of the biological world to my students. The work towards a more mathematically minded Biology curriculum needs a sustainable and collaborative approach. This manifesto documents the collection of principles that I will use going forward in my work.

To provide some context, my thinking in this area is evident in an activity that I have my classes do based on the Anoles lizards of the Caribbean islands (Liu, n.d). This is a web-based lab from the hhmi BioInteracitve team that is based on the research of Jonathan Loso. The biological content associated with the activity is natural selection, adaptation and related ecological concepts. The activity promotes the process of science principles in the area of experimental design, sample size, observation and inference. The activity is wonderfully presented and very interactive for the students. The activity engages students directly in taking measurements and performing calculations. The students are tasked with doing some of the statistical calculations that mirror the work of the researcher and include means, standard deviation and confidence intervals. Students represent the data by constructing a graph. The calculations in the past I have regarded as something to push through in the activity so that we can get the point of discussing how the data support that natural selection did indeed take place in the test populations.

The example above is an example of the type of experiences that I provide to my students that I want to consider on a mathematical level. The rational for pushing through the calculations is what I want to critically analyze going forward in my teaching. It is important that my approach is a change in habits of mind and in sustainable practice if the process is going to be successful. To often have I seen initiatives fail to develop into common practice because they bump into institution barriers. (Appendix A illustrates an example of this that I recently have observed in my school). To that end I have put together manifesto that is based on three themes. The purpose of the manifesto is to create a reference for the new habits of mind and practice that I can refer to as I do my curriculum work and my planning for teaching. The manifesto adds new think steps to my process that I can implement personally but also will influence the kinds of conversations I have with my colleagues. I plan to include my colleagues on this professional shift in my work and to convince them of the value of the aspects of my manifesto. Appendix B contains the manifesto organized into themes and sub points.

The first theme directly relates to my planning and selection of my curriculum, *Consider curricular items in terms of biological objectives and mathematical objectives.*This theme is best understood by returning to the lizard lab example. The lizard lab from a biological content and pedagogical perspective is a wise selection. The students regularly concluded that natural selection has occurred in this experimental setting. They can explain why it likely occurred and they do a good job with some common misconceptions, such as individuals vs. populations as the evolving unit. When I reconsider the use of this activity in the light of theme one, I see the missed opportunities of slowing down at the calculation stages. When I stop to consider my students education holistically, I can see that the lizard lab provides an important context for the students to understand the mathematical relevance of calculating standard deviations and 95% confidence intervals and provides a framework to apply this to error bars on a graph. These are exactly some of the aspects of data literacy, defined as the ability to read, work with, analyze and argue with data that can be addressed in this activity (Bhargava and D ’ignazio, n.d.). It is interesting to re-see an activity that I consider a biological pedagogical success as a mathematical pedagogical missed opportunity.

The application of manifesto theme 1 requires two actions from me in my practice. The first is a critical evaluation of what it is I do in my classes and then a thoughtful approach to what it is that I actually change. The example given in the lizard lab is low hanging fruit, the conclusion is now obvious and the curricular adjustment is easy when I accept the sub point four of the manifesto theme – *Be open to changing the activities and to adjust the time spent of various parts of the activities.*

The second theme in the manifesto, *scientific inquiry,* is a curricular value that I already try to bring to my classes. It is included here, as a part of a mathematical thinking manifesto, because of its importance in relation to not just biological leaning but also the mathematical thinking that is embedded into the scientific process. Previous work in which I looked closely at an inquiry based lab I do in my classes (see CE2) I uncovered many critical points where students needed to think mathematically in order to execute an investigation of radish seed germination. The scientific process is systematic and requires stating assumptions, planning ahead, considering how to measure dependent variables, organization of collected data, presentation of data, and analysis of outcomes. This is a meaningful process in the service of learning biology but it is also an application of universal logical processes that have their root in mathematical thinking. Theme 2 is a reiteration of an existing value but now with additional emphasis on the mathematical and data literacy components of scientific inquiry. It is, therefore, somewhat interwoven to the first theme, in that as I consider my curriculum in both biological and mathematical contexts I will try to reflect the scientific process whenever possible.

Chinn and Malhotra (2002) study the differences between the scientific work that occurs in professional scientific settings and lab work that occurs in schools. The difference between the two settings illustrates that what we call science in school settings looks very different from authentic science. Often labs are procedural and students revert more to a ‘cookbook’ style of completion of the steps as opposed to engaged understanding of why they are doing each step. This manifesto theme aims to infuse authentic scientific inquiry for the purpose of learning biology but by employing mathematical thinking.

The lizard lab from a scientific process perspective is a good choice because the experiment, as presented, is straightforward. Lizards with one set of physical characteristics are transported to islands with a different habitat. Students get a sense for control groups and controlled variables. They also can see the importance of measuring many lizards an as opposed to measuring just one. This is another way in which the activity provides the context for needing to do both careful measurement, a principle of the process of science, and doing some statistical analysis to compare the two groups, a principle of mathematical thinking and data literacy. The lizard lab for all its positive attributes does have a notable negative that relates to this manifesto theme. The lizard lab is not theirs. Students are walking in the footsteps of Jonathan Losos, who along with collaborators did much of the work on Anoles lizards in the Caribbean. I do not think this is a reason to exclude the activity, in fact there is a demystifying power in seeing what science looks like in the field, but it becomes a consideration when thinking about the collection of inquiry experiences that are offered to the students. At some point they should experience all phases of imagining, planning and carrying out an experiment.

Much of the success of the themes 1 and 2 of the manifesto are intertwined with theme 3, *teacher collaboration.*Returning to the sustainability aspect of the manifesto, if this plan is going to have meaningful impact on my teaching and my students learning I will need to apply the themes across the entire year. A shotgun approach to revamping the curriculum is a foreboding concept; this is an approach that I think would strain the institutional structures because my collaborative teams do not have the time or the collective will.   Collaboration also must extend into areas that allow for extension of my own mathematical content and pedagogical knowledge.

Riodain, Jonhston and Walshe (2016) point out the institution challenges of integrating the subjects even though at a theoretical level the benefit of merging aspects of the discipline is regarded as obvious. They point to curriculum that can improve critical thinking and problem solving skills and more real world presentation of scientific principles. The institutional barriers discussed include a perception of the “other subject” taking time away from the primary subject and a lack of teacher pedagogical content knowledge. The institutional barriers that are discussed in this article sound very familiar and exist in my school. (Consider again the events presented in Appendix A). The conceptual framework Technological Pedagogical and Content Knowledge (TPACK) brings in an additional variable of technology but is also useful for thinking about the intersection of content and pedagogy (Koehler &Mishra 2009). This concept relates to collaboration because it illustrates well that good teaching and learning occurs when teachers possess both the content knowledge and an understanding of how to convey that knowledge.

Reading about this concept sheds new light on some of my experiences in a different program at my school. The tutorial program is an academic and executive functioning support at my school. Pairs of teacher are assigned to 12 students to provided a goal setting structure and support of individual needs. This often manifests in teachers helping students in content areas that they do not teach. For example a Biology teacher, maybe me, is helping a student with their math. It can be humbling to have to relearn a math concept while trying to help a student who is having their first experience with that concept. In these moments there is a bit of content lag as my brain flashes back to remember how to factor or reflect a trapezoid over the y-axis. Relearning or remembering is the first step, providing the support to the student is the next step. Conveying how I know what I know to the student is the math pedagogy of which I am not an expert. Over the years, I have been paired with several different content area teachers and each experience has added insight into how they do what they do. These collaborations are a unintentional positive outcomes of staffing the tutorial program in the school. They create cross-disciplinary rapport and understanding between individuals in the building and this is the traction that I want to use to execute part of the third theme of this manifesto.

The TPACK model illustrates that each content domain comes along with pedagogical knowledge that is essential to successful teaching and learning. Undertaking deliberate mathematical teaching objectives in a biology class posses several questions – *what are those objectives?, how do I scaffold complex topics?, how do math classes approach big ideas like probability or statistics?*These questions provide the basis for a collaboration with a math teacher using some of the relational traction that was built-in the tutorial program. The school has a small amount collaborative time set aside weekly for teachers to use. There are some complexities in repurposing this time that will take some professional capital but they are not insurmountable. Here the application of personal relationships built in tutorial classrooms and desire to have some variety in collaboration will help over come the current routine of using our collaborative time only for discipline specific planning.

Weinberg & Mcmeeking (2017) report that math teachers in preparation for participation for implementation of an integrated math-biology module comment that a benefit of integration is to widen their scope of ways to apply the mathematics that they teach. The collaborations that I propose would seek overlapping areas in our content that could strengthen our work collectively. While I come to the table keeping in mind sub point 2 of theme one – *Biological thinking is supported by mathematical thinking and not the other way around,*I would expect my collaborator to have their specific content area at the forefront of their mind. Wienberg & Mcmeeking (2017) also provide a list of stated trade-offs that teachers consider when doing the work of integrating curriculum. The list categories include; differing content standards, level of control, fit, teacher content knowledge/skill and collaboration. This list is a good start point for addressing concerns that might arise in the collaborative process.

The manifesto is a statement that should guide the changes in habits of mind and common practice. Revisiting the themes regularly while I plan is needed to influence my habits and practice but I will also need to enlist my fellow biology teachers. I should note that several of the sub points of the themes are related to conversations that I have with my biology teacher colleagues. Pulling in authentic inquiry and modeling the scientific process whenever possible will not be hard selling points. My hope is that the math-biology teacher collaboration will serve as a way to bring new and more mathematical aspects to the biology curriculum. What will make this sustainable is that it is a shift in thinking applied to already existing structures. It does not require grant funding or large blocks of time. If the collaborative structures are maintained and I continually use the principles set forth in the manifesto, then changes and new approaches will accumulate over time and run through the grinder of the classroom. The continued process will need to include an aspect of assessing the students learning and hearing from them about their experiences. It would be interesting to see if development of mathematical skills and data literacy in the context of biology improves their ability to transfer this knowledge to new and different contexts.

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Appendix A – The Putt-Putt story

The Putt-putt project was a grant funded contextual learning project that occurred during the 2015-2016 school year at Brookline High School. The project was a part of the Massachusetts Department for Elementary and Secondary Education’s (DESE) Creativity and Innovation Initiative. In this project 9th grade art, math and science classes collaborated to design and construct a temporary 28 hole putt-putt golf course. (Further details on the project can be found at the two links below.) The project was innovative and engaging, students were certainly learning in context and applying their knowledge. The effort put in by the organizers was extensive. One curriculum coordinator explained that it was difficult to get teachers from different departments to collaborate and follow through with the plans even though all parties agreed to incorporate the project into their curriculum and they were getting paid through the grant. He also noted that in order to plan the project it required additional time outside of the school year and the typical school day hours (personal communication, November 28th 2017). When observing this project from my point of view I could see the challenges of implementation of a new large-scale initiative. It is not surprising that it has not been adopted as a regular occurring activity. The lesson that I draw from this story is that sustainable and real curricular change needs to be grounded in the day-to-day practices of teaching. To be fair my colleagues did not set out to integrate math and science teaching but instead to develop an immersive experience. Looking back it was a positive one for that 9th grade class. But, what has changed in the school in terms of math and science department collaboration? Nothing of note.

[http://www.doe.mass.edu/ccr/initiatives/CreativityBooklet2016.pdf](https://href.li/?http://www.doe.mass.edu/ccr/initiatives/CreativityBooklet2016.pdf)

[http://resources21.org/forum/creativityrubric.asp](https://href.li/?http://resources21.org/forum/creativityrubric.asp)

Appendix B– Personal Manifesto for integration of Mathematical thinking into my Biology curriculum

*Theme 1: Consider curricular items in terms of biological objectives and mathematical objectives*

* *Consider the sequence of biological learning and the sequence of mathematical thinking in the context of data literacy*
* *Biological thinking is supported by mathematical thinking and not the other way around.*
* *Seek alternatives for biology learning that does not have a mathematical component but potentially could have a mathematical component.*
* *Be open to changing the activities and to adjusting the time spent on various parts of the activities.*

*Theme 2: Scientific Inquiry*

* *Select authentic experiences that model the scientific process whenever possible. (Chinn & Malhotra 2002)*
* *Edit existing activities to incorporate components of the scientific process.*
* *Prioritize and emphasize a scientific inquiry in which students follow all the steps, from planning, to reflecting on outcomes, to proposing next steps.*
	+ *Work towards students carrying out redesigned experiments based on their previous work.*

*Theme 3: Teacher collaboration*

* *Interdepartmental collaboration will strengthen student’s experiences in my class and in math classes.*
* *Intradepartmental collaboration provides a buffer against stagnation of individual effort.*
* *In collaborations discuss trade-offs of math-science curricular integration (Weinberg & Mcmeeking 2017)*