Bringing Social Justice Topics to Differential Equations: Climate Change, Identity, and Power

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Recently, Adiredja and Andrews-Larson (2017) challenged the field to consider and recognize the political and contextual nature of teaching and learning postsecondary mathematics education including its power dynamics and social discourses. In this preliminary report, we discuss the early stages of a classroom teaching experiment to bridge research and practice by bringing social justice topics into a differential equations course. Our iterative research process consists of using theory that informs our instructional design and theory that informs our classroom analysis. Here we discuss preliminary results from the classroom analysis through Gutiérrez's (2009, 2013) four dimensions of equity. Preliminary results show that identity and power emerge from student portfolios after engaging in a climate change problem but more work is necessary in our instructional design to draw out those dimensions more explicitly.

Keywords: Differential Equations, Social Justice, Equity, Teaching Experiment

Issues of equity have come to the forefront in postsecondary mathematics education. Recently, scholars have argued that a sociopolitical perspective shift is necessary for the advancement of critical postsecondary mathematics education research (Adiredja & Andrews-Larson, 2017). Adiredja and Andrews-Larson (2017) challenge the field to consider and recognize the political and contextual nature of teaching and learning postsecondary mathematics education including its power dynamics and social discourses. Further, issues of identity and power are of critical importance in today's climate and must be considered at every level of our research (Gutiérrez, 2013). One avenue to include such topics in postsecondary mathematics education is to bring in relevant discussions through the mathematical content itself.

In this preliminary report, we discuss how undergraduate mathematics students in inquiry oriented differential equations (IODE) courses confronted the social justice and environmental topic of climate change. The ultimate goal of this work is weave research and practice through conducting a teaching experiment (Cobb, 2000; Confrey & Lachance, 2000). Namely, we aim to conduct an iterative research process by using a Realistic Mathematics Education (RME) theory that informs our instructional design and an equity theory that informs our classroom analysis (in this case, the dominant and critical dimensions of equity (Gutiérrez, 2009, 2013)). In this report, we discuss only the preliminary analysis of the first iteration of our classroom analysis through Gutiérrez's (2009) lens of the critical dimensions of equity (i.e., identity and power) as a means to inform future instructional designs. We aim to answer the research question: *How are students' identities and conceptions of power shaped and/or influenced by engaging with a differential equations task on climate change?*

Literature Review

Here, we first briefly discuss the framing of equity and how it aligns with the framing of this study. We then discuss literature related to climate science to root our students' mathematics exploration in current climate science research findings.

Framing Equity

Gutiérrez (2009) argues that equity must be framed from four dimensions: access, achievement, identity, and power. Access considers the resources that students have available to them (e.g., technology, curriculum, teachers), but often does not consider that simply giving access to a resource at a time point in a student's education does not account for the fact that this resource may never have been available to them in the past (Gutiérrez, 2009). Achievement refers to various student outcomes measured in many, inconsistent, ways. Oftentimes, achievement is tied to the idea of closing the achievement gap (Gutiérrez, 2008). However, Gutiérrez (2009) argues that moving from access to achievement is important considering the various levels of access of students. These two dimensions are the dominant dimensions of equity, that is, they prepare "students to participate economically in society and privileg[e] a status quo" (Gutiérrez, 2009, p. 6). Here, access is a precursor to achievement and moving from access to achievement measures "how well students can play the game called mathematics" (Gutiérrez, 2009, p. 6).

Identity refers to focusing on students' pasts including how they have been racialized, gendered, and/or classed. "The goal is not to replace traditional mathematics with a pre-defined 'culturally relevant mathematics' in an essentialistic way, but rather to strike a balance between opportunities to reflect on oneself and others as part of the mathematics learning experience" (Gutiérrez, 2009, p. 5). Lastly, power considers social transformations such as who has the voice in the classroom or if students have opportunity to use mathematics to critique society (Gutiérrez, 2009). These two dimensions are the critical dimensions, where identity can be seen as a precursor to power, "ensur[ing] that students' frames of reference and resources are acknowledged in ways that help build critical citizens so that they may change the game" (Gutiérrez, 2009, p. 6).

In this preliminary report we focus on how differential equations students may 'change the game' (i.e., student identity and power systems) in reference to studying climate change and its impact on the world and society.

Climate Change Background

In studying climate, scientists are often concerned about positive feedback loops: two or more processes that magnify each other, creating a system of amplification that leads to an enhanced cycle (Kellogg & Schneider, 1974). One example is the interaction of water vapor with global temperature. As the global temperature increases, the capacity of the atmosphere to contain evaporated water vapor also increases. Continued relative humidity levels would result in an increased amount of water vapor in the atmosphere. Water vapor is a greenhouse gas. Thus, if a climate system has more water vapor in the atmosphere, the global temperature will elevate due to the increased insulation of the atmosphere. These positive feedback loops will eventually equilibrate at a higher temperature. In a high emission scenario, scientists predict that a global increase in average temperature would be enough to kick off a system of positive feedback loops that would equilibrate, by the end of the 21^{st} century, relative to 1986-2005, to a temperature between 2.6 and 4.8 degrees Celsius higher (Intergovernmental Panel on Climate Change [IPCC], 2014). The result of this increase would be enough to melt ice caps, completely shift ecological systems, and contribute to species extinction due to significant changes in temperature, precipitation, and ocean acidification (IPCC, 2014). It may even redistribute the areas of the world that can support human life, making previously uninhabitable places like the northern reaches of Siberia and Canada habitable (though they may not support agriculture), and previously habitable places, like coastal zones (McGranahan, Balk, & Anderson, 2007) and southwest Asia (Pal & Eltahir, 2016), uninhabitable.

Climate Change Problem

This environmental phenomenon can be studied in a first course in differential equations using bifurcation diagrams. A bifurcation diagram is a plot of equilibrium solutions as a function of a parameter in a differential equation. The climate change problem has important mathematical concepts, namely bifurcation analysis (i.e., the effect of varying a parameter in a differential equation) and practical implications related to understanding societies' and governments' impact on the climate. Specifically, this problem highlights how it may be the case that damage done to the environment by a small change cannot be reversed merely by undoing that small change. Instead, reversing the damage may require dramatic changes in policy. The problem sequence is as follows:

- A group of scientists came up with the following model for this global climate system: $\frac{dC}{dt} = \frac{1}{10}(C-20)(22-C)(C-26) - k$, where C is the temperature, in Celsius, and k is a parameter that represents governmental regulation of greenhouse gas emissions. Assume the baseline regulation corresponds to $k=0$, increasing regulation corresponds to increasing k, and the current equatorial temperature is around 20 degrees. To what equatorial temperature will the global climate equilibrate?
- Sketch a bifurcation diagram and use it to describe what happens to the global temperature for various values of k.
- Suppose at the start of a new governmental administration, the temperature at the equator is about 20 degrees Celsius, and $k=0$. Based on the model and other economic concerns, a government decides to deregulate emissions so that $k=-0.5$. Later, the Smokestack Association successfully lobbied for a 5% change, resulting in $k=-0.525$. Subsequently, a new administration undid that change, reverting to $k=-0.5$, and eventually back to $k=0$. What is the equilibrium temperature at the equator after all of these changes?
- Use your bifurcation diagram to propose a plan that will return the temperature at the equator to 20 degrees Celsius.

Methods

The climate change problem is part of a full course on differential equations taught from an inquiry-oriented perspective. By inquiry-oriented we mean mathematics learning and instruction such that students are actively inquiring into the mathematics, while teachers, importantly, are inquiring into student thinking and are interested in using it to advance their mathematical agenda (Rasmussen & Kwon, 2007, Rasmussen, Marrongelle, Kwon, & Hodge, 2017). An inquiry oriented differential equations (IODE) course is problem focused, with problems being experientially real, meaning students can utilize their existing ways of reasoning and experiences to make progress (Gravemeijer & Doorman, 1999), and class time is devoted to a split of small group work and whole class discussion. Whole class discussion is facilitated by the instructor who focuses on generating student ways of reasoning, building on student contributions, developing a shared understanding, and connecting to standard mathematical language and notation (Kuster, Johnson, Andrews-Larson, & Keene, 2017).

Data for the first iteration of this classroom teaching experiment comes from student work submitted as part of an end of the semester portfolio. The portfolio consisted of the complete responses to three problems from the course (with the climate change being one of them) and a rationale statement that explains the personal significance of their work on that problem. Future iterations of this cycle will videotape students engaging in the tasks for a deeper look at in-the-moment discussions of identity and power, and discussions of how the bifurcation diagram can functions in the RME inspired instructional sequence.

We collected data from one IODE class resulting in 12 portfolios. These data were deidentified during analysis. Consequently, while we acknowledge the importance of reporting on student demographics in equity research (Adiredja & Andrews-Larson, 2017), we cannot do that in this first preliminary iteration. Future iterations of this classroom teaching experiment that collect video will be able to report on student demographics. The student works were coded using a constant comparative method (Strauss & Corbin, 1998) with particular attention given to how students discussed the critical dimensions of equity (identity and power). We acknowledge the dominant dimensions is also of importance but in this preliminary work we are not focusing on access nor achievement.

Preliminary Results

Recall our research question is: *How are students' identities and conceptions of power shaped and/or influenced by engaging with a differential equations task on climate change?* This analysis is important in the iterative process of a teaching experiment as our prompting and facilitating of this task in future iterations will be shaped by the results here tacitly tied to the critical dimensions of equity. As stated, future iterations will also consider students' mathematics engagement from an RME perspective. Overall, students gave a general thesis that this problem was important for them to work on because it showed them "mathematics in the real world." These responses were not as deep as we would have liked to see, as educators. However, there were several instances of identity and power that emerged from students' portfolios.

Identity. Our climate change problem did not seek to draw out students' pasts directly. Rather, through engagement with the task students sometimes positioned themselves and their identities within the context and spontaneously referenced such issues in their rationale statements. Two tentative themes emerged from the analysis of rationale statements: empowerment and future teaching practices. For example, one particular student discussed the pride they felt while engaging with this problem. In particular, they discuss how they knew they were truly learning:

> …it was the first problem that I completely understood the topic the entire way through. Even though that idea seems basic for people in an upper division class, for myself this was a very prideful moment. It made me realize that these difficult topics aren't as daunting as they seem. Since the first day it was introduced to our class, my table seemed to click with what the question was asking. … Then I felt as if my brain went onto autopilot, it was exhilarating. The concept of each question became clear and I understood the path to finding each upcoming answer. It was the first time that I knew I was learning, with my group able to bounce ideas off each other as if we were discovering bifurcation for the first time, there was no stopping our progress. … The most rewarding part, was that I knew my mathematical ability was growing, and all this led to me getting my highest grade on an exam in my entire college career of a 99%. … It [the climate change problem] ignited my curiosity for mathematics.

Some of the students in these courses were pre-service teachers. As an example of the second theme, one student highlighted how this problem probed them to consider their identity as a future teacher.

> To me, as a future teacher it is a great reminder of how if you can make the material relevant and slightly more interesting to the student it can make a big difference on how well the student understands the material. … What this problem taught me is that working with problems in a context that the student is interested in is very beneficial to allow the student to truly own and understand that material in their own way.

This preliminary analysis highlights how this context holds promise for situated students within the context of the mathematics they are studying. However, if we are to gain deeper insights our future iterations must more directly inquire into students' pasts and identities.

Power. In our analysis we found two ways in which power was discussed. First, it was discussed in the context of the mathematics (i.e., who has the power to do something about climate change). Second, it was discussed in the context of who has the power in the class. While different in their scope, both are important aspects of power.

For example, one student said "I remember there was a time in Mexico City where people could not go outside because there was a lot of pollution in the air. The city got so polluted that the government placed oxygen tanks on the streets." Here this student showcases that the power in this context lies with government. Another student said, "this is because after deregulation, you get stuck at the repeller [unstable equilibrium point]." Similarly, this student shows that the power to do something about climate change is tied to regulation/deregulation. Of course, this is tied to the problem we constructed, but it is important to reiterate that this problem is rooted in current climate change science research.

Lastly, many students discussed how it was important for them to talk to their peers about this problem. In particular, one student said "for all of us, it took listening to other students' ideas to really understand what was happening." This power is related to the structure of an IODE class (i.e., focused on group work). While we are not explicitly analyzing the instruction here we believe this to be a critical aspect of power (i.e., whose voice is being heard in the classroom (Gutiérrez, 2009)).

Questions for Audience

We conclude with three questions for the RUME community:

1) How can we better analyze the four dimensions of equity? In that same vein, is that lens appropriate here?
2) How might we leverage the existing heuristics of the instructional design theory of Realistic Mathematics Education (guided reinvention, emergent models, and didactical phenomenology) to disrupt current teaching and learning practices?
3) What other social justice contexts lend themselves to modeling with differential equations?

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