Disciplinary Inqu[ee]ry in Computational Physics

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As opposed to practices that reinforce inequitable power structures, disciplinary practices in STEM that converge with themes of resistance (identified through Critical analysis) are better suited to support marginalized students. We identify two instances (within the setting of a computational physics course) where we notice resonance between disciplinary practices and queer theory. We use this queer reading of our learning environment to explore possibilities for queering physics education. We argue that identifying and amplifying STEM practices that are compatible with such themes can support justice-oriented pedagogy and align with efforts to incorporate agency and scientific practices into Physics classrooms.

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I. VIGNETTE

Emerson is a fourth-year undergraduate double majoring in Computer Science and English. On the first day of the course, Emerson was the last student to share their major, year of study, and pronouns. “Hello everyone, I’m [Emerson][1]. Um..I..am a senior, studying..Computer Science, English, and ((voice slightly shaky)) Applied Physics in the School of Engineering; uh.....yeah.” While many students did not appear practiced in sharing their pronouns, Emerson was the only student to decline to answer. Given this ambiguity, we use they-series pronouns to refer to them. In a computational physics course, they are in the middle of a group project to create and model an oscillator with Ashley (she-series pronouns), Tommy (he-series pronouns), and Asia (she-series pronouns).

As Emerson steps closer, their last few steps are short and subtly mimic light stomping—like a child might shamble over to a new group of friends. As Tommy speaks, Emerson looks towards the whiteboard, then looks down at Tommy’s paper. Before Tommy looks up at them, Emerson has looked back to the whiteboard with an open expression.

> EMERSON; Ok guys, what are we doing now?
> TOMMY; Um, I think we’re thinking about what physics question we’re doing [unintelligible]
> EMERSON; umm...
> TOMMY; But I’m not sure [unintelligible]
> ASHLEY; Neither am I

We start with a diffractive reading [2, 3] of one moment during their group work. The ethnographic data, passing through the theory we bring with us, and our interpretations of this group’s dynamics, produces a unique interaction (akin to a diffraction pattern) that we wish to study and describe.

Emerson is White, and today they are wearing a grey cardigan, a mustard-colored crocheted headband, and red T-shirt that says, “no perfect people allowed.” They are pursuing a minor in Physics along with their double major. Before this course, they have coded video games and posted them to their personal website as well as github. They frequently carry a rubik’s cube, and sell custom parts and cases for various sizes of rubik’s cubes on their online shop. They are interpersonally easy-going and charming, engaging frequently in conversation with peers, and confident in their physics and programming knowledge.

Before they answer, Emerson shifts their weight—in hipled turns of their body as they alternately make eye contact with Asia and Tommy, and turn towards Ashley as she looks up at them. They look down as they think, and then stand still with their arms at their sides and their feet close together.

> EMERSON; Super position of um..of, uh, centripetal force.
> TOMMY; I don’t know what that means, although it sounds like something. [laughs]
> ASHLEY; I mean theoretically we should be able to do it with just like basic F = ma for the acceleration of each and the velocities of each time...
> EMERSON; [nods] Yeah.
> ASHLEY; It’s just more complicated

Before this conversation, Emerson has been working with Ashley to capture video data of an assemblage of craft materials that they built under the open-ended project prompt to, “Make an oscillator." They are using a model of a double-pendulum system to build a computational model of their “oscillator.”

> EMERSON; Um, so, like, what I meant by that —to —what we’ll probably say is probably not that, because that might mean something different than what we mean to say —but, like, what we’ll probably say is like, ..how having multiple, um, centripetal forces acting on...uh..bodies..affects their motion.
> ASIA; So, how having multiple centripetal forces affects...

Throughout this project, Emerson’s charisma, facility with Python, and experience with Physics has helped position them as a leader in the group. We noticed some relational moves that Emerson used to distribute power across the group and moves to deemphasize their authority.

> EMERSON; the motion of a body. Yeah.
> ASIA; ok
> AUTHOR4; [in background, headed to another group, Emerson and Tommy turn to watch] YAASSS. YAS!

Our interpretation of the video and transcript in this vignette is that Emerson approaches the group without any expectation of what the group should or should not be doing. Tommy leaves space for Emerson to step into a leadership role by exposing the confusion he is feeling about which direction to go next with the group project. Emerson desettles their potential authority in the group through a performance of improvisation (and with shrugs of uncertainty) as they suggest a potential research topic. Their performance of the physics practice of crafting a research question involves a playful first try, and successive refinements to find something that appears (at least momentarily) to fit.

Their existence in this moment is, of course, many things–not all of them captured here, and the pieces presented here are not more important than other aspects of this (almost mundane) snapshot of disciplinary work. But we were drawn to these moments because Emerson–a genderqueer student (who during an interview identified experiences of tension and discrimination in another STEM environment)–performs disciplinary practices (such as working in groups and crafting research questions) with authenticity to their queerness. They disrupted the accumulation of their power in the group. They were unfazed by uncertainty and failure[4, 5]. And they approached the creation of a research question as a playful and iterative game of refinement.

We find it interesting that these aspects of disciplinary practice—so common as to be nearly invisible—carry portions of Emerson’s queer identity. We see disciplinary practices in physics as potential sites of resonance with themes from other scholarship such as queer theory. And we understand disciplinary practices to be composed of harmonics that resonate with tones of queering.

II. INTRODUCTION

Education researchers have only relatively recently begun to explore the climatic experiences of LGBTQ+ people in Physics and STEM more broadly. Early qualitative efforts to understand the experiences of faculty [6] and students [7] found these groups often felt compelled to hide their gender and sexual identities to navigate their respective STEM communities. More recent quantitative work has highlighted climate issues limiting retention of LGBTQ+ faculty work [8] and shown disadvantages to LGBTQ+ employees in federal agencies [9].

Considering LGBTQ+ people in Physics is becoming more common, but there is much to study. Two papers from one initial study in Texas addressed race, gender, and sexual orientation in physics [10, 11]: One looked at how participants saw themselves as a physicist and their views on stereotypes that may have prevented this self-identification [10]. The second examined how departmental structures and culture led to participants finding "success together" [11]. A second set of papers [12, 13] using data from a survey of 324 LGBTQ+ physicists and interview data examined LGBTQ+ experiences of harassment and exclusionary behavior [12] as well as intragroup differences in the LGBTQ+ community [13].

Despite these preliminary efforts, there is very little work or observational data on the classroom experiences of LGBT+ people in Physics. In this paper, we envision what "queering a physics classroom" could mean (and might look like) by performing a queer reading of a designed [14] learning environment. Using Rands's framework of Inqu[ee]ry [15, 16], we examine some ways that queer theory might illuminate physics pedagogy. One way to "queer" disciplinary practice in physics is to craft learning spaces with a diversity of performances of gender, family structures, sexualities, etc. Another way to "queer" disciplinary practice might be to find and amplify resonances between physics and queer. Some disciplinary practices in physics already seem to resonate with queer theory: troubling settled assumptions and norms [17], framing failure and recreation as necessary for progress [5], and perpetual doing/undoing of understanding [3]. Yet not all of these practices are routinely included, noticed, or highlighted in a typical physics classroom. To illustrate our argument, we draw from ethnographic data of an undergraduate computational physics course. We present examples (situated in a learning environment) of disciplinary practices in physics that are in alignment with themes developed for queer theory.

The disciplinary setting for this work is an undergraduate computational physics course taught at a small liberal arts university in the Northeastern United States. One of the five projects of the course is to model the behavior of a physical construction made from everyday craft materials–string, magnets, wooden hoops, tape, dowels, and cardstock. With the materials on display at a communal table, the students are invited to "make an oscillator." After constructing and refining an assemblage of materials, the students collect video data and use tracking software to create a data set of position coordinates. The students then design and code a computational model of the system. Throughout this project, we have noticed resonances between disciplinary practices in physics and themes from queer theory.

III. INCLUSION, QUEER THEORY, AND INQU[EE]RY

Queer theory is an umbrella term that refers to a number of bodies of work originating in the interdisciplinary field of Cultural Studies and rooted in Critical Theory. The word "queer" has history as a heteronormative slur that has become a self-identifying term for people crafting a range of particular minoritized sexual and gender identities[18]. An identity in itself, the word "queer" is closely related to many kinds of marginalized identities including Lesbian, Gay, Bisexual, Transgender, Intersex, Asexual, Questioning, and others.

A dual usage of "queer,"

> "alludes to a view of identity as unfixed, contingent, and in a process of constant reconstitution through discursive practices... whereas in [this] sense the term is defined against normalcy or normativity" [15].

Identity (each aspect of identity, including sexual and gender identities) is continually made and remade through dynamic social co-construction, individual performance, and emergent processes [19, 20]. As both a verb and an adjective, "queer"–as in queer theory–signifies a poststructural perspective of the discursive nature of identity as well as a description of resistance to the normalizing flows of culture that straighten people into uncomfortable shapes [15, 16, 21, 22].

In contrast, Physics Education has tended to construct the identities of its participants as fixed, immutable and often, to the extent that marginalized groups have been studied, as inhibitions or challenges to be overcome [23]. Queer theory offers an alternative set of tools that instead allow us to scrutinize the power structures at play in an educational environment, the ways in which identities are inculcated in and leveraged by those power structures, and how processes of marginalization or exclusion emerge from particular features of an educational environment. Hence, "rather than inclusion and representation, queer theory emphasizes questioning and inquiry" [16, p. 186] —inviting us as researchers to look beyond merely who is present in the classroom to how they are navigating it and learning, and which features of the design are supporting that growth or otherwise.

A. Inqu[ee]ry

As a valuable example of how queer theory has been deployed in education, Kai Rands [15, 16] takes these two usages of the word "queer" to describe "queering" mathematical learning environments in two complimentary ways–queer as in LGBTQ+, and queer as in queer theory. In what they playfully name an "Add-Queers-and-Stir" approach, Rands describes "queering" mathematics education in the first sense of the word–inclusion and representation for LGBT people. As an example of the first sense of the word "queer," we might imagine representing a diversity of family structures in the context of physics questions and lessons, or avoiding problematic heteronormative analogies such as gender and electromagnetic attraction. Rands also describes ways to add "queer" to other frameworks for mathematics education; such as, culturally relevant pedagogy, critical mathematics literacy, or feminist perspectives on mathematics education [15].

In the second sense of the word "queer," Rands suggests that we question "the tasks, strategies, the very ways of thinking and doing mathematics, as well as the way mathematics is used to interpret and act in the world" [16, p.186]. Mathematical Inqu[ee]ry, as they describe it, might challenge normativity and question "the boundaries of social, identity, and mathematical categories" [16, p.188]. Some examples they give are: "What shapes are included in the pattern block set? What types of pictures do these shapes make possible or impossible?"; and "Can you make a contradicting argument using the same data?" [16, p.188].

We emphasize that questions such as these are *already within* the boundary of what counts as doing mathematics. What makes these practices "inqu[ee]ry" (as well as "inquiry") is their resonance with themes from queer theory. In the first example, by considering how the rules we create can include or exclude exclude. And in the second example, by questioning how we construct understanding. Along with including "queerness" in mathematics education, recognizing that some existing forms of mathematical inquiry also resonate with themes from queer theory is a second possible way to "queer" mathematics education.

In Physics education, we can interpret Rand's call more broadly to re-imagine the set of tasks that we ask students to do, replacing standard problem sets, lectures, etc. with opportunities to engage in doing science as scientists; to go beyond students answering assigned questions and instead posing and answering questions for themselves.

We ask: In the specific context of computational physics; can we envision inqu[ee]ry as an element of disciplinary practice that aligns with themes from queer theory? During our "oscillator" project, we noticed multiple instances of such an alignment—and here we will describe two.

IV. DATA COLLECTION

The course design and this activity are fully described in [24]. This project occurred over 5 class periods in the middle of the course and incorporated multiple rounds of making, data collection, computational modelling and comparing data with models. Observations of the class sessions were conducted by members of the research team, and field notes [25] were generated by each observer. Additionally, video recordings were made of students working around the materials table and in their project groups. Roving cameras were used [26] to capture specific interactions such as students making and remaking their artifacts as described here. Student presentations were recorded, and all work submitted for the course was collected for analysis. Finally, selected students were interviewed at the end of the course.

Our analysis involved repeated and collaborative review; and the creation of content logs, transcript, and analytical memos. Our particular use of Interaction Analysis [27] involved an iterative pattern of interpreting ethnographic fieldwork in order to understand the "ways in which participants utilize the resources of the complex social and material world of actors and objects within which they operate" (p. 41). Our interview protocol was designed by the research team to investigate students' changing relationships to tools, materials, each other, the instructors, and the discipline. Noticing elements of queer identity surface in interview data, such as Emerson's comments on experiencing a hostile climate in another context, caused us to look more fully at queerness in the video data.

V. DISCIPLINARY ELEMENTS OF QUEERNESS

A. Troubling understanding

In our "oscillator" project, we observed a pattern of students building a computational model, and then queering it. And we see this as a ordinary and desirable disciplinary trajectory: Physics inquiries are rarely, if ever, "complete", but are conducted to produce new knowledge. As this knowledge is produced, new questions emerge and new acts of inquiry follow, sometimes with the same tools, experimental apparatus or even data. In this way, physicists "trouble" or perturb settled knowledge. The students build an assemblage of parts that move. The students have freedom to define what "oscillate" means for them in their context, as well as agency to decide what they will model, and what constitutes a computational model. Once the students have a sense of "what" is happening in the movement they record, they almost always investigate some kind of complicating factor. For instance, further investigating: sensitivity to initial conditions and chaotic behavior; finding and tweaking parameters of the model (drag, energy dissipation, Reynolds number, coefficient of restitution, etc); or precision in measurement (capturing the data in the best way, calculating differences and error). The students have agency to pile on complications—asking new questions—until their work feels to them to be sufficiently interesting.

Emerson's group reported that the reason they chose a double pendulum was specifically because the complicating factor of "chaos" was "interesting" to them. Their group's first assemblage essentially involved three independent simple harmonic oscillators, but they instead decided to build a double-pendulum system because it was "more interesting" and "chaotic." At the initial conditions they modeled, the double-pendulum does not, in fact, exhibit sensitivity to initial conditions in the sense of chaos theory. But we believe that because of the double-pendulum system's connection to the development of chaos theory, Emerson's group coded it as "chaotic," in this way strange, and therefore interesting.

The students have agency to pile on complications and troubling factors until their work feels to them to be sufficiently comfortable. In a sense, what drives the project–what is interesting–is the strangeness of the behavior that they have sought out. The most common self-descriptions of these moves (of intentionally looking for weirdness) is that they are done to make a project more interesting. The aesthetic that determines "sufficient," and the affect determining "comfortable" and "interesting" are examples of epistemic affect [28, 29]. In this case, these disciplinary tenets are tied to undoing understanding and searching for more/enough strangeness. Essentially, queering is among disciplinary sensibilities that they are bringing into practice.

B. Agency as an ingredient for queering physics

Agency is central to scientific practice because scientific progress is not linear and there are often fundamentally different ways to approach the same problem. Agency offers the possibility of revising, iterating, and improving the outcome of an inquiry, as well as its objectives. There has been considerable recent interest in agency within Physics Education in laboratory settings (e.g. [30, 31]); here we briefly consider the queer implications of such agency.

In the "oscillator" project of our study, we facilitated the students' agency to bring into being: objects of study, meanings of terms such as "oscillate" and "model," and disciplinary relationships and group structures. Ashley described the agency to determine what to study and how to study it–even for different members of the same group–as a positive element of project:

> ASHLEY; I think a lot of that was very personal. People would take their piece of the project as far as they wanted to.
> AUTHOR3; And iterate as much as they felt comfortable –
> ASHLEY; Yeah. But then if another person came to us and was like 'I've done this cool thing.' We're like 'Cool–that's great!'

Emerson described their experience working with Ashley as a positive and productive disciplinary kinship:

> EMERSON; ...So one thing I learned is that Ashley and I make a great duo because I have this chaotic energy about me, and Ashley's very stable and ... I will just explore various exponential branch trees. And then Ashley will be like 'okay, let's do this.' And then we'll get it done. [Interview]

With Barad [3] in mind, we see these individual craftings of disciplinary exploration and disciplinary kinship as outcomes of the many types of disciplinary agency facilitated by the design of the project. This agency—as a part of what made up the disciplinary environment for students—helped support Emerson (at the very least) in feeling comfortable in crafting disciplinary relationships and bringing their whole self to the disciplinary project:

> EMERSON; And that feeling also is very dependent on the space I'm in. So, when Ashley's around I'm very comfortable. But if it was just me in a room with some of the straight, White, cis guys in the room, I probably would all of a sudden not have been speaking as much, and then the camera would make it worse. And I'd just be like "well, this sucks". So it just depends how much of a community you have in the class at certain times too. [Interview]

We are led to speculate from this datum that space for disciplinary indeterminacies led to disciplinary agency, disciplinary knowledge, experience with disciplinary relationships, and support for queer expression.

VI. CONCLUSION AND IMPLICATIONS FOR PEDAGOGY

We described two ways that queer theory can be used to read what is happening in the disciplinary practices of our designed learning environment, an undergraduate computational physics course where students were asked to make objects they would then model.

The first type of queering of Physics that we have suggested is to recognize and support the aspects of Physics practice related to searching for what is surprising or unknown and building something creative and new. In our project to "make an oscillator, and build a computational model," this queering of Physics showed up in the students' search for "interesting" behavior and creative interpretations and models for their data.

The second type of queering of Physics that we have suggested is to recognize, support and centralize student agency. In our project to "make an oscillator, and build a computational model," this queering of Physics showed up in the open ended nature of the project. The students' experience involved types of agency to determine (in ways that fit them) what to build, what to notice, what was interesting, what data to collect, how to interpret it, how to model it, how to craft interpersonal relationships, where to find support, how to construct or deconstruct leadership, and what performances of knowledge they would enact.

In conclusion, we suggest that queering physics could entail searching for queer themes within the practice of Physics—and finding ways to amplify those practices. We envision "queering Physics" to be possible through both (as Rand puts it) an Add-Queers-and-Stir approach as well as searching for what Inqu[ee]ry in Physics can look like. So far, we notice that "troubling assumptions" and "agency that leads to re/creation" are queer themes that can emerge in a Physics classroom given appropriate design.

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[1] All names are pseudonyms.
[2] K. Barad, Posthumanist performativity: Toward an understanding of how matter comes to matter, Signs: Journal of women in culture and society **28**, 801 (2003), publisher: The University of Chicago Press.
[3] K. Barad, Transmaterialities: Trans*/matter/realities and queer political imaginings, GLQ: A Journal of Lesbian and Gay Studies **21**, 387 (2015), publisher: Duke University Press.
[4] A. M. Phillips, J. Watkins, and D. Hammer, Problematizing as a scientific endeavor, Physical Review Physics Education Research **13**, 020107 (2017).
[5] J. Halberstam, The queer art of failure, in *The queer art of failure* (Duke University Press, 2011).
[6] D. Bilimoria and A. J. Stewart, " don't ask, don't tell": The academic climate for lesbian, gay, bisexual, and transgender faculty in science and engineering, NWSA Journal , 85 (2009).
[7] E. A. Cech and T. J. Waidzunas, Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students, Engineering Studies **3**, 1 (2011).
[8] E. V. Patridge, R. Barthelemy, and S. R. Rankin, Factors impacting the academic climate for lgbq stem faculty, Journal of Women and Minorities in Science and Engineering **20** (2014).
[9] E. A. Cech and M. V. Pham, Queer in stem organizations: Workplace disadvantages for lgbt employees in stem related federal agencies, Social Sciences **6**, 12 (2017).
[10] E. M. Schipull, X. R. Quichocho, and E. W. Close, 'success together': Physics departmental practices supporting lgbtq+ women and women of color, 2019 PERC Proceedings , 24 (2019).
[11] X. Quichocho, J. Conn, E. Schipull, and E. Close, Who does physics? understanding the composition of a physicists through the lens of women of color and female lgbq+ physicists, in *Proceedings of the 2019 Physics Education Research Conference* (2019).
[12] R. S. Barthelemy, Lgbt+ physicists qualitative experiences of exclusionary behavior and harassment, European Journal of Physics **41**, 065703 (2020).
[13] R. S. Barthelemy, M. Swirtz, S. Garmon, E. H. Simmons, K. Reeves, M. L. Falk, W. Deconinck, E. A. Long, and T. J. Atherton, Lgbt+ physicists: Harassment, persistence, and uneven support, Physical Review Physics Education Research **18**, 010124 (2022).
[14] P. Cobb, J. Confrey, A. diSessa, R. Lehrer, and L. Schauble, Design experiments in educational research, Educational Researcher **32**, 9 (2003).
[15] K. Rands, Mathematical inqu [ee] ry: beyond 'add-queers-and-stir' elementary mathematics education, Sex Education **9**, 181 (2009), publisher: Taylor & Francis.
[16] K. Rands, Mathematical inqueery, in *Critical Concepts in Queer Studies and Education: An International Guide for the Twenty-First Century*, Queer Studies and Education, edited by N. M. Rodriguez, W. J. Martino, J. C. Ingrey, and E. Brockenbrough (Palgrave Macmillan US, 2016) pp. 183–192.
[17] J. Rosiek, Visibility, in *Critical Concepts in Queer Studies and Education: An International Guide for the Twenty-First Century*, Queer Studies and Education, edited by N. M. Rodriguez, W. J. Martino, J. C. Ingrey, and E. Brockenbrough (Palgrave Macmillan US, 2016) pp. 453–461.
[18] M. Bronski, *A queer history of the United States*, Vol. 1 (Beacon Press, 2012).
[19] L. Avraamidou, Science identity as a landscape of becoming: rethinking recognition and emotions through an intersectionality lens, Cultural Studies of Science Education **15**, 323 (2020).
[20] R. Rogers, *An Introduction to Critical Discourse Analysis in Education* (Routledge, 2011).
[21] C. Dubbs, *A Queer Turn in Mathematics Education Research: Centering the Experience of Marginalized Queer Students* (North American Chapter of the International Group for the Psychology of Mathematics Education, 2016) publication Title: North American Chapter of the International Group for the Psychology of Mathematics Education.
[22] J. M. Wargo, Queer, quare, and [q]ulturally sustaining, in *Critical Concepts in Queer Studies and Education: An International Guide for the Twenty-First Century*, Queer Studies and Education, edited by N. M. Rodriguez, W. J. Martino, J. C. Ingrey, and E. Brockenbrough (Palgrave Macmillan US, 2016) pp. 299–307.
[23] G. L. Cochran, M. Boveda, and C. Prescod-Weinstein, Intersectionality in stem education research, in *Handbook of Research on STEM Education* (Routledge, 2020) pp. 257–266.
[24] A. M. Phillips, E. J. Gouvea, B. E. Gravel, P.-H. Beauchemin, and T. J. Atherton, Physicality, modeling and making in a computational physics class, arXiv preprint arXiv:2203.04134 (2022).
[25] R. M. Emerson, R. I. Fretz, and L. L. Shaw, *Writing ethnographic fieldnotes* (University of Chicago Press, 2011).
[26] M. J. Leonard and S. J. Derry, Insight into teaching and learning, Handbook of design in educational technology **439** (2013).
[27] B. Jordan and A. Henderson, Interaction analysis: Foundations and practice, The journal of the learning sciences **4**, 39 (1995).
[28] L. Z. Jaber and D. Hammer, Engaging in science: A feeling for the discipline, Journal of the Learning Sciences **25**, 156 (2016).
[29] L. Z. Jaber and D. Hammer, Learning to feel like a scientist, Science Education **100**, 189 (2016).
[30] Z. Y. Kalender, E. Stump, K. Hubenig, and N. Holmes, Restructuring physics labs to cultivate sense of student agency, Physical Review Physics Education Research **17**, 020128 (2021).
[31] M. Kinnischtzke and E. M. Smith, Investigating relationships between emotional states and self-efficacy, agency, and interest in introductory labs, in *Proceedings of the Physics Education Research Conference (PERC* (2021) pp. 209–214.