The foundation and building blocks of inclusive and equitable classrooms in STEM

by

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Abstract

Equity and Inclusion are matters of Justice, a laudable goal in its own right. They are further matters of Justice in science, technology, engineering, and mathematics (STEM) classrooms. There have been calls across the globe for more diversity in the workforce. Specifically in Canada and the United States of America, there is a need for diverse problem solvers to tackle the unique challenges societies face today. STEM disciplines provide individuals with the skills to help solve these problems, but are also disciplines that push out individuals from underrepresented groups, and therefore lack diversity. We see a great attrition of qualified individuals and diversity at the university level that perpetuates the lack of diversity in the workforce.

One research area of discipline-based education research (DBER) assesses how equitable and inclusive classrooms can support and retain individuals from underrepresented groups in their fields. While the evidence of how to use equitable and inclusive classroom practices and tools is vast, these practices and tools are not fully accepted by the wider teaching community at the university level.

We discuss what equity and inclusion are, the current state of STEM disciplines and the (lack of) progress toward equity and inclusion and the effect of retention of individuals from underrepresented groups. We provide a discussion on two main teaching practices in STEM classrooms, traditional lecturing and active learning, and where these practices uplift or fail students, especially those underrepresented in their discipline. These discussions aim to help the reader start their journey toward a better understanding of equity and inclusion in STEM classrooms.

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Acknowledgments

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Chapter 1

Introduction

All students need to be supported in their learning. It is fundamental than when we want to support all students, we need to have equitable and inclusive learning spaces. Inequitable and non-inclusive classrooms have a persistent effect on the diversity of individuals that we see in post-secondary education, especially in STEM disciplines[11;12], which then has effects on the (lack of) diversity in the STEM workforce. Both Canada and the United States have made calls to action to attend to the lack of diversity in the STEM workforce, and equity and inclusion have become highly researched topics within discipline-based education research to help address these calls. These topics exist in a large range of literature and can be hard for beginners to parse[13], and are largely researched in the United States, which provides excellent results but they are not directly correlated to Canadian classrooms and demographics.

The Canadian Consortium of Science Equity Scholars (CCSES) is a collaboration that is dedicated to improving equity and inclusion across university-level science courses to better support all students, especially those who are historically and currently underrepresented. The CCSES is specifically interested on investigating equity in Canada to continue the work done in the literature around equity in the United States, to ensure there is data and results within the Canadian landscape. The CCSES has the impact objectives to develop and disseminate high-quality research-based tools and frameworks suitable for Canadian university STEM classrooms and to cultivate a national community of science equity scholars. Their research goals include identifying how an inclusive classroom climate, or lack thereof, impacts students' sense of belonging across science courses in biology, chemistry, and physics, across institutions and demographic groups, to identify inclusive teaching practices that have the most impact on a student's sense of belonging, and to reframe approaches to university-level science equity work through a critical perspective. The work done in this report provides insight into what teaching practices exist in the post-secondary classroom and what the literature says about their validity so that we can begin to assess the needs within the Canadian post-secondary science classroom landscape for creating and developing research-based tools and frameworks.

This report serves two purposes: to create building blocks and a foundation for interested parties to start their journey into creating more equitable and inclusive classrooms and set up a literature review for my future work with the CCSES. In practice, it acts as an introduction to equitable and inclusive classrooms, ending with the teaching method of active learning, an alternative set of methods to traditional lecturing. Active learning has been shown to have a positive impact on a student's sense of belonging and community and achievement measurements are increased for all students. In turn, under the employment of active learning teaching methods, there is an increased rate of retention in STEM degrees for diverse individuals. The building blocks and foundation built to get to active learning include learning about diversity, equity, inclusion, and justice (DEIJ) as values, understanding the statistics around why we should care about making more equitable and inclusive classrooms, learning about theories surrounding how people learn, theories that pertain to the needs of different underrepresented groups, and finally teaching methods. Understanding how students learn and the theories around the needs of individuals from underrepresented groups can better inform teaching practices through intentional choices designed around the support of these theories.

Chapter 2

Defining Diversity, Equity, Inclusion, and Justice

Diversity, equity, inclusion, and justice are values that are closely linked together. They are a framework to address and uphold human rights from the understanding that society is inherently unequal[14]. Within education, these values are used to drive policy with targeted solutions to support underrepresented individuals within classrooms, and other communities on campuses. When prioritizing DEIJ to make progress in a policy's respective area it is important to understand each value on its own[15]. This section works to define these values to start the journey in understanding why DEIJ in education matters and how they can affect classrooms and student populations.

In its definition, diversity is "the fact, condition, or practice of including or involving people from a range of different social and ethnic backgrounds, and (more recently) of different genders, sexual orientations, etc."[16]. We adopt this definition with the addition and emphasis that "these identities lead to different ideas, perspectives, and values". In the classroom, we also consider a non-exhaustive list of other identities such as disability, marital status, parental status, first-generation status, language, and socio-economic backgrounds. Having diversity in a classroom can have an impact on a student's overall experience, learning, and sense of belonging which in turn can affect the retention of diverse voices in the classrooms and disciplines.

Inclusion in the context of education can be defined as "the action, practice, or policy of including any person in an activity, system, organization, or process, irrespective of race, gender, religion, age, ability, etc." [17], or as "the act or practice of including and accommodating people who have historically been excluded (as because of their race, gender, sexuality, or ability)" [18]. In a practical sense, inclusion is the ability of diverse individuals to "raise their perspectives authentically and for those voices to matter and impact decisions, where the organizational culture has been enabled for that to happen" [19]. Within education, inclusion has been thought of as an approach to support children with disabilities in their learning environment, but there has been a shift to see inclusion as a tool that supports and welcomes diversity among all learners[20]. We want our classrooms to include all types of students who can participate and have their voices heard.

Equity is defined as "the quality of being fair or impartial" [21], "justice according to natural law or right, specifically: freedom from bias or favouritism" [22], "a process of equality turned into action, a process of making fair and equal" [23], or "equity is partly the quality of being just and fair, and partly as the process that supplies the underlying principles as to why a system is fair" [23;24] Equity differs from equality as equality lacks the confines of justice, being fair, or being impartial. Equality assumes that given the same resources, everyone has the same opportunities, while equity recognizes that individual circumstances require an individualized allocation of resources to be able to provide opportunities that reach an equal outcome or achieved results. The Race Matters Institute says that equity strategies must be targeted to address the unequal conditions, needs, and positions of groups and individuals that are created by institutional and structural barriers. This requires a set of informed policies and practices internationally designed to promote opportunity, rectify disparities, and have informed individuals positioned to implement these policies effectively[19]. In education, the concerns of equity include the treatment of different groups, such as men and women, curriculum content, forms of assessment, and more[23]. On a larger scale, equity can address the needs of different groups to help all students achieve and persist in their courses and educational spaces.

Justice is a quality of being just, and to be just is "acting or being in conformity with what is morally upright or good" [25;26]. Justice is the view that everyone deserves to enjoy the same rights regardless of identity. Equity is defined by "justice", and the two go hand in hand, but they are not the same. Equity provides the support to overcome barriers that cause inequity, and justice instead removes the barrier that causes inequity [27]. Figure 2.1 is a widely used figure by Tony Ruth called "The Giving Tree" [1]. It provides a visual representation of what we mean when we say equality, equity, and justice, and what it means to have needs met or barriers removed, a key difference between equity and justice. When it comes to policy, justice is often seen as the active work done to achieve equity, but equity policies can claim to do the work without providing justice- it can be performative. For equity policies to be effective, they must be just and in practice improve the system in which they were trying to change. Performative equity policies that do not actively try and change their environments reinforce the root systems that created the problems in the first place [28]. A common example is gender equity policies, as they can improve gender equity for white women, leaving black women behind and reinforcing the racist roots in the system [29].

Equity, justice, inclusion, and diversity are parts to a machine. To have a diverse society, we need to include all diverse individuals, provide tools to ensure all diverse individuals have access to the same opportunities, and fix the system in which diverse individuals are excluded and experience inequities. To demonstrate how these values work together in practice, Dafina-Lazarus Stewart has the following example rhetoric that communicates exactly these parts in the machine [30]: "Diversity asks, 'who's in the room?' Equity responds: 'Who is trying to get in the room but can't? Whose presence in the room is under constant threat of erasure?' Inclusion asks, "Has everyone's ideas been heard?' Justice responds "Whose ideas won't be taken as seriously because they aren't in the majority?'" Or, a powerful example: "Diversity asks, 'Isn't it separatist to provide funding for safe spaces and separate student centers?' Equity answers, "What are people experiencing on campus that they don't feel safe when isolated and separated from others like themselves?' Inclusion asks, "Wouldn't it be a great program to have a panel debate Black Lives Matter? We had a Black Lives Matter activist here last semester, so this semester we should invite someone from the alt-right."

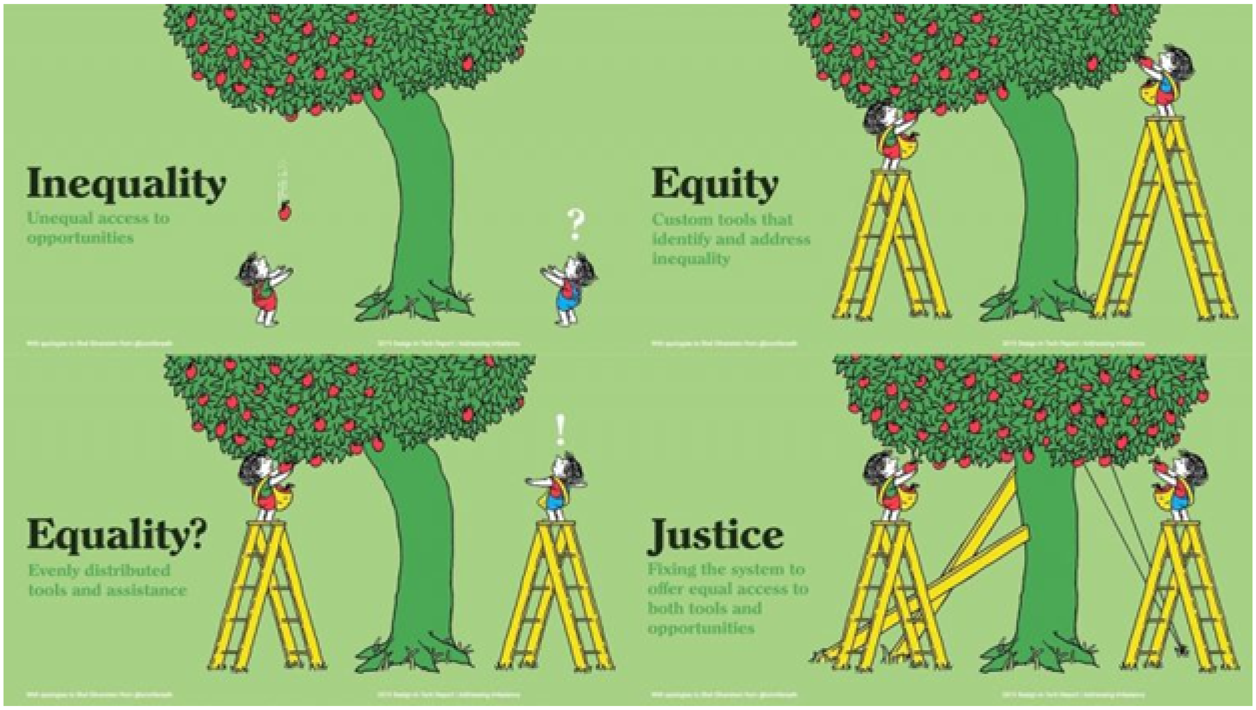

Figure 2.1: Tony Ruth's "The Giving Tree"[1]. This graphic is a visual representation of the differences between inequality, equality, equity, and justice.

Justice answers, 'Why would we allow the humanity and dignity of people or our students to be the subject of debate or the target of harassment and hate speech?'".

As this report looks into the existing literature on equitable and inclusive classroom practices, we do so in the hopes of including voices excluded commonly in STEM. There is also the caveat that justice is often not described in this literature, as the university system as an institution has systemic roots in racism, classism, and sexism that cannot simply be undone when intertwined with a government institution that has roots in racism, classism, and sexism. The practices and tools we as researchers and educators can create are to make changes in classroom-level policy, ones that are within the control of educators.

Chapter 3

National Statistics for STEM Disciplines

As the world grapples with existential challenges, such as the COVID-19 pandemic and climate change, there has been a greater need for effective, diverse problem solvers[31;32]. Individuals with STEM degrees offer up the skills that are looked for to solve the problems the world faces, but these disciplines push out individuals from underrepresented groups at every level, from dimming interests in grade school, to university spaces, and in their careers. The lack of diversity in STEM is a problem, and there have been several calls to action to increase diversity from the wider research community, and the Canadian and U.S. governments[33–36]. Diversity is particularly a problem in physics, engineering, mathematics, computer science, and to a lesser extent chemistry. In this section, we use data from Statistics Canada and Canada's Postsecondary Student Information System (PSIS), and the U.S.'s Integrated Postsecondary Education Data System (IPEDS) to show the statistics surrounding the (lack of) diversity within STEM.

The CCSES is collecting data from physics, biology, and chemistry, which will also be the disciplines we focus on for this report. These 3 disciplines, while all belonging to the larger field of science tell a very different story from each other when it comes to diversity. These stories can also be told for both Canada and the U.S., which is important to consider because a majority of the literature around diversity in STEM that exists is from the U.S., and while insightful, is not representative of the Canadian population but still applied to Canadian classrooms.

3.1 National Data Sources

Canadian data available to the public is collected by Statistics Canada through censuses and the Postsecondary Student Information System, which collects enrollment and graduation data from public universities[4]. A shortfall of PSIS is that data isn't collected by race/ethnicity, but by citizenship. Someone can be a Canadian citizen, but racially non-white, which makes the data ambiguous when looking at diversity. Citizenship is an excellent tracker for international students but is still largely unhelpful when investigating racial aspects. Information for race/ethnicity is gathered from Statistics Canada to create the statistics available, but this means we cannot find information about intersectional identities like women and visible minorities, and in general race/ethnicity data is minimal when looking at degree/field types. Statistics Canada has recognized there is a growing demand for more detailed data on their category of racialized groups beyond a yes/no answer to get a better understanding of the diversity in the population and to provide further data to help develop policies for fighting racism and discrimination in the country[37].

In the U.S., every institution receiving federal financial aid, or Title IV institutions report to the Integrated Postsecondary Education Data System[38]. IPEDS collects all sorts of information about their institution populations, like enrollment and degree attainment. These individuals have their gender and race/ethnicity identities reported along with the type of degree programs students are enrolled/graduated in. This information is publicly available for analysis and allows researchers to find out information about gender and race/ethnicity breakdowns at the institution and degree level, as well as the intersections available from the data. In contrast to Canada, it is easier to discuss the data for the populations in physics, biology, and chemistry robustly. Due to the nature of the data sources, Canadian and American data are represented separately, especially as the American data provide robust statistics on intersectional identities. The intent is to not contrast the two countries but to show gender and race-based data to highlight the problem of the lack of diversity in post-secondary university classrooms.

3.2 Canadian Data

3.2.1 Racialized Groups

According to Statistics Canada, "racialized groups" include South Asian, Chinese, Black, Filipino, Arab, Latin American, Southeast Asian, West Asian, Korean, and Japanese. White/Caucasian individuals make up 69.8% of the Canadian population as of the 2021 census, and of these individuals, 83.7% of them are third-generation Canadian or more[37]. Of graduates from public Canadian universities, approximately 30% of them are from racialized groups, which is on par with the Canadian population[39] from the 2014-2017 cohorts. Of these racialized groups, Chinese, South Asians, and Blacks make up two-thirds of graduates. Just under 3% of these graduates are third-generation students or more. These graduates are overrepresented in Ontario, and to a lesser extent British Columbia, and are underrepresented in the Prairies (Alberta, Saskatchewan, and Manitoba)[39]. Generally, we know that STEM is a popular degree among racialized minorities, both men and women, however, science tends to be more popular among women racialized minorities than non-racialized minorities[39]. This is currently the available national information for racialized groups among graduates, and unfortunately, we cannot discuss racialized groups within STEM disciplines.

The Canadian Association of Physicists (CAP) did a Canada-wide survey on equity, diversity, and inclusion in physics back in 2021 that does have more specific data, but is only sampling 3000 individuals who opted into responding to this survey[2;3]. 880 of these participants were undergraduate students, and gender and race/ethnicity data is shown in Figure 3.1. BIPOC refers to Black, Indigenous, and People of Colour, and Gender Diverse includes individuals who identify as non-binary, gender non-conforming, genderqueer, transgender (only if man or woman is not specified as gender identity), and those who preferred

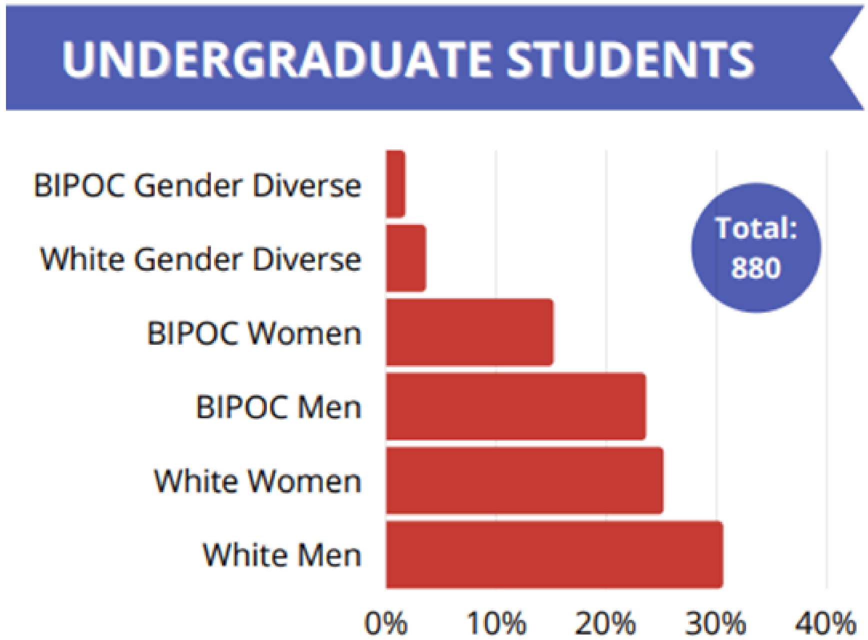

Figure 3.1: Identity results of the participating undergraduate individuals in the CAP survey on equity, diversity, and inclusion in physics[2;3]. This sample set on Canadian undergraduate physics reflects some of the U.S. physics data; the discipline is overwhelmingly white, and overwhelmingly men.

to self-describe another gender identity. The data is not a fully representative sample of the undergraduate physics community but begins the journey of discussing the population. Among all participants, it is noted that only 1% identified as Black, including graduate students, post-doctoral researchers, faculty members, staff at research institutes, and staff in the industry/government sectors. Similar data has not been collected for chemistry and biology.

3.2.2 Gender

Gender data is also more difficult to parse at the discipline-specific level. While the PSIS has reporting codes for specific disciplines, the publicly available data combines physics, chemistry, geological and earth sciences, astronomy and astrophysics, and material sciences all into the same category of "physical sciences". Biology with its subdisciplines is combined into a larger "biological and technology sciences" category, which provides a clear picture for biology, but we do not have the same for chemistry and physics. On a Canada-wide scale, in 2020 59.8% of bachelor's degree graduates were women[40]. In "physical and life sciences and technologies" 50.9% of graduates were women, which encompasses biology, physics, and chemistry among other physical and life science disciplines. It is advantageous to report that "architecture, engineering and related technologies" graduated 25.2% women, and "mathematics, computer and information sciences" graduated 28.5% women, as these fields help make up the STEM statistics that will be encountered[40]. It happens to also be advantageous since disciplines like mathematics, engineering, and computer science tend to be more closely linked to physics than biology and chemistry, and can help us extrapolate what physics could look like if separated from the other physical sciences. The Statistics Canada 2021 Census is able to break down "physical and life science and technology" graduates to show that among "physical sciences" 33% of graduates are women, and in "biological and life and technological sciences" 57.2% of graduates are women[41]. Biology disciplines together had a population 2.3 times greater than the physical sciences, which can help explain why the "physical and life sciences and technologies" statistics seem closer to the overall post-secondary statistic for women graduates, which can imply that the disciplines within this category are representative of the undergraduate population, and this is misleading.

A survey of graduates in STEM and business, humanities, health, arts, social science, and education (BHASE) populations in Canada from 2010-2018 by the Council of Ministers of Education, Canada[42] discuss trends of data that present a narrative of gender in STEM that is enlightening. It highlights that women are underrepresented amongst the graduates of STEM programs. Of the 22.1% of total STEM degrees attained, 14.1% were men, and 8% were women. Enrollment data shows a growth of 47% of STEM degrees from 2010-2018, but the growth rate of men students was faster at 53%, leading to an increased gender gap of 1.3%. Figure 3.2 from PSIS shows the gender differences in 2018[4;5]. Using the 2016 Census, women make up 34% of STEM bachelor's degree holders and represent only 23% of science and technology workers among Canadians aged 25-64[42–44]. The representation of women that hold STEM degrees is 22% for 65-year-olds, 37% for 40-year-olds, and 36% for 30-year-olds. This suggests that there was earlier progress in improving women's representation in STEM,

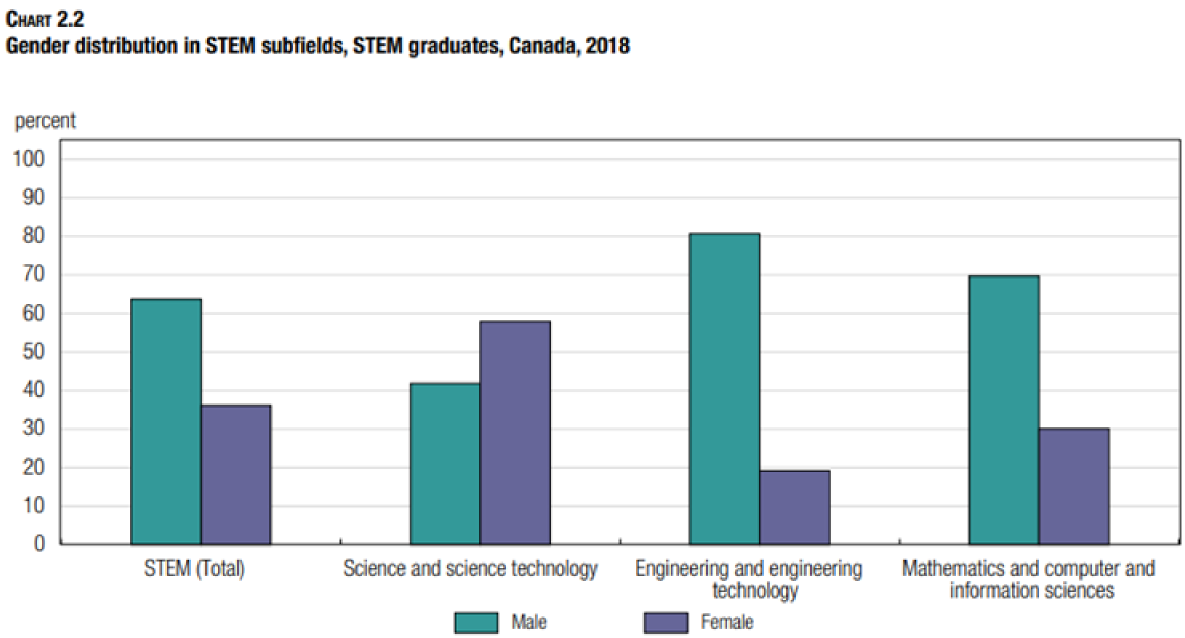

Figure 3.2: PSIS statistics showing the gender distribution of STEM graduates in STEM subfields in 2018[4;5]. In all of STEM, the field is dominated by men. Science and science technology is where we see that women dominate more than men, and this is likely due to biology being the largest discipline within science and science technology and being overrepresented by women.

but that there is little change in recent years, especially since enrollment has remained steady from 2010-2015.

3.3 American Data

The data collected in the U.S. provides a bigger, more specific picture of diversity statistics in STEM and specifically, physics, chemistry, and biology. Figure 3.3 from the American Physical Society using IPEDS data shows the trends of bachelor's degrees earned by women in the U.S., which includes U.S. citizens, residents, and temporary residents[6;38]. In 2020, women earned 58% of bachelor's degrees, 65% of biology degrees, 53% of chemistry degrees, and 25% of physics degrees. When considering gender, biology is overrepresented by women, chemistry has roughly equal representation, and physics is extremely underrepresented by women. The bachelor's degrees earned by women have increased over the last 50 years, but physics's rate of increase is much slower as compared to chemistry and biology. Succinctly, APS also provides trends for "individuals marginalized by race/ethnicity" in physics using IPEDS data[7;38]. Figure 3.4, individuals marginalized by race/ethnicity include African Americans, Hispanic Americans, American Indians, Alaska Natives, and Native Hawaiians and other Pacific Islanders that are U.S. citizens or permanent residents. This notably excludes Asians, and under IPEDS "White" includes those from the Middle East. Noting that as of July 2022, the percentage of the U.S. population that identifies as only white is 75.5%[6], the number of bachelor's degrees earned by individuals marginalized by race/ethnicity peak at 16%, which does not fill the remaining 24.5% of U.S. individuals who are non-white. This shows that these individuals are underrepresented in physics. Figure 3.5 from APS shows information for intersectional identities in physics. Women across all race/ethnicities are extremely underrepresented, and notably, women of colour (non-white women) are also underrepresented compared to men of colour[8;38]. In chemistry, data from 2015-2018 shows that 7.9% of African American individuals earned bachelor's degrees, compared to the 12.3% of the U.S. population that they make up[45].

In the U.S. across all STEM disciplines, degree attainment has increased, and increased

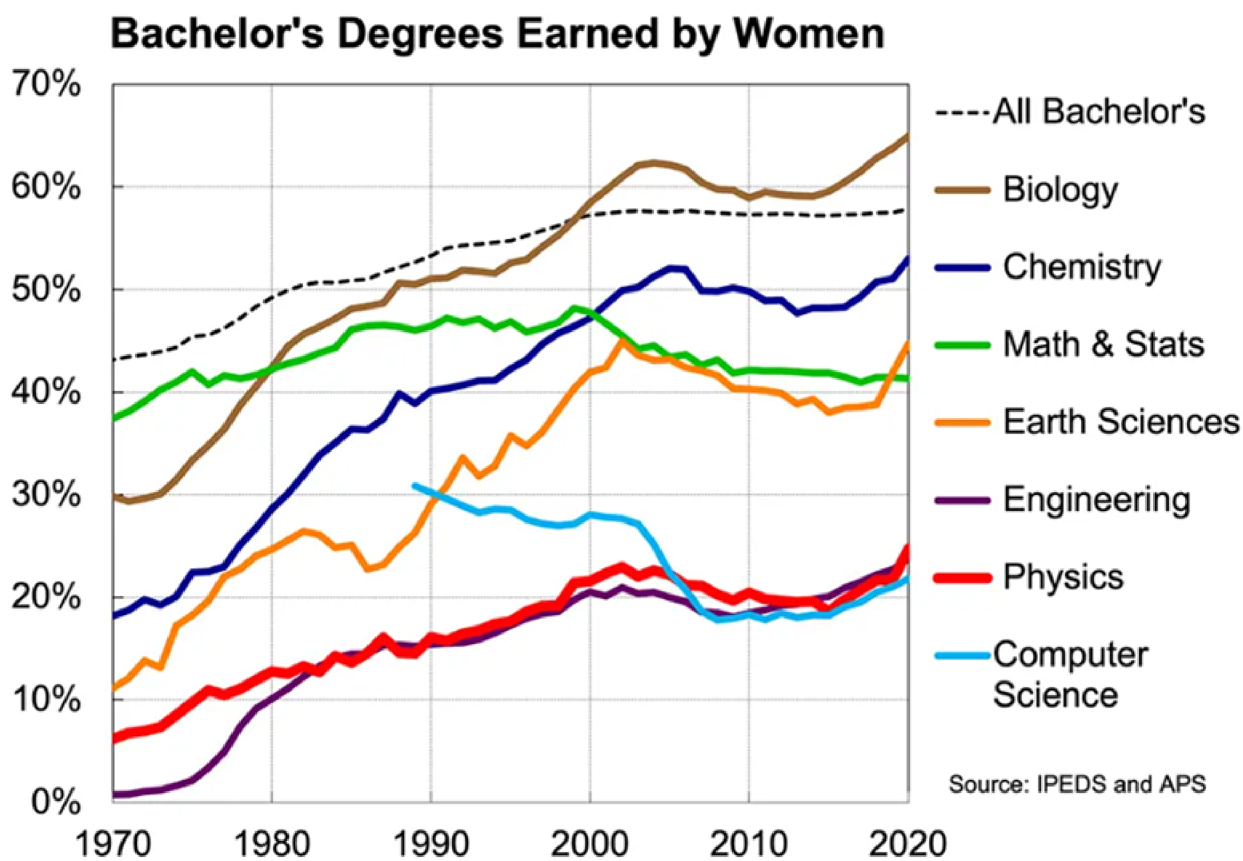

Figure 3.3: Bachelor's degrees earned by women citizens and permanent residents in the U.S. over time in STEM degrees[6]. These trends show an increase in women attaining degrees over time in most disciplines, except for mathematics and statistics, and computer science. These growth trends are not as strong in physics compared to chemistry and biology. In 2020, we see that physics is still largely underrepresented women as compared to the college-going population.

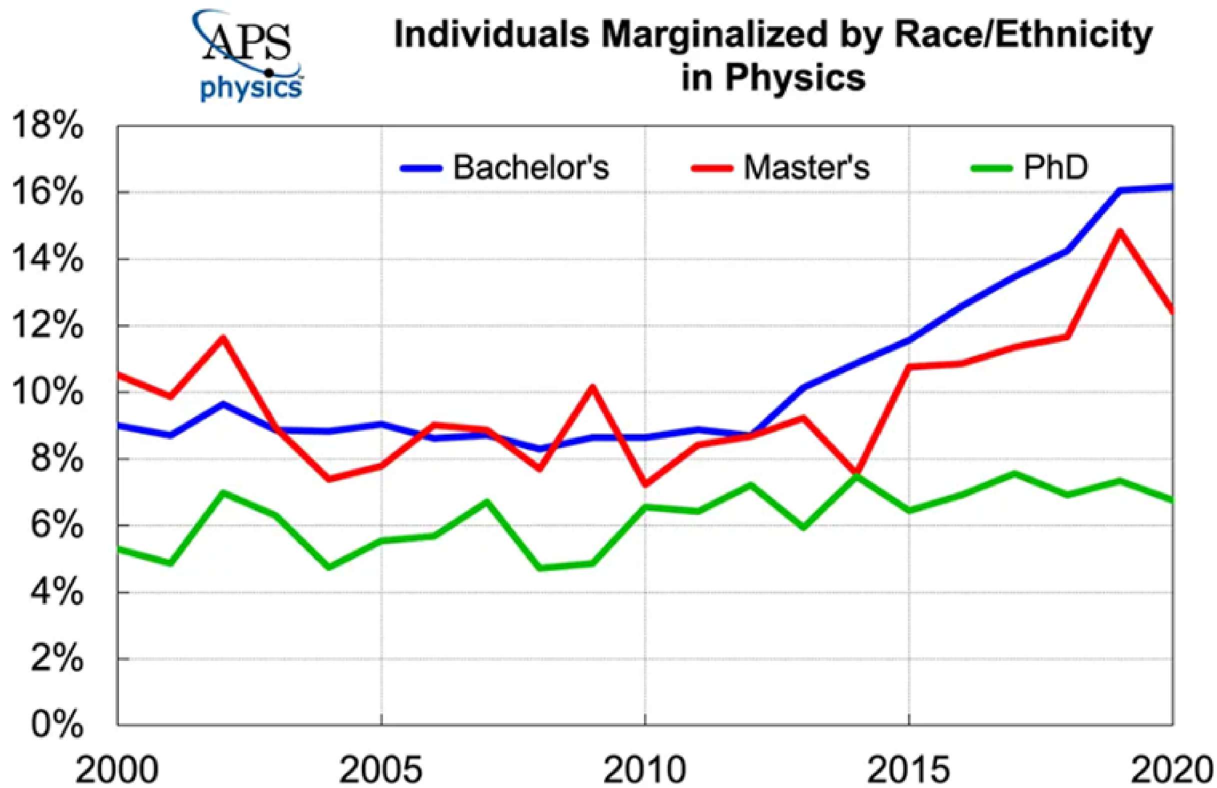

Figure 3.4: Trends of degree types of physics over a recent 20-year span of individuals marginalized by race/ethnicity from APS[7]. These individuals come from the groups of African Americans, Hispanic Americans, American Indians, Alaska Natives, and Native Hawaiians and other Pacific Islanders. If we consider the bachelor's degrees attained by marginalized individuals by race/ethnicity, we see an increase of attained degrees since 2013, but these numbers only climb to 16% of degrees attained.

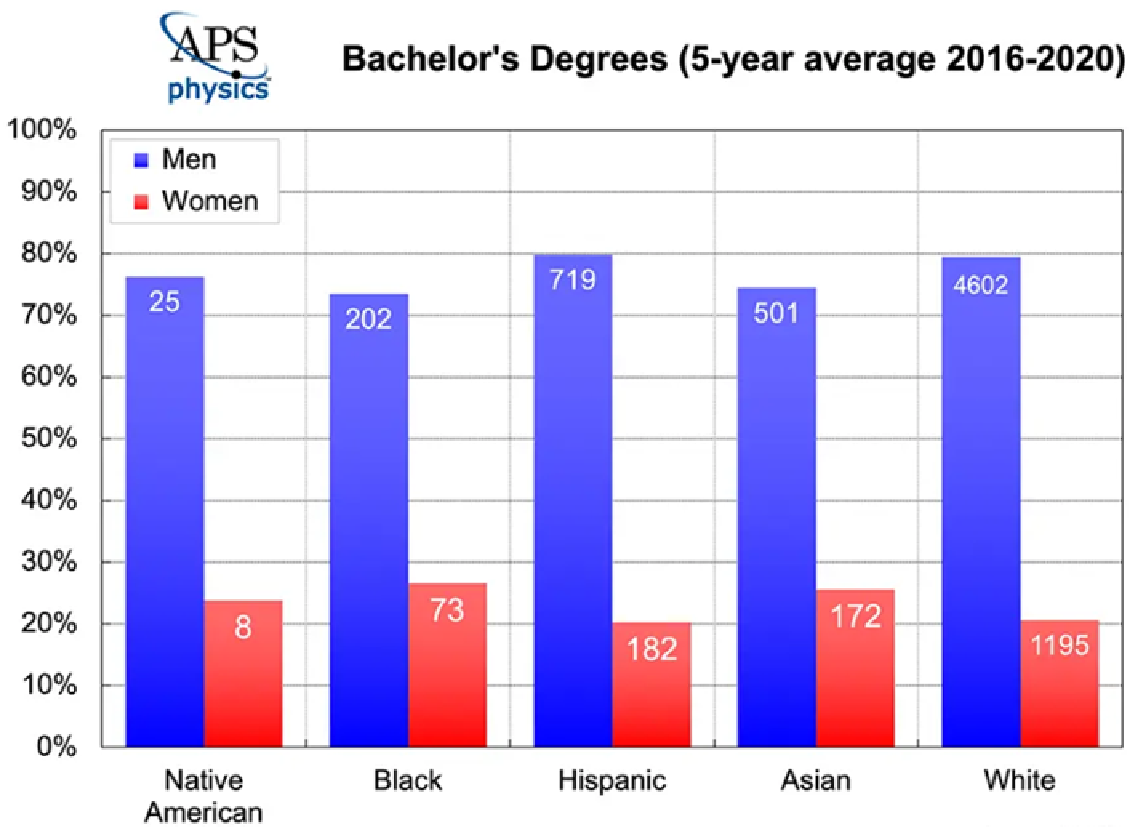

Figure 3.5: Bachelor's physics degrees earned by gender and race/ethnicity in the U.S. from 2016-2020[8]. This graph shows gendered data within race/ethnicity groups, and it shows that in physics, men are 70% of the discipline regardless of race/ethnicity. While these numbers are counted within race/ethnicity groups, we can point out that the number of white individuals attaining degrees is at least 6 times greater than any other race/ethnicity group.

Degree Earners	All STEM	Biology	Physics	Chemistry
All Women	58.6%	62.7%	20.6%	50.7%
All Men	42.4%	37.3%	79.4%	49.3%
White	59.1%	55.3%	69.7%	52.8%
People of Colour	40.9%	46.7%	30.1%	47.2%
Women of Colour	24.7%	28.5%	7.9%	22.8%
Men of Colour	16.2%	16.2%	30.6%	18.9%

Table 3.1: Percentage of degrees earned in the U.S. in STEM, biology, physics, and chemistry by gender, race, and gender and race together to consider intersectional identities[10]. In biology, women and white individuals are overrepresented, and women of colour are more represented than men of colour. In physics, men and white individuals are largely overrepresented at rates higher than in biology for women and white individuals. There is also more representation of men of colour than there are women of any race/ethnicity. In chemistry, there is approximately equal representation between genders, and we see this with women of colour and men of colour also having approximately equal representation compared to each other, but not to their white peers.

for women, as seen in Figure 3.6[9], and further shows that women are underrepresented in STEM compared to their men counterparts. The National Center for Science and Engineering and the National Science Foundation compiled data for degrees earned in 2018[10]. Looking at the intersections of gender and race/ethnicity in Table 3.1, we see that men and men of colour are more represented than their women and women of colour counterparts in physics, but there are more representative populations in chemistry and biology.

3.4 Discussion

Canada and the U.S. show similar gendered trends within STEM. While our populations are not the same, we can extrapolate the more discipline-specific data in the U.S. to be relatively similar to that in Canada. Anecdotally, physics has fewer women in their degrees compared to biology and chemistry in Canada. It can be seen that both countries struggle with appropriate representation within STEM. Biology overrepresents women, and chemistry with physics underrepresents women. If we extrapolate the U.S. trends to Canada, chemistry when combined with physics is pulled down by the extreme underrepresentation of women in physics. Figure 3.7 shows the Female STEM graduates as a share of total tertiary graduates,

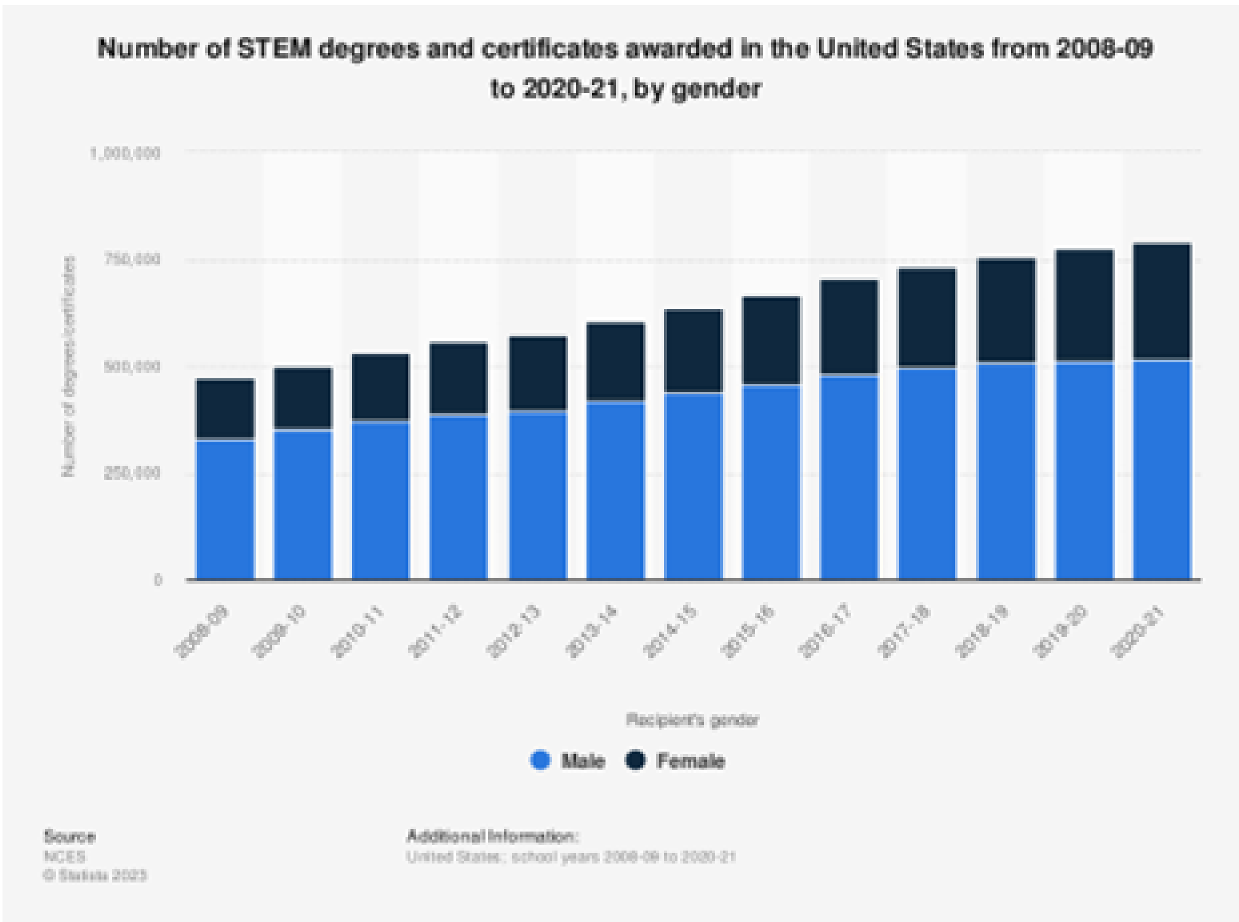

Figure 3.6: Data from the NCSES, analyzed by Statistica to show growth trends of degree attainment in STEM by gender[9]. Largely, we can see that the number of degrees attained in STEM has increased year by year. We see a higher representation of women over time, but they are still underrepresented in STEM.

by level of education, OECD, G7 countries, 2018 [4;5]. From this visualization, we can see that compared to the U.S. for all types of degrees, Canada has a higher representation of women in STEM.

In general, biology does not have equal representation but has a relatively similar representation of women as compared to the entire university-going population. Chemistry also is a more positive space for women and people of colour as they have higher levels of representation. Physics is struggling compared to other science disciplines, as shown in smaller rates of change for having women graduate from it, and generally has a lot of room to grow to be a more representative discipline. Within physics, women and people of colour would be considered to be underrepresented individuals, but this is not the case for women in chemistry and biology. Women of colour would be considered underrepresented in all three.

Addressing underrepresentation among groups looks different for each considered group. In STEM careers, degrees that typically have better gender representation are lower-paying than degrees that have underrepresentation. In fact, biology-related degrees tend to pay less than engineering and computer science fields (where the majority of the jobs are as well) [44]. Women in STEM can be lost along the pipeline from their high school education to their post-secondary education, to their careers [46;47]. Women see lower self-identification as a scientist or mathematician than men [48], and even women who do report strong self-identification, are less likely to pursue a major in either field. Women and people of colour can struggle to persist in STEM degrees due to feeling isolated by their identities compared to their peers [47;49;50], and can face negative pressures from professors through negative instructor talk [51;52], or their needs for counter-spaces are not met by the university. Many other factors affect underrepresented groups in their fields, such as non-inclusive and non-equitable teaching practices, assessment types, and classroom types that will be discussed further in a later section.

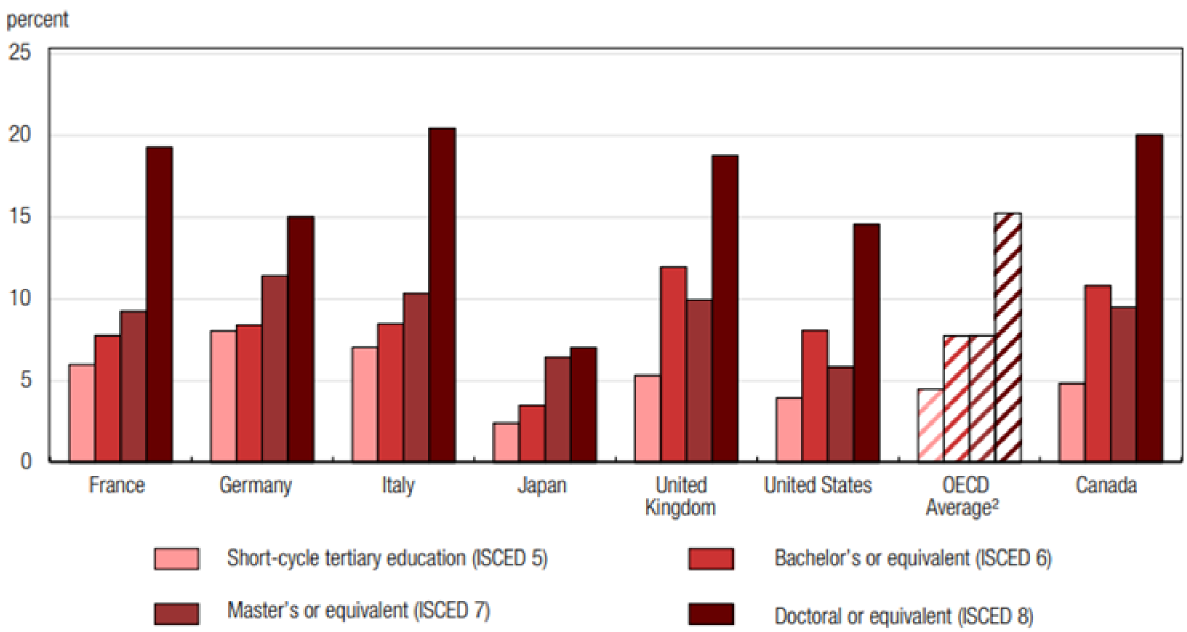

Figure 3.7: A comparison of degrees earned by women in STEM within the Organization for Economic Co-operation and Development (OECD) countries[4;5]. This graph shows that compared to most of the OECD countries, Canada is (roughly) leading in graduating women in STEM in bachelor's and graduate degrees. Except for Japan, the U.S. is graduating the least amount of women in STEM by percentage across bachelor's and graduate degrees.

Chapter 4

Learning Theories

To prime the discussion around equitable and inclusive classroom practices, it is useful to know how they ask students to learn in their spaces. Learning theories inform these practices and how knowledge is gained by a student, such as in traditional lecture styles or in active learning which are discussed in future sections. Learning theories provide a framework to describe how learners acquire, process, recall, and retain knowledge[53]. These theories come from multiple disciplines, such as sociology, philosophy of education, and psychology[54], and with the variety of disciplines participating, there is an abundant set of literature to help in our understanding of learning. Within the literature, there are 3 widely accepted umbrella theories of learning: behaviourism, cognitivism, and constructivism. Under these umbrellas, we can find more specified learning theories, especially in cognitivism, but since behaviourism and constructivism are the most commonly used learning theories in post-secondary classrooms, we do not focus on the specified theories.

Behaviourism was first defined by John B. Watson in the early 20th century as a reaction to depth psychology, or the relationship between the conscious and the unconscious. As defined by Watson, behaviourism is "a natural science that takes the whole field of human adjustments as its own. It is the business of behavioristic psychology to... predict and control human activity", "Behaviorist psychology has as its goal to be able, given the stimulus, to predict the response- or, seeing the reaction [to identify the stimulus that] called out the reaction"[55]. In a learning environment, this translates to a teacher-centred approach in which the role of the teacher is to create a specific environment for learners to elicit a specific, observable response[56;57]. Behaviourism assumes that given the correct environmental stimuli, all learners acquire identical understanding and therefore all students can learn[58;59]. With emotions, consciousness, meaning, and other mental activities excluded from this learning theory, an empirical approach is taken to focus on the observables[58;60]. The environmental stimulus presented to learners has 3 basic assumptions: the focus of learning is observable, the environment shapes the behaviour, and reinforcement is central to the learning process[56]. The theory also assumes that knowledge is independent of the learner, and becomes cemented in a learner through natural consequences, like rewards or punishments as tools for behavioural modification[53;54;58]. These consequences can come in the form of grades, prizes, recognition, and privileges[58], and are typically evaluated quantitatively with a simple examination to assess students' learning[61;62]. Behaviourism is useful for the development of competencies, demonstrating technical skills, and reinforcing memory associations[56], and has an emphasis on systematic routine, organized activities, and the teacher specifying the structure, content, and clear and accessible learning objectives with target outcomes[55]. Critiques of behaviourism say that it takes a perspective of "teachers being seen as the owner of knowledge, controller of the learning environment, with students acting as passive recipients; empty vessels to be filled with knowledge"[54]. The emphasis on short-term attainment of the learning outcomes assumes that the given education is successful if learners meet target outcomes, but these achievements might have questionable long-term effects, especially when the routine and repetition are taken away from the learner.

Cognitivism arose as an alternative to behaviourism by arguing that the association is only an isolated part of a larger learning process. Jean Piaget argued that conditioned association could fade if the successful repetition of a skill was not rewarded and that there must be assimilation with other concepts as part of an active process of skill building and modification for this association to persist[54]. The focus of cognitivism is on the process rather than the environment; to use the learners' internal environment and cognitive structure and tools such as insight, information processing, perceptions, and memory to facilitate learning by assigning meaning to events[56;57]. The teacher's role is to facilitate this cognitive processing by helping the learner "learn how to learn"[56]. The development of the learner's skills and capacity allows for learners to have more self-directed learning and critical thinking, and to develop skills that are applicable in other learning situations outside the behaviourism environment, regardless of context or topic. Reflection helps develop critical thinking and happens in stages: returning to and replaying the experience, attending to the feelings that the experience provokes, and re-evaluation of the experience[56]. Cognitivism has practical applications, such as emphasizing the assimilation of new knowledge with prior understanding, using a variety of mixed media in teaching to accommodate sensory preferences, and activating prior learning through the use of summaries, reading prompts or questions. A critique of cognitivism by social psychologists and sociologists is that it tends to have an emphasis on learning as an isolated individual, which often is not the case in classrooms and learning environments[54].

The most recent emerging learning theory is constructivism. Evolving from cognitivism and its roots in philosophy and psychology, constructivism exists on a multi-dimensional continuum that has created branches within itself, such as social constructivism[58;63]. The main, overarching theme is that learning is a search for meaning, and that knowledge is constructed through meaning from the students' individual experiences[53;56;58;59;63]. This knowledge is formed within the learner by integrating learning activities and experiences into existing knowledge and beliefs[56]. These learning activities involve active participation from the learner in their learning and often through interactions with other people. Constructivism leans into the idea that not all learners share the same understanding in the same environment[59]. Teachers who use constructivism assist learners in their understanding and how they developed certain assumptions, and prompt learners with questions as to whether those assumptions remain valid. They understand that learning is an interpretive, recursive building process by actively interrelating the physical and social world[58]. This process for developing learners happens through cooperative learning, experimentation, open-ended problems, and other practices that are rich in conversation[58;64].

Behaviourism and constructivism are the learning theories rooted in the teaching practices we later discuss. Traditional lecturing is rooted in behaviourism, while active learning is rooted in constructivism. Introducing these learning theories will be a foundational step to understanding how these two teaching practices work, and that they are indeed supported by learning frameworks in literature. The decision between choosing behaviourism, constructivism, or a combination of the two frameworks impacts the way students are learning and therefore inclusive and equitable classroom practices.

Chapter 5

Theories that Inform Equitable and Inclusive Classroom Practices

Equitable and inclusive classrooms are created when the needs of all diverse students are considered. To inform our teaching practices, we can rely on theory about the identities we want to support in post-secondary STEM classrooms, among others. This section provides an overview of some of these theories, what they do, and how they have been used within DBER. This section does not provide an exhaustive list of theories, and instead focuses on theories that we can situate in the gender and race-based data reported previously. Other theories like Queer Theory, Neurodiversity, and others not included are theories to consider learning about to ensure that students who are LGBTQIA2S+, neurodiverse, etc. are a part of these equitable and inclusive classrooms.

5.1 Critical Theory

Critical Theory is a philosophical approach that seeks to challenge existing cultural, political, and social structures. As defined by Marx in 1843, the "self-clarification of the struggles and wishes of the age"[65]. Critical Theory (capitalized) refers to generations of philosophers and social theorists in the Western European Marxist tradition, Frankfurt School. Critical

Theory seeks human "emancipation from slavery", acts as a "liberating influence", and works "to create a world which satisfies the needs and powers of human beings"[66;67]. Lowercase critical theory expands beyond the thought of the Frankfurt School with philosophical and normative bases for social inquiry aimed at decreasing domination and increasing freedom in all forms[66]. Common critical theories are feminism, critical race theory (CRT), and forms of post-colonial criticism. Horkheimer defines 3 criteria for a critical theory: it must be explanatory, practical, and normative[68], or to explain what is wrong with current "social reality", identify the actors to change it, and provide both clear norms for criticism and achievable practical goals for social transformation[69]. When used in education, critical theories can assist to reduce the impact and dependence of social systems on the education structure[70]. In education research, the use of critical theories can help center race, class, and gender within policy and classroom pedagogy[71]. How critical theory is used within education research depends on the specific theory.

5.2 Critical Race Theory

Critical Race Theory (CRT) emerged as a counter-legal scholarship to the positivist and liberal legal discourse of civil rights[72]. It critiques liberalism by examining the ways in which superficially neutral, "colourblind" laws perpetuate the systemic, unequal protections of rights and privileges in (American) society as the primary beneficiaries of civil rights legislation tended to be white individuals[69;72]. CR has a broader perspective beyond civil rights currently, where activists and scholars are interested in studying and transforming the relationship between race, racism, and power[68]. While CR began in law, it got quickly swept up into the field of education. In education, CRT has been to critique the racial inequities in educational policy, such as issues of school discipline and hierarchy, controversies over curriculum and history, and IQ and achievement testing[68;72]. There are 4 consistent tenets in CRT: 1) race is socially constructed, 2) racism in the U.S. is normal; an ordinary experience for most people of colour, 3) most anti-racist policies were formed to benefit and serve the interests of white elites, and 4) minority groups periodically undergo "differential racialization" to serve the needs of white individuals, and it is imperative that people of colour use their unique voices of colour to own their counter-narratives from having different experiences from the mainstream experiences[68;69].

CRT is a useful analytic tool that is used to help understand racial inequities in education. The tenets say that racism is ordinary, and it persists and thrives in the U.S. education system to this day. People of colour experience fewer opportunities within their disciplines had less access to resources, and higher dropout and lower graduation rates[73–76]. Students and faculty alike also feel isolation and microaggression from their white peers, affecting retention within less diverse fields. Physics, like many sciences, is dominated by white empiricism, the ideology that only white individuals, particularly white men have the fundamental capacity for objectivity, which results in noninclusive environments for people of colour, and especially women of colour[77]. CRT in physics education and the larger discipline-based education is the foundational framework for many race-based studies into understanding the unique experiences of people of colour in STEM (or physics) disciplines. The literature around CRT and racial inequities in STEM help inform more inclusive classroom practices and enforce the notion that we should pay attention to how race can factor into new educational tools.

5.3 Feminist Theory

Feminist theory was formed through feminist scholars thinking and writing about how and by whom knowledge is produced[78–80]. Contemporary feminism is often composed of theories of social transformation that describe a woman's life in a hierarchical, structured, male-dominated society[81]. While there are many different versions, or "waves" of feminism, they are all rooted in and responsible to movements for equality, freedom, and justice[82]. Feminist theory has 3 contemporary questions of concern: 1) subjectivity, narrative, and materiality, 2) global neoliberal geopolitics, and 3)global ecologies[82]. Current feminist theories employ tools of intersectionality to drive change in the world through critical intersectional perspectives, but intersectionality itself will be discussed as a separate theory.

Like CRT, feminist theory is applied in education to inform policies of best practice, as well as research. In STEM, women face unique experiences as compared to their men counterparts. Exploring sense of belonging, self-efficacy, and microaggressions in women in STEM, researchers are able to discuss reasons women are pushed out of STEM fields and develop instructional tools to help retain women in classrooms[73].

5.4 Intersectionality

Intersectionality is a framework that asserts that the human experience is jointly shaped by multiple social positions (such as race, gender, sexuality, class, and ability) and cannot be adequately understood by considering these social positions independently or exclusively[83–85]. These jointly connected experiences produce social experiences like privilege and marginalization, and the use of intersectionality allows researchers to seek to understand the interaction of these multiple social positions and how these interactions define societal power hierarchies[86]. Rooted in activism, intersectionality was coined by Kimberle Crenshaw who critiqued the "single-axis framework that is dominant in antidiscrimination law... feminist theory and anti-racist politics"[69]. The experiences of those who have social positions intersect, have experiences that are largely due to interpersonal and structural systems of oppression such as racism and sexism that are intersecting[84;87]. However, when tackling racism and sexism in policy, race-based laws in practice protected men of colour, and gender-based laws in practice protected white women, failing individuals but together to protect women of colour. Intersectionality started as a way to inform protections for women of colour amongst policies that neglected them. While women of colour inspired the intersectionality framework, it has expanded to include those social positions before for homosexual, disabled people, or low-income people of colour, or any composition of multiple identities that are uniquely considered. Exploring intersectionality in policy is important to ensure that everyone has protections within our societal power hierarchies until they are dismantled. Collins states that there are four guiding premises of intersectional projects: 1) race, class, gender, sexuality, nationality, and similar markets of power are interdependent and mutually construct one another; 2) intersecting power relations produce complex, interdependent social inequalities; 3) the social location of individuals and groups within intersecting power relations shapes their experiences within and perspectives on the social world; and 4) solving social problems within a given local, regional, national, or global context requires intersectional analyses[87]. She states that intersectionality is not a critical social theory yet, but is on its way to becoming one, and that manipulating intersectionality into a narrow pathway for a social theory would undermine its critical potential[88] as it currently has a lot of possibilities for work to be done as a discourse of social change, of hope, and of possibility.

Chapter 6

Teaching Practices

There are two main types of teaching practices in STEM education: traditional lecturing and active learning. Traditional lecturing is simple to define and often considered as passive knowledge transfer. Active learning is considered to be the converse of traditional lecturing, and therefore active in how students engage in their learning. Active learning has a vast toolbox of different techniques for actively engaging students in their learning that are relatively new compared to traditional lecturing. After providing an overview of both types of practices, we discuss the implications they have in post-secondary STEM classrooms and the critiques of the available literature.

6.1 Traditional Lecturing

Traditional lecturing, or lecture-based learning is rooted in behaviourism and had been used as a teaching method for centuries; it's traditional. In these classrooms, the instructor's primary role is to introduce and passively transfer knowledge, or they are teacher-centred environments[89]. Often this style of teaching is often done through oral language, or "chalk and talk". Chalk and talk colloquially is writing down what is being said orally, originally on a chalkboard, and has evolved to also include lecture slides instead of physically writing the content in real-time[90]. This method gives full play to the teacher's leading role to enable students to learn knowledge, but students lose the learning initiative and creativity at the same time[90].

6.2 Active Learning

The literature around active learning can be hard to parse as a first-timer engaging with the content. The fluid definitions, the literature failing to specify what instructional tools were used to achieve their results, and the questions around determining when improvement is or is not significant are just some of the barriers within the literature. This part of this chapter aims to provide clarity on the instructional tools used in active learning and how effective they are for their specified outcomes.

6.2.1 The History of Active Learning

As far back as the 1980s, there have been national U.S. reports and leaders in higher education that have called on higher education faculty to actively involve students in their learning process[91]. The U.S. Department of Education's 2022-2026 Strategic Plan includes several goals that go towards engaging their students in their learning, such as ensuring all students have access to these learning opportunities[92]. With these calls for engaging students in their learning, there is still resistance to making the change from traditional lectures to active learning. Active learning is perceived as a radical change to instruction or as an educational fad that is unnecessary since students engage in their homework and in their labs[13].

6.2.2 Various Definitions

Defining active learning with a specified, universally accepted definition has yet to be done, as often different authors interpret active learning differently in their respective fields. Rooted in constructivism, active learning opposes traditional lecturing, just as constructivism opposes behaviourism[93].

The literature can often interchangeably use "high-structured courses" with active learning, but high-structured courses are not a definition of active learning. They are instead a way to describe a classroom that uses active learning. In practice, high-structured courses include elements of active learning and can be described as having more structure the more active learning tools are used in the classroom.

Some have further defined active learning based on instructional methods commonly used such as small group activities within a classroom.[94] As there is no specific definition, we can generally define, and we do for this report, as any instructional method that engages students in the learning process[13;91].

6.2.3 Types of Active Learning Practices

The Flipped Classroom

A flipped classroom is the inversion of expectations in a traditional lecture. The learning that would typically take place inside the classroom through lecturing is done outside the classroom, and outside of the classroom activities such as homework are done in the lecture time[95;96]. Within the classroom, homework, or posed problems are discussed in groups so that students can actively engage with the material with access to their peers and instructor for discussion. Learning outside the classroom can happen through readings, videos, or other methods of knowledge transfer and is meant to prepare students for the problems worked on in the classroom. Martin describes the in-class portions of the flipped lecture as chaos; students are moving about the classroom to engage in discussions and educate each other. The chaos represents students being in control of their learning and not the instructor[95]. When teaching in a flipped classroom, students' misconceptions can be corrected in real-time before they emerge on an exam, resulting in more learning. Students are learning how to think when engaging with problems, and instructors are learning what students are struggling with.

Pause Procedure

An easy-to-implement instructional method is the "pause procedure". This is when an instructor will pause for two minutes every 12-18 minutes of lecturing to encourage students to discuss and update their notes in pairs[97]. Students can take this time to clarify material while increasing their understanding of the lecture material, which will better help students achieve the lecture's learning outcomes. Pause procedure also allows time for students to catch up on their note-writing. Combining pause procedure with traditional lecturing acts as a form of scaffolding for the students to stretch their learning in a smaller, but engaging way[98].

In-Class Worksheets

In-class worksheets are used to train critical thinking skills during the learning process[99]. They act as problem-based learning models to help students apply knowledge to known and new problems through scaffolding. Using pre-test and post-test criteria, Yulianti et. al, found that worksheets increase critical thinking ability and are feasible for use in the classroom to achieve learning goals outside of lecturing[100]. Worksheets have been shown to not only increase student understanding of the learning outcomes but also the increase self-efficacy of students in their studies[101].

Clicker Questions and Peer Instruction

Clicker questions can act as mini concept tests within a lecture. Originally done in the form of using a "clicker" to select answers, the technology has advanced to allow clicker-style questions on apps. Clicker questions can provide instantaneous feedback to students and the instructor[102]. Clicker questions have other uses, such as teaching case studies, but in the mode of active learning, we will focus on concept testing. Clicker questions have had mixed results in their effectiveness when compared to a control classroom without clicker questions. The study by Shapiro and Gordon confirms that students saw an improvement on exams from control to clicker conditions. This however comes from factual, multiple-choice questions that can mimic test questions and do not necessarily address misconceptions about concepts, or help students apply concepts to new topics. Shapiro and Gordon also state that clicker questions help improve learning by alerting students to important material. This study looked to document the effects of clicker questions in a classroom through targeted exam questions but did not speak to effective question-making to allow clicker questions to be effective. Clicker questions are often used to say an instructor is using active learning while providing these types of ineffective questions. Clicker question creation is notably not easy[103]. Using clicker questions to support learning goals will help guide the creation of the questions. Peer instruction is another term to describe the use of clicker questions. Peer instruction is known as an evidence-based teaching tool[104] but emphasizes working through clicker questions with pairs or small groups of students rather than alone. This can be done purely through discussion, or through a similar process to think-pair-share where students record their initial answers and can update their answers when talking to their peers. The impact of peer instruction is commonly measured in physics through normalized learning gains[105]. Vickrey, et. al., determined through pre-post FCI data that there are medium normalized learning gains through peer instruction[104]. Attrition is also impacted, where the dropout rate decreased by 15.5% between traditional lectures and peer instruction[106]. Higher order questions compared to recall questions yield better student results[104].

Think-pair-share

The think-pair-share method is exactly these steps: think, pair, share. When an instructor poses a question to their class, with this method students are prompted to engage and think about the questions individually, then pair up with another student to discuss their thoughts, and finally come together as a class to share these discussions[107]. The types of questions asked with think-pair-share are intended to invoke higher-order thinking skills, such as application or analysis. This approach helps students form mental connections through articulating their thoughts to their peers[97].

6.2.4 Discussion

The literature surrounding active learning tends to be vague surrounding what methods are effective and how they are implemented. Andrews et. al's study surrounding multiple instructors in an introductory biology course using varying amounts of active learning in their classrooms showed that student learning was not positively related to how much active learning was used or not used; I.e. the use of more active learning does not necessarily mean an increase in student learning[107]. Andrews et. al attributed this to active learning methods being used, but this was not communicated effectively. Instructors can implement actions when using active learning methods that affect how successful the method could be. The study highlights that there needs to be a better understanding of how to effectively use active learning and what aspects of a method are necessary for student learning to improve[107]. Another complicated aspect of the literature speaks to how there isn't necessarily a dichotomy between lectures with just lecturing and just active learning implementation[108]. Swisher's meta-analysis of 57 active learning studies shows that 72.4% of lectures devoted at least 20% of lectures to traditional lecturing, which is a significant amount of lecturing mixed with active learning[108]. Eddy et. al. 2015 also found a large variation of implementation in classrooms[109]. These studies often discuss that active learning is what improves classrooms, and they should instead discuss the pairing of lecturing and active learning together. Many of the active learning techniques mentioned here say the improvement in student learning and achievement, but the impact the individual methods have and the impact on different types of learners is not well parsed. Often these tools are used in tandem with each other, so it is difficult to see how effective each individual tool is.

A misconception about how much students learn with active learning also acts as a barrier to implementing these methods in classrooms. Students with active learning exposure in their lectures are said to learn more, but the students feel like they learn less[110]. Students have these negatively correlated feelings about their learning because of the increased cognitive effort necessary for participating in their learning. This misconception about their learning can be avoided if there is instructor intervention early in the semester to prepare students for the change to active learning, and for instructors to persuade their students that they are indeed learning, and learning more.

The implementation of active learning and the perception of the perceived benefit from active learning can influence student anxiety[111]. The amount of anxiety a student experiences can affect their performance. Studies have shown that moderate anxiety and stress can help improve performance, but once a threshold is reached, it decreases performance. The relationship between anxiety and performance is very dependent on the individual and the circumstances they find themselves in[112]. If the goal is to increase student participation, care should be shown to how participation is drawn on. Students are used to seeing their learning evaluated on exams, but active learning asks for constant evaluation which can raise anxiety, and if those evaluations happen in real-time, the risk of being called upon and being incorrect is stressful. Calling upon random students can have this effect, especially among populations who have lower self-efficacy. It is also important to consider that women and lower-performing students tend to experience increased anxiety compared to their peers[113]. We know that increased anxiety and stress can have a negative impact on performance and therefore retention, especially in STEM[114].

More generalized practices were found in Eddy et. al, 2015 in the PORTAAL paper that calls on evidence-based best practices such as giving students confirmation, praise, and encouragement individually, emphasizing hard work over ability, activities with course points, and error framing. These are elements of active learning that help reduce apprehension, add dimensions of accountability for students, and logic development, But I believe the scope of this is more so around logic development.

Chapter 7

Conclusion

STEM disciplines have a long way to come before they are inclusive and equitable at the post-secondary level. While some disciplines do better than others when we look at degree attainment, we need to consider the fact that students take breadth courses within STEM to support these degrees. Chemistry majors take biology, physics, and mathematics courses. Physics relies on a foundation of mathematics and is evolving to use computer science within courses. The effects of coming from a discipline that has more inclusion and equity but taking classes in a discipline that does not, and vice versa, are not well known. The CCSES is investigating this sense of belonging between majors taking different disciplines courses, but this research is ongoing.

To create more inclusive and equitable classrooms, educators should spend more time investigating equity theories such as CRT, Feminist Theory, and Intersectionality. The willingness to engage with these theories is more complicated in our current societal climate, understanding that these theories are coming under fire within government policy, but to move forward as a more inclusive and equitable field for learners and for careers, it is imperative.

Active learning tools are a great way to change up a classroom from a traditional lecture to engage all of our diverse students. The shift from learning in a more active environment in grade school to post-secondary can be jarring, and if we combat this by using active learning, we can help retain students at all levels of their degrees. Active learning does not come without faults though, and these are important to recognize. It is hard to understand exactly how well they improve student achievement, especially when they are measured by not necessarily equitable tools such as exams. We don't necessarily have exact results about how these tools are used together or individually and the impact they have in a classroom, and that is a space within the literature that has the opportunity for growth and future work.

Inclusive and equitable classroom practices are paramount to producing positive experiences and retaining diverse students within STEM. To understand these practices, the literature is overwhelming, as the building blocks to this understanding come from many different spaces. This report scaffolds these building blocks, such as the fundamental understandings of DEIJ, learning theories, and equity and inclusion theories to situate active learning as an inclusive and equitable umbrella set of tools to use in the classroom. Active learning when used well has many benefits on student learning outcomes and achievements and supports all types of learners and individuals. The literature around active learning supports these benefits as provides examples of evidence-based tools, but does not do a robust job at individualizing tools within active learning and how well they work on their own. Most of the literature discusses active learning tools used in conjunction with traditional lecturing, which muddies the significance of the results to an individual new to active learning. We make this muddiness more clear with critiques and discussions. This report adds a launching point for readers to continue their learning about inclusive and equitable classroom practices without getting overwhelmed by the "how do I begin", and transition readers to get excited by the "how do I keep learning from here?"

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