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Final Report

Harnessing the Digital Economy for Women of Colour in Undergraduate Science, Technology, Engineering, and Mathematics programs

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Table of Contents

Executive Summary

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Executive Summary
Harnessing the Digital Economy for Women of Colour in Undergraduate Science, Technology, Engineering, and Mathematics programs

Background: The Issue

COVID-19 has made us as a society more aware of equity, diversity and inclusion issues. Of the myriad issues, one of them is representation in the STEM fields. When we most needed it, we could not mobilize all the minds and talents that could have helped us. More diversity leads to a diversity of ideas which leads to the innovation we needed and need now. However, this is really old news. We have known for quite some time that North America has a diversity problem in STEM— women, people of colour, and women of colour are all significantly underrepresented in the STEM fields. Much of the research efforts around the issue of underrepresentation have been focused on access or recruitment. While well-intentioned, focusing on access and recruitment is not a complete solution. Studies (Cf. Eagan et al., 2014) have shown that upwards of 71% of underrepresented people in undergraduate programs who enter a STEM degree program do not complete the STEM degree. Underrepresented people are leaving STEM in droves. Focusing on access and recruitment is clearly not enough. We should also be directing our research and intervention efforts towards retention and persistence.

Objectives

The overarching objective of our project is to support a more diverse, equitable and inclusive STEM field. In this report, we explore current research about retention efforts for women of colour in post-secondary STEM programs. We ask three questions:

- What institutional, faculty, and personal strategies support women of colour towards completing their undergraduate STEM degrees?
- What is the Canadian state of the field in supporting women of colour towards completing their undergraduate STEM degrees? What are the gaps in Canadian research in this area, and what should the research priorities be to support Canadian retention efforts?
- How is the digital economy being leveraged in these strategies and efforts of retention?

Through our knowledge mobilization goals we intend to engage stakeholders, build awareness and increase visibility of the issue.

Results

Results of our project include three key findings: (i) strategies for retention of women of colour are successful when they support developing STEM identity and creating a sense of belonging, and when institutions internally critique their specific inequities and develop strategies to mitigate their specific barriers, (ii) there is an alarmingly significant research gap of Canadian data on STEM retention in general and specifically in the experiences of underrepresented people in STEM, and (iii) leveraging the digital economy to support specific digital skills development and to support STEM learning environments have the potential to have high and long-lasting equity and retention impacts.

Key Messages

Women of colour face multiple barriers to completion in their STEM programs. Presently there is a significant gap in data in this area. It is an imperative of equity for Canadian policymakers and researchers to mobilize to solve this data gap.

There needs to be a concerted effort to collect data across Canada about the retention and individualized experiences of underrepresented people in Canadian post-secondary STEM programs.

Through this research we created a clearinghouse of strategies that are successful for supporting the retention of women of colour in STEM.

Generally, strategies that are strengths-based and focus on supporting STEM identity and sense of belonging will equitably support retention of women of colour in STEM.

There are STEM culture barriers that exist across institutions and barriers that are specific to institutions. Both types of barriers need to be tackled to create equitable spaces for women of colour.

Institutions should critically analyze their own specific programs to identify institution-specific barriers to equity in STEM programs.

The digital economy can be a tool of support to create equitable learning environments and can be leveraged to empower learners in STEM.

A policy priority should be for STEM programs to intentionally create learning opportunities and goals that integrate their STEM courses with real-world digital literacies, including exploring real-world STEM problems of social significance through digital literacies.

Methods

For this study, we conducted a systematic review of the literature. We followed Bacca and colleagues' (2014) three-step process (p.133): (1) planning the search, (2) conducting the search, and (3) reporting the search. We conducted three separate analyses to answer our three research questions. In our first analysis, we coded for strategies that support the retention of women of colour in STEM. We then created three themes from our analysis. In our second and third analyses, we coded subsets of the data from the first analysis to answer our research questions about the Canadian state of the art and how the digital economy can support retention.

Full Report

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Background

The Issue

The problem of low proportionality of women of colour in the science, technology, engineering, and mathematics (STEM) fields is a wicked challenge. From governments to non-governmental organizations, to academia, and media, there is no shortage of groups calling attention to the problem. Canada's own Minister of Science and Sport, Kirsty Duncan, recently announced a "made-in-Canada" approach to promoting equity, diversity, and inclusion (EDI) in STEM at Canadian educational institutions ("Government of Canada," 2019). Even more recently, COVID-19 has turned our attention towards the issue of disproportional representation in STEM and made us as a society more aware of these EDI issues. Importantly, when we needed it the most, we could not mobilize all the minds and talent that could have helped us in our fight against COVID. The lack of diversity in our mobilized efforts due to lack of representation led to significant disparities and inequities in our response to the virus (Crooks et al., 2021; Pinho-Gomes et al., 2020), including for underrepresented communities (Ryan & El Ayadi, 2020), and in lack of innovative input (Gibson et al., 2020). More diversity leads to a diversity of ideas which leads to the innovation we needed and need now. There is no doubt that Canadian society will benefit from a more diverse STEM field. At the same time that diversity in STEM benefits wider society, on an individual level STEM provides social capital (Gutierrez, 2002) and supports upward mobility (Howcroft & Rubery, 2018).

An important goal and a wicked challenge, then, is to create a more diverse, equitable and inclusive STEM field. The reason this is a wicked challenge is that there is a multiplex of factors along one pathway to a STEM career. Researchers (e.g., Blickenstaff, 2005) have used the metaphor of "pipeline" to describe the long pathway to a STEM career. The term "leaky pipeline" arose because there are so many junctures in the pathway where women are lost to STEM. The pipeline metaphor has been rightly criticized (Cannady et al., 2014) because it evokes an image of a linear model of the STEM pathway with pre-determined junctures. In actuality, most pathways to a STEM career are curvy and recursive and constituted with much improvisation. Regardless of the limitations of the pipeline metaphor, the metaphor does accurately convey the "leaking" of women of colour from STEM starting at K-12 schooling to post-secondary education and beyond in the workplace. The leaky pipeline metaphor is also valuable because it demonstrates that there are leaks all along the pathway. Subsequently, focusing on one leak or one area cannot solve the entire problem— hence the wicked challenge.

So far, there has been a myriad of research and intervention efforts exploring ways to stop the leaks from STEM. In K-16 education, research on interventions has included: increasing self-efficacy (Falco & Summers, 2019), developing attitudes (Wieselmann et al., 2020), supporting identity (Steinke, 2017), and increasing motivation (Master et al., 2017), among others. Yet, despite these significant research and intervention efforts, there remain

significant disparities with diversity in the STEM fields. Much of these research efforts around the problem of underrepresentation have been focused on access or recruitment. While well-intentioned, focusing on access and recruitment is not a complete solution. American studies (Cf. Eagan et al., 2014) have shown that upwards of 71% of underrepresented people in undergraduate programs who enter a STEM degree program do not complete the STEM degree. Underrepresented people are leaving STEM in droves. Focusing on access and recruitment is clearly not enough. We should also be directing our research and intervention efforts towards retention and persistence— the pathway space after access and recruitment.

There are many points along the educational pathway that leak because of issues of retention and persistence. In our project we specifically focused on undergraduate education and women of colour because the access and recruitment efforts in K-12, although still necessary, have seen success. More women of colour are opting into STEM fields because of these valiant efforts at recruitment (e.g., McGuire et al., 2012). At the same time women of colour, with their unique intersectionalities, face many barriers in post-secondary education. It is then important to explore what occurs for women of colour after recruitment.

Retention/ Persistence

The terms “retention” and “persistence” are similar in that they both focus on the same outcome. However, they are different in that the term “retention” is institution-centric— i.e. the efforts an institution makes to retain students— and the term “persistence” is student-centric— i.e. the choices that students make about whether to persist or not (Rodgers, 2016). Our intention with this project is to explore both institutional systems and strength-based strategies that support women of colour in undergraduate STEM programs. Subsequently, although we only use the term “retention” in the title of our project, we included “persistence” in our study.

Notably, everyone suffers as a result of a lack of both retention and persistence. When a student leaves a STEM program before graduating, universities lose both their own investment in the student and government funding, the student loses out on the upward mobility and benefits of knowledge offered by a STEM education, and society loses out on the potential contribution the student could make as a result of their schooling (Parkin & Baldwin, 2009).

Retention and persistence are complex, with many issues contributing to women of colour leaving their STEM programs. These issues must be explored in relationship to each other, and within the contexts they occur (Ulriksen et al., 2010; 2015) qualitatively (we need to understand experiences) and quantitatively (we need to understand overall patterns through extensive data collection). Yet, this area is understudied in Canada mainly because there is a lack of Canadian data on post-secondary education (PSE) retention rates across Canada in general (Finnie & Mueller, 2008), let alone specifically on STEM retention rates for women of colour. Instead, Canadians have been relying on the more robust data (e.g. Seymour & Hunter, 2019) collected by our American neighbours. This is an issue because American and Canadian

institutions are different in several ways (Mueller, 2008). We note here there are a few Canadian studies (e.g. Finnie et al., 2008; 2010; Lambert et al., 2004; Malik et al., 2011; Wall, 2019) that explore retention in PSE. While important to our understanding, these studies provide small snapshots of the overall issue of retention and persistence in Canadian PSE.

Digital Economy

In this project, we explored how to leverage the digital economy to support the retention of women of colour in undergraduate STEM programs. In other words, we explored how digital information and technological innovations can support institutional and strength-based efforts for the retention of women of colour in STEM. At the foundation of the digital economy is 21st-century skills (see, Van Laar et al., 2017) that underpin critical requirements for participation and navigation in the current and future world (Berjakovic & Mrnjavac, 2020; Chinien & Boutin, 2011; West et al., 2019). 21st-century skills have been defined in different ways by different researchers. Still, definitions generally include a focus on digital skills combined with digital, problem-solving, creativity, collaboration, communication, critical thinking, and technical proficiency in coding, operating devices and software (Van Laar et al., 2017; Chinien & Boutin, 2011). These overlapping and converging skills reflect the adaptability that is required in the digital workforce writ large and are seen as fluid and contextual (Chinien & Boutin, 2011; UNESCO, 2018; West et al., 2019).

Digital skills are crucial for inclusion and success in the digital economy. Yet, despite the overarching necessity for these digital skills, there is a worldwide gendered divide (Mariscal et al., 2019; West et al., 2019). According to West et al. (2019), the digital skills gap between women and men has permeated all proficiency levels, from access and basic usage to more advanced creative and transformational applications of digital technologies. Largely attributed to patriarchal structures, the masculine stereotyping of ICT negatively affects women's digital self-efficacy and participation starting from mid-elementary school (West et al., 2019; Wilson, 2003). This impact continues as they progress through secondary and post-secondary education, further reducing access and exposure to technologies. Consequently, financial and labour inequalities prevail as girls progressively opt-out of STEM education and women progressively opt-out of STEM careers (Mariscal et al., 2019; West et al., 2019). Lack of representation, inclusion, compensation, and career advancement opportunities for women in STEM is exacerbating gender inequality. Notably, it excludes women from accessing and developing the digital skills necessary to be successful and productive members of the digital economy.

Objectives

The overarching objective of our project is to support a more diverse, equitable and inclusive STEM field. We specifically focus on the retention and persistence of women of colour in undergraduate STEM programs. In support of this objective, we developed research and knowledge mobilization subgoals.

In meeting our research subgoals, we asked the questions:

- What institutional, faculty, and personal strategies support women of colour towards completing their undergraduate STEM degrees?
- What is the Canadian state of the field in supporting women of colour towards completing their undergraduate STEM degrees?
    - What are the gaps in Canadian research in this area, and what should the research priorities be to support Canadian retention efforts?
- How is the digital economy being leveraged in these strategies and efforts of retention?

In order to understand the state of the field, we coded and analyzed the literature and produced themes of retention strategies, we identified gaps and highlighted research priorities in retention efforts, and we specifically identified culturally relevant and responsive retention efforts. We then analyzed two subsets of data: (i) the Canadian subset of this data, and (ii) the technology subset of this data.

Our knowledge mobilization subgoals include sharing our research, engaging stakeholders (women of colour, academics, higher education administration, students, the public, not-for-profits, businesses), and building awareness and increasing visibility of the issue.

Methods

For this study, we conducted a systematic review of the literature. A systematic review is similar to a literature review, but the method of design is "explicit, transparent and replicable in order to overcome many of the potential problems associated with the design of traditional reviews" (Torgerson et al., 2017, p.166). We followed Bacca and colleagues' (2014) three-step process for conducting systematic reviews (p.133):

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- Step 1: Planning
    - This step describes the rigorous and meticulous planning before conducting a systematic review. At the conclusion of this step, researchers have identified the journals, search engines, keywords and Boolean search operators, categories for analysis, and inclusion and exclusion criteria.

- Step 2: Conducting the Review
    - This step describes the activity of collecting primary data sources, coding, analyzing the content, and synthesizing the data. At the conclusion of this step, researchers will have created themes from the data and will produce findings.

- Step 3: Reporting the Review
    - In this step, Bacca and colleagues (2017) follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). The authors of PRISMA developed a 27 item checklist for reporting systematic reviews.

Search Strategy

In determining our research strategy, we planned the three types of databases in which we would conduct our search: Google Scholar, Omni, and in the archives of journals. We then developed a systematic search methodology. First, we established the keywords and Boolean operators for our Google Scholar searches. This was an iterative process; we conducted multiple searches utilizing various sequences of keywords and Boolean operators with the purpose of refinement. We then compared the results of these initial searches for inclusivity. One example of a successful search string for Google Scholar is: AND retention AND "computer science" "women of color" -doctoral -workplace -disability - sexuality -sport -crime -police -military -violence -HIV -geography -cell. We then utilized results from the Google Scholar search to conduct searches in our university's academic search tool, Omni. We took the Canadian data generated by the Google Scholar search and entered each data into Omni. Data entries generated records containing searchable subject keywords. We then conducted a search for each subject keyword that included Canadian keywords (e.g. Canada, Ontario, Atlantic Provinces, Province). One example of this type of subject keyword search is for the book "Too Asian?": Racism, privilege, and post-secondary education (Gilmour, 2012). This record contained the subjects: Racism in higher education- Canada, Minority college students- Canada, and Race awareness- Canada. Finally, we used our Omni and Google Scholar searches to find journals with focusing on higher education and/or STEM and/or Underrepresented People and/or Canada. We searched the journal archives of 9 different journals including the Canadian Journal of Higher Education, the Journal of College Student Retention, Research, Theory and Practice, and the Journal of Women and Minorities in Science and Engineering.

Inclusion and Exclusion Criteria

Similar to Bacca and colleagues (2014), we first established general criteria and then next established specific inclusion and exclusion criteria. The process of establishing general, inclusion, and exclusion criteria for our overall research question, “What institutional, faculty and personal strategies support women of colour towards completing their undergraduate STEM degrees?” was straightforward and linear. The criteria were established before data collection, and we followed our planned method. Our original intention was to analyze a Canadian subset of these results to answer the second question, “What is the Canadian state of the field in supporting women of colour towards completing their undergraduate STEM degrees?” and a digital technology subset of these results to answer our third research question, “How is the digital economy being leveraged in these strategies and efforts of retention?” However, we were only able to accomplish our planned method with the third question. We only found two Canadian articles in our search that somewhat met the specific inclusion criteria of exploring retention of women of colour in STEM fields. Since an objective of our study was to understand the Canadian state of retention in STEM, we decided to conduct a future study with broader inclusion/ exclusion parameters for Canadian retention articles.

General Criteria

- Studies published between 2000 and 2021
- Studies printed in books and book chapters, articles, conference proceedings, and not-for-profit reports
- Studies about undergraduate women and retention in STEM
- Studies in English

Our search strategy for each of our searches was iterative. Each search began by going through titles and abstracts. We downloaded all the data that met our general inclusion criteria. We then removed duplicates across the searches, and coded and analyzed the remaining documents for our specific criteria. We removed any article that did not meet our specific inclusion/ exclusion criteria.

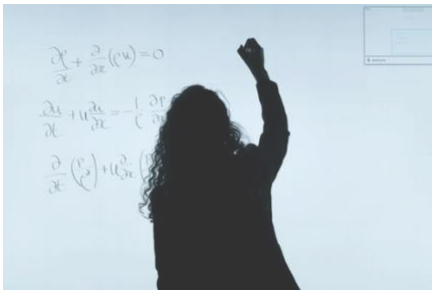
Specific Criteria

- Studies that include the complete intersection of retention of women of colour, STEM, and undergraduate students.
- Studies with a finding of retention in undergraduate STEM programs. Although our general criteria included studies about retention in STEM, we noted through our second iteration of the data that while many studies used the term retention prominently in their titles or abstracts, the actual study content, goals, and findings were only loosely connected to retention. The connections to retention these studies actually stated were usually through possible implications of their study or as an argument for the need for their study.

- Besides the exceptions listed in the exclusion criteria below, we follow Song and colleagues (2020) category definition of STEM programs. In this definition STEM programs include: the basic and applied sciences, or any program with a focus in biology, chemistry, general science, and physics; technology, or any program with a focus on information technology, technology, and computer science; engineering; or mathematics.
- Studies that include women and women of colour in their retention findings. We note that many studies included "women" and "people of colour" as categories of participants in their studies but did not include "women of colour" as a category. In these cases, we coded and included retention findings that overlapped the two categories of "women" and "people of colour."

Exclusion Criteria

- Studies that contained a deficit perspective of women of colour. Some studies ignored the systemic issues that contribute to women of colour's experiences in their post-secondary STEM programs and instead located problems within the students (Samuelson & Litzler, 2016). These studies often focused on the "under-preparedness" or "ability" of women of colour to complete their STEM programs. Strategies for retention in these studies tended to be remedial in nature. In other words, strategies looked to "fix" the learner.
- Studies that only focus on achievement. We noted in our coding process that many studies conflated achievement with retention. While some studies (e.g., Ceglie, 2020) have demonstrated that achievement can be connected to retention and that lack of achievement can lead to attrition, achievement and retention are not the same things. Some students leave STEM even with high achievement (Katz et al., 2006) and some students with low achievement leave STEM for reasons other than achievement (Corwin et al., 2020).
- Studies that focus on what Song and colleagues (2020) term "STEM-adjacent" (p.229) programs. STEM-adjacent programs apply STEM fields to their particular field of study. These fields include health studies, medicine, kinesiology, education, and economics, among others.
- Studies conducted outside of North America. Our original intention was to include international studies in this project. However, when coding the data and reading each study, we recognized substantial contextual differences between North American studies and other international areas. For example, in contrast to the North American context, some countries have parity between women and men in STEM disciplines (UNESCO, 2019).
- Dissertation and theses.



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Results

We conducted three separate analyses to answer our three research questions. In this section, we present the results from these analyses.

Result #1 Strategies that Support the Retention of Women of Colour in STEM

In our first analysis, we sought to answer the question, “What institutional, faculty and personal strategies support women of colour towards completing their undergraduate STEM degrees?” In exploring this question, we coded all the included articles. We found three themes: (i) strategies that develop STEM identity, (ii) strategies that develop a sense of belonging, and (iii) strategies that support academic needs, and systemic/top-down strategies.

Identity

Identity is not a fixed entity that is possessed; instead it is intersectional and fluid and built on social and cultural contexts (Leggett-Robinson 2020). As such, STEM identity is not monolithic; rather, it intersects and is influenced by student’s gender, racial, and ethnic identities (Carlone & Johnson, 2007; Chavous & Drotar, 2016, Fries-Britt et al., 2013; Ulriksen et al., 2010) and is solidified through the acceptance and recognition by meaningful others in the STEM or the outside community (Carlone & Johnson, 2007; Flowers & Banda, 2016; Lane, 2016). Notably, STEM identities are supported and reinforced through racial and cultural identities. Racial and cultural identities that are connected to STEM identities play a key role in promoting well-being, community, resilience, and persistence in STEM (Cajax et al., 2018; Chavous & Drotar, 2019; Holley & Joseph, 2020).

Significantly, lack of representation coupled with a dominant white male hegemonic culture in many STEM programs create an environment where racial, gender, and culturally diverse students are forced to negotiate or disconnect conflicting aspects of their social and cultural identities in compliance with prevailing cultural norms (Carlone & Johnson, 2007; Chavous & Drotar, 2019; Leggett-Robinson, 2020). A student's STEM identity has the potential to impact how they learn, interact, and grow, and ultimately their retention in their STEM academic programs. Still, STEM programs and culture present a number of barriers to women of colour that challenge their STEM identities. Therefore, strategies that challenge barriers to developing STEM identity and at the same time support and value racial and cultural identity are critical in supporting women of colour in STEM programs.

Table 1 Strategies that support developing and strengthening STEM identities

Strategy	Description	Reasoning
Mentorship	It is notably a mutually beneficial relationship. Can include peers, faculty or academic advisors.	*reduces the effects of stereotype threat (Beasley & Fischer, 2012) *helps with cultural knowledge to navigate academic systems (Ceglie, 2020) *initiates students into a community of practice (Ceglie, 2020)
Support cultural and racial identities	This includes using real-world examples from home communities in class, introducing role models, and including work from non-white scientists and mathematicians.	*classwork connected to home communities and service help learners to "see the impact of their work and to make a difference in the world around them" (Lindemann et al., 2016, p.234) *students can relate and see themselves in the role when they see others that look like them in that role (DuBow et al., 2016) * develops science self-efficacy (Brahmia, 2008)
Provide Research Opportunities	Opportunities include structured and unstructured and paid and volunteer research in the student's STEM field. Giving students opportunity to present their research is especially beneficial.	*through research experiences, students both develop STEM behaviours and are recognized for their STEM ability (Barrow et al., 2016) *bridges course learning to science practice (Barrow et al., 2016) *introduces students to the "joy of discovery and intellectual stimulation" (Robnett et al., 2020, p.194) *students contribute to knowledge creation (Lane, 2016)

Sense of Belonging

Belonging is a fundamental human need that can be characterized by feelings of connectedness, meaningful relationships, support, and acceptance in a specific social setting (Fink et al., 2020; Lane, 2016; Leggett-Robinson, 2020). Perceptions of belonging in STEM are a strong predictor of student success and retention (Johnson & Elliott, 2020; Lane, 2016; Lewis et al., 2016), especially when belonging is supported in courses (Fink et al., 2020). In STEM education, perceptions of being valued as legitimate members of their fields and academic communities are particularly crucial for inspiring scholarly engagement and building STEM identity (Leggett-Robinson, 2020). However, when students lack a sense of belonging they are at risk for experiencing feelings of isolation, imposter syndrome, and disconnectedness from their academic communities. These feelings consequently undermine self-efficacy and achievement (Leggett-Robinson, 2020; Lewis et al., 2016).

Lack of belonging is particularly pervasive for historically marginalized students, especially women of colour (Johnson & Elliott, 2020; Leggett-Robinson, 2020). Women of colour consistently report a lower sense of belonging than other student groups such as men and white women. Women of Colour face identity threats and barriers to their belonging at the

intersection of race *and* gender (Leggett-Robinson, 2020). A key factor that inhibits women of colour's sense of belonging in their STEM classrooms and academic communities is gender and racial bias and discrimination, or perceived lack of gender compatibility in STEM (Fink et al., 2020; Johnson & Elliott, 2020). Supporting women of colour's sense of belonging in STEM is critical for their success in higher education and their respective fields.

Table 2 Strategies that support developing and strengthening sense of belonging in STEM

Strategy	Description	Reasoning
Create an inviting environment	An inviting environment in STEM programs and classrooms includes inclusivity, diverse representation, cultural competence, allowing for student voice, and community.	*supports students against the competitive culture of STEM (Esquinca, 2021) * students develop a sense of belonging when there is a more diverse representation (DuBow et al., 2016) *giving students a voice allows them to actively resist barriers (Rodriguez, 2020)
Counterspaces	Counterspaces are considered academic safe and inclusive social spaces for underrepresented students that *counter* the dominant educational climate and culture.	*Counterspaces support students' well-being through challenging deficit narratives, providing a place free of racial discrimination and microaggressions, creating a sense of belonging, supporting intersectional STEM identities, and validating experiences (Leggett-Robinson, 2020).
Faculty and teaching	Faculty can play an active role in creating a sense of belonging through showing care, monitoring their own biases, teaching through active and collaborative learning, making connections to learner's personal identities, and promoting confidence and ability.	*faculty have a lot of influence on the experience and sense of belonging of students (Robnett et al., 2020). *when faculty reach out and show care, it invites learners into the science community, and they feel a sense of belonging (Ceglie, 2020). *collaborative and interactive teaching can mitigate bias and discrimination in the classroom (Johnson et al., 2017) *approachable faculty allow students to approach them when students need help or do not understand, helping the student to navigate their needs (Perna et al., 2009)

Academic Needs and Systemic/Top-Down Strategies

Faculty and institutions play an important role in supporting women of colour in their STEM programs. Many barriers for women of colour are ingrained in programs and the culture of STEM. Institutions need to do internal reviews to determine the specifics of their own culture and barriers (Chang et al., 2014; Lane, 2016; Maltby et al., 2016) and to critically determine

where inequities lie in their programs (Morton, 2020). Once a university or faculty has determined where inequities lie, they can then strategize solutions. Some universities have created programs specific to the needs of their institution that support women of colour in STEM. Our research uncovered many different post-secondary programs across the US that support women of colour in STEM. We share an example of two programs in this report:

- AEMES (Achieving Excellence in Mathematics, Engineering and Science) Program is a program at Smith College in Northampton, Massachusetts. This program gives mentorship and research opportunities to underrepresented women in STEM. There is also outside programming that supports identity development and sense of belonging of students (Katz et al., 2017).
- ICP (I Can Persist) STEM Initiative is a program at Indiana University in Bloomington, Indiana. The program is set up for women from African American, Latinx, Asian, and Indigenous ethnic communities. The program is meant to be a counterspace and offers different opportunities that support and empower women in STEM (Davis et al. 2020).

Barriers for women of colour can be specific to institutional STEM courses and programs, but there are also barriers that exist across institutions because of the culture of STEM. One common example of a barrier that exists across campuses is weed-out courses. Weed-out courses are large introductory courses that are feeders to multiple STEM programs (e.g., calculus, chemistry, physicsI). These courses are usually packed with information, lack interactive teaching, and have a “survival of the fittest” mentality underlying course design (Robnett et al., 2020). Often stereotypes, bias, and discrimination are embedded into these courses.

Table 3 Strategies that faculties and institutions can use to support women of colour

Strategy	Description	Reasoning
Develop faculty capacity	This includes giving faculty professional development about culturally responsive teaching, valuing the service of faculty in supporting underrepresented students, giving faculty resources, supporting teaching development, and hiring diverse faculty that is representative of students	*even a small number of faculty can influence a program to be more inviting (Speed et al., 2019). *faculty need to be a part of the change or change will not occur (Nahapetian et al., 2019). *students feel more belonging to the field and program when faculty represent their own communities (Posselt, 2018). * the manner in which faculty demonstrate support is important to the sense of self-efficacy of learners (Fries-Britt et al., 2010).
Focus on anti-deficit support and anti-deficit policies	This strategy locates the issues in the institution (culture and programs) and not in the students themselves. Instead of remediation, the focus of support should be on inclusion and enrichment.	*institutions cannot change when they locate the problem in the student (Hodari & Johnson, 2019). *allows institutions to value the contributions of all students (AAPT, 2016). *deficit approaches to intervention do not change situations and therefore cannot have a lasting impact (Samuelson & Litzler, 2016).
Focus support on the first two years	Strategies include supporting strong teaching in weed-out and introductory courses, creating clubs and organizations, enrichment support, and creating smaller class sizes.	*women of colour are most at risk of leaving STEM in the first two years (Chang et al., 2014). *first-year courses are usually not taught by the strongest faculty and therefore discourage students (Richardson & Crabtree, 2020). *students can leverage the success that they developed earlier in their STEM academics (Robinson et al., 2019).

Result #2 The Canadian State of the Field

In our second analysis, we sought to answer the questions “What is the Canadian state of the field in supporting women of colour towards completing their undergraduate STEM degrees?” and “What are the gaps in Canadian research in this area, and what should the research priorities be to support Canadian retention efforts?” We have very swift answers to these questions:

The state of the field is lacking. There are massive gaps everywhere.

We only found two Canadian articles in our search that somewhat met the specific inclusion criteria of exploring retention of women of colour in STEM fields. However, the absence of data is also data, and in this section we discuss the equity implications of the lack of Canadian data.

In 2008 Finnie and colleagues conducted a revolutionary Canadian study on access and retention in Canadian post-secondary education. They noted that until then, not much data

existed that would support pan-Canadian studies on retention. Since then, Finnie's and colleague's work have been somewhat extended, but mostly not into STEM areas. Only one of the 63 articles that cite Finnie et al.'s book focuses on STEM (Finnie & Childs, 2018). Notably, the focus of this one article is on access and not retention. The lack of Canadian data is a problem for primarily two reasons. First, the absence of Canadian data and research means we need to rely on the robust American production of data and research about the retention of women of colour in undergraduate STEM programs. Yet, our Canadian situations, policies, and institutions are vastly different from American institutions (Mueller, 2008). Making correlations between the two countries may only allow us to mitigate issues; it will not allow us to solve our uniquely Canadian issues. Second, data helps us to understand the problem so we can strategize solutions. Data has already demonstrated discrepancies in access to a Canadian university education. Indigenous peoples, first-generation students, people of colour, immigrants and students who experience low socio-economic status all experience barriers to accessing post-secondary education (Canada Millennium Scholarship Foundation, 2009). Data has also already demonstrated that students experience stereotype threats, bias and discrimination throughout their Canadian post-secondary experiences regardless of their fields of study (Crichlow et al., 2010). Additionally, the culture in STEM fields is typically more problematic and toxic to gender, race, and class than other fields (King et al., 2018). We can surmise the difficulties the intersection of all these issues will create for women of colour in STEM programs, but we do not understand the Canadian specifics of these issues. The fact that we do not have data about what happens to students and especially women of colour in STEM programs, is an equity issue for all the reasons we outlined in the background section.

We note here a study by Wall: while it did not meet our criteria for inclusion because the study did not disaggregate the category of woman, it is somewhat informative as to why we need more data. Wall (2019) provides a strong and recent quantitative analysis regarding the persistence rates of women in Canadian university STEM programs. Wall found a 34% attrition rate of women (compared to 28% of men) from Canadian STEM undergraduate programs. This attrition rate includes 23% of women who transfer to non-STEM degree programs and 11% of women who leave post-secondary education altogether. However, a limitation of Wall's study was that they did not disaggregate the category of "woman." Women have intersectional identities— all of which or some which— and in relation to each other or not— can influence the experiences that lead to attrition. Therefore these percentages are not necessarily representative of the whole category of "woman." Importantly, the aggregated category of woman is assumed to represent the majority (the white woman) which in turn negates and others those who are not white (Pawley, 2019). Studies (e.g., lord et al., 2014) have demonstrated significant differences in experiences and proportions of retention for different ethnicities and cultures of women within the subfields of STEM. Additionally we make the intersectional identities of women invisible by including all women in one category and not disaggregating the data.

Result #3 Results About the Digital Economy and Retention

In our third analysis, we sought to answer the question, “How is the digital economy being leveraged in these strategies and efforts of retention?” In exploring this question, we coded all the included articles, and found two themes: (i) leveraging technology to support women of colour in STEM programs, and (ii) leveraging technology to give women of colour tools of and for the digital economy.

Leveraging Technology to Support Women of Colour

West and colleagues (2019) remark that intervention with technology and, therefore research, is only in its infancy stages. Subsequently, there is a real lack of worldwide intersectional data exploring the affordances and barriers of the use of technology to support women of colour. As such, there were few articles in our data set that leveraged technology to support the retention of women of colour in STEM.

- These studies included online teaching tools that were useful in creating virtual learning centres (Kane et al., 2013), helped students learn content before taking courses (Harrington et al., 2016), and helped create online community (Biswas & Lin, 2014). Of note is the artificial intelligence called ALEKS that responsively aids in mathematics learning (Bouniaev et al., 2014).
- Three studies found success because of the flexibility of hybrid learning (Drew et al., 2016; Matlin et al., 2019; Muis et al., 2010).
- Technology was also leveraged to support specific pedagogies, such as giving students a voice in course content (West et al., 2019) and using digital environments to support community service (Allison & Turner, 2017).

Levering Technology to Give Tools of and for the Digital Economy

In this third and final analysis, we sought to understand how STEM programs are leveraging digital literacy skills in their programs to support retention and to empower women of colour towards inclusion in the digital economy. Digital literacy is literacy skills that allow for meaningful engagement with technology (West et al., 2019). Digital literacy has become necessary in the digital economy for upward mobility and inclusion (West et al., 2019; Wing, 2006).

Table 4 Strategies that leverage technology to give tools of and for the digital economy

Strategy	Description	Reasoning
Promoting Digital Competence	Programs use meaningful engagement with technology to promote the digital skills needed in the digital economy.	*including the learning of computational problem-solving allows students to integrate their STEM courses with real-world digital literacies (Burg et al., 2015) *giving students real-world problems to solve together with computational reasoning (Shamir et al., 2019) supports the development of STEM identity while supporting digital literacies *we note here a novel and innovative intervention where a university created a STEM incubator to promote the digital economy (Burg et al., 2015)
Integrating Digital Skills throughout the curriculum	Programs are intentional in mapping out digital literacies and integrating them into STEM programs.	*gives students the tools needed for upward mobility (Darden et al., 2019) *project-based and informal learning help to establish connections between STEM and digital literacies (West et al., 2019)
Digital Rights	Educate students on their own digital rights and employ digital equity in teaching students.	*learning about digital rights and digital learning that is gender-transformative empowers students (West et al., 2019)

Research Strengths and Gaps

Through this research synthesis, we were able to answer our first question about strategies that support women of colour in STEM post-secondary learning environments. We found three themes and these themes will be able to inform the development of new strategies and programs to support women of colour in Canadian STEM programs. Through this study, we were also able to document emerging areas that support the development of digital literacies and access to the digital economy.

As we noted in the above sections, the lack of Canadian data on retention, STEM, and women of colour in STEM significantly hindered our efforts at answering our second question about the Canadian state of the field. We were too early in Canadian post-secondary retention studies to conduct a study about specific populations. This means there is a lot of work to be done in Canada around STEM, retention, and underserved populations of learners. Additionally, when we designed this study, we grouped women of colour into one category knowing that this aggregation of women of colour would be problematic. Grouping women all together like this makes invisible the specific and intersectional experiences of the different cultures within the groups (Pawley, 2019). Yet, we aggregated all women of colour into one group because we anticipated both the small number of articles we would find and the reality

of the complicatedness of intersectionality— where women identify with multiple identity groups. We see this synthesis as a first step. We now need to go back into our data and use a methodology that allows us to see the "small numbers-ness" (Pawley, 2019, p.368) in the data and make the different experiences of different intersectionalities of women visible.

Implications for Policy, Practice and Research

We conclude this report with implications for policy, practice and research. Supporting women of colour in their STEM programs is an equity imperative. STEM is a gateway to knowledge, culture, social activism, innovation, and upward mobility for students and for Canada.

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- *We need more Canadian data and research*. This is the most important finding that has arisen from our research. At present, a whole group of people already underserved in our education system have also been ignored in our research and data collection. Canada is a unique context with unique policies and cultural climates. While we can draw on the robust research generated from US sources, this can only be a stop-gap measure until we understand our own Canadian context and find solutions to our specifically Canadian issues.

- *Interventions in STEM programs for women of colour and other underrepresented students should be strength-based, value the cultures and be inclusive.* There is a difference between remediation and enrichment. When an intervention is focused on remediation, it centers the student as a problem. An intervention focused on enrichment, on the other hand, is inclusive and values the prior background and experiences of the students and empowers them to develop. Specific strategies in which policymakers, institutions and faculty can focus on include targeting efforts in the first two years, placing the strongest faculty in introductory and first-year courses, redesigning weed-out courses to be inclusive, establishing mentorship programs, supporting faculty to develop culturally responsive pedagogies, and embedding research experiences and digital literacies across courses and programs.

- *Each Canadian institution of higher education should conduct internal reviews to identify their specific barriers and answer how they can provide learning space that develops STEM identity and a sense of belonging*. Many institutions and organizations offer scholarships and financial incentives to women of colour in STEM. While this is commendable and does aid with access to STEM, the institutional support while

students are in their programs is imperative for creating inclusive environments students need to persevere in their programs.

- There have been two ways of leveraging the digital economy to support retention. One way supports STEM learning and STEM course development, and the other supports digital skills development. *Both ways of leveraging the digital economy have the potential to have high and long-lasting impacts*. Subsequently, it would be well worth the effort to make policy changes to incorporate both types of digital strategies into post-secondary STEM learning environments. Courses, programs, and clubs can be redesigned to support this new learning.

- *Several opportunities for future research were made explicit through this research*. First, anything in the area of retention of underserved populations of learners in STEM programs from a Canadian perspective is needed. Second, research can ask questions around the experience of specific groups of women in STEM and the intersectionalities of their STEM identities. This type of research is needed from both an international and Canadian perspective. Third, research on how the digital economy can be leveraged to support STEM learning is only in its infancy. There are a number of avenues that remain unexplored, including how specific technologies can support underrepresented people in developing STEM identities and belonging that lead to retention, and in how the two types of digital literacies, those that support learning and those that develop digital empowerment, interact to support the development of STEM capital.

Knowledge Mobilization Activities

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Activity	Description
Conference #1 Gaining STEM capital	A conference is planned for August 30. At this conference, members of the research team and BIPOC women higher education students from across Canada will engage in a roundtable discussion. The discussion centers on the students' experiences in STEM education in relation to the findings from this study. We will produce short video clips through this conference to disseminate on social media and through our websites.
Conference #2 Building STEM Capital	A conference is planned for September 13. This conference will have three sessions. Each session has 3 BIPOC women with expertise in STEM responding to the results of this study and discussing either community and counterspaces, STEM identity, or empowerment through research. We will produce short video clips through this conference to disseminate on social media and through our websites.
Conference #3 STEM and social-emotional learning	In April, the researchers organized a conference through FIELDS to present early results of this study. Participants were various stakeholders of academia, teaching professionals, educational administrators, and government policymakers.
Social Media/ Digital Tools	We are disseminating short bytes of findings on social media. Additionally, the research team is in the process of creating video clips and other digital tools to disseminate results through social media. These will be available on the researchers' websites.
Publications	One chapter based on these findings is in review, and we have plans to write other articles and chapters to disseminate our results.
Conference Proceedings	One conference proceeding based on these findings has been accepted, and two others are under review. We intend to submit other proceedings to share our findings.

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