WATERLOO INSTITUTE
for COMPLEXITY & INNOVATION

2021-2025

Five Year Plan

UNIVERSITY OF WATERLOO

Prepared by

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Under the direction of Dr. Vanessa Schweizer (Director, WICI) & Dr. Dawn Parker (Core Member and former Director, WICI) and in consultation with Dr. Sharon Kirkpatrick (Associate Director, WICI), the WICI Steering Committee and Board, and members of the Waterloo Institute for Complexity and Innovation.

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EXECUTIVE SUMMARY

The Value of WICI

WICI will build on a solid foundation of interdisciplinary events, activities, and notable research achievements in its eleven years of operation to take complex systems research at the University of Waterloo and across Canada to the next level of impact. We will pursue emerging opportunities for complex systems education and training initiatives and continued development of our Canadian Network for Complex Systems (CNCS), maintaining strong alignment of key complex systems research directions with the University of Waterloo's strategic plan for addressing global challenges.

WICI received, and submitted with its 2021 Progress & Renewal Report, 18 letters of support from deans, members and collaborating scholars who attest to the value WICI has brought to their research careers as well as the incredible potential of the Canadian Network for Complex Systems.

Vision, Mission and Strategic Directions

Vision 2021-2025: Supporting transdisciplinary collaborations in Canadian complex systems research and education for global impact in addressing society's most pressing complex challenges.

Mission 2021-2025: Facilitate complex systems collaboration, research and education within University of Waterloo and across Canada to equip students and professionals to address complex challenges at the intersection of society, environment and health.

Scientific Direction: Grand social-environmental-health challenges.

Strategic Goals & Objectives Through 2025

Facilitate Interdisciplinary Complex Systems Research at the Intersection of Society, Environment, and Health

- Continue to support new and ongoing core complex systems research projects.
- Continue to develop and grow a Canadian Network for Complex Systems (CNCS).
- Provide and support interdisciplinary networking opportunities and activities, including a bi-annual conference to bring researchers together around grand challenge themes.
- Actively promote current work and member achievements through regular seminars, WICI newsletters, social media, and media outreach.
- Utilize dynamic web-based content to facilitate searching and connecting with complex systems researchers across all disciplines.

Prioritize Complex Systems Education Initiatives

- Explore professional development offering(s) in collaboration with Professional Development, Co-operative Education and the Problem Lab.
- Pursue collaborative training grants around interdisciplinary complex systems training.

- Host regular WICI workshops and support working groups that bring complex systems researchers together from multiple disciplines.

- Work with University of Waterloo and/or potential partner institutions to develop graduate and/or undergraduate complex systems programming by 2025.

Establish a Viable, Long-Term Resource Base

- Identify and harness potential revenue through Professional Development offering(s).

- Partner with faculty and university advancement offices to identify potential sources of endowment funds for WICI.

- Seek regular opportunities for collaboration and/or resource-sharing with deans, departments and other research centres and institutes, as well as external nodes of a Canadian Network for Complex Systems (CNCS).

Consolidation with WISIR: WICI's plans to consolidate with Waterloo Institute for Social Innovation and Resilience (WISIR) will bring cost savings to the university and improve administrative efficiency.

Projected Budget: WICI needs an operating budget of at least **$90K** per year, including core funding for an administrator, to support the priorities of its membership over the next five years. While WICI has secured funding commitments from faculties of Environment, Mathematics, Science and Engineering, alternative sources of income and resource-sharing will continue to be explored over the next five years.

Metrics for Success: To ensure WICI is supporting the University faculties and departments in a valuable and measurable way, a clear understanding of which metrics, and what levels thereof would constitute "success" need to be agreed upon. WICI will seek a better understanding with University of Waterloo research leaders on this matter and will work to improve its own metrics going forward. Possible reporting mechanisms proposed include modified cover sheets for WICI-supported grants, use of bibliometric analysis tools, and tracking of co-supervisions.

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Figures and Tables

FIVE-YEAR PLAN 2021-2025

As detailed in the WICI 10-Year Progress Report (2021), WICI has advanced the science of complex systems at the University of Waterloo and beyond through a solid foundation of interdisciplinary events, activities, and notable research achievements in its eleven years of operation. Continued support will allow WICI to build on this foundation to take complex systems research at the University of Waterloo and across Canada to the next level of impact. In this strategic plan document, we set forth a refined vision and mission and outline future scientific directions of the centre. We define specific goals and objectives to move WICI forward and introduce a proposed consolidation with the Waterloo Institute for Social Innovation and Resilience (WISIR). Finally we share a proposed budget model for WICI's next five years and discuss refined metrics for evaluating the centre's achievements in the future.

INTRODUCTION: THE VALUE OF WICI

The field of complex systems is inherently transdisciplinary. Complex systems researchers often see themselves as doing basic science, investigating the question of what complex systems are and what makes them similar across living and non-living systems. Clear scientific understanding of how complex systems work and are best analyzed also provides important insights for their management, e.g. environmental resource management, disease transmission, human resources within a large firm. In short, advances in basic complex systems science support policy-relevant complex systems applications. Complexity scientists are very open to the idea that insights generated in one discipline, e.g. physics, might be applicable to another field, e.g. biology. Thus the field of complex systems advances most effectively through interdisiplinary networking and collaboration, with a dual focus on basic and applied science.

For these reasons, WICI has focused on building interdisciplinary networks and activities that bring members together over the past eleven years. At the outlook of our next five years, WICI will continue this work and also pioneer new and exciting opportunities: namely **Canadian complex systems education and training, a national network for complex systems research, and innovative research programs around grand complex challenges that are relevant to the University of Waterloo's research priorities over the next decade**.

> "WICI provides incredible networking and capacity for trainees to engage in complex systems science training that fits their level of knowledge and discipline."
>
> *- Amanda Raffoul, WICI Affiliate Member & Postdoctoral Fellow at Harvard STRIPED*

1. Canadian complex systems education and training

There is increasing, immediate interest in professional training in the area of applied complex systems and WICI has already begun considerable collaboration to develop material and content in this pursuit. We anticipate that by pursuing this innovative option, WICI can explore this potential source of external funding while promoting University of Waterloo's professional development, cooperative education and top-level education programs. Dr. Larry Smith of the Problem Lab has indicated in his letter of support (Appendix A) that through WICI's developing connection with the Problem Lab, WICI has the potential "to serve external players in their thoughtful pursuit of innovation."

In preparation of his recent *Proposal for Training Program* (Appendix B), Truzaar Dordi conducted an inventory of current complex systems offerings at University of Waterloo. Results of that search show that there continues to be capacity for teaching and supporting complex systems research at the University of Waterloo, if this capacity can be organized and made more accessible to students across a variety of programs. WICI proposes to support the University of Waterloo to leverage its existing curricula and resources on campus to develop formalized training programs. Such programs may attract top students and scholars to the University of Waterloo to learn about and advance the field of complex systems in the future.

2. **Canadian Network for Complex Systems Research**

In Jinelle Piereder's recent report, *Mapping Canadian Complex Systems Scholarship*, we learned that complex systems research at University of Waterloo is much more robust than WICI membership alone would suggest. WICI's name and reputation have already achieved international recognition, and WICI believes that continued efforts to promote complex systems research at University of Waterloo will enable continued growth, increased member engagement, and effective interdisciplinary research collaborations across campus.

> "WICI has become the most predominant networking hub for complex systems research in Canada"
>
> *- Keith Hipel, Adjunct University Professor, O.C.*

WICI recently established the Canadian Network for Complex Systems (CNCS), which uniquely connects top complexity science researchers across Canada for stronger collaborations on larger research projects. Several external members of the CNCS are already on board, with support from their respective institutions, to develop and grow this network, and have expressed strong support for WICI's renewal.

3. **Innovative and relevant research programs around grand complex challenges**

> "A particular strength of WICI is that it focuses on the interaction of human and natural systems, and is thus inherently interdisciplinary"
>
> *– Roger White, Honorary Research Professor, Memorial University of Newfoundland*

By focusing on grand challenge research themes that support the University of Waterloo's research priorities as identified in its *2020-2025 Strategic Plan: Connecting Imagination with Impact* and which are centered at the intersection of health, society and environment, WICI will leverage its existing membership and networks to continue building partnerships across Canada and internationally.

The complex systems work of WICI core members has secured an estimated $16 million dollars in successful research funding over the past ten years. WICI core members currently represent about 8 percent of WICI's full membership, and core member contributions represent only 6.3 percent of the complex systems research being done at University of Waterloo (Piereder, 2020). Within the shifting institutional environment for research centres at the University of Waterloo, now is the time to redefine WICI's path to supporting and facilitating complex systems scholarship at UW to best capture this additional research and funding potential.

1. VISION AND MISSION

"WICI's mandate is vital to innovation, and its basic methodology is indispensable to a thorough understanding of any complex problem."

– Larry Smith, Director of the Problem Lab

Since its inception, WICI's **vision** has been to create an interdisciplinary institute that integrates complex systems knowledge from the university's faculties, departments, centres and schools, and that draws complex systems expertise from around the world to address the most pressing problems of the 21st century. Over the next five years, WICI will continue to make headway on this vision. With the Canadian Network of Complex Systems (CNCS) being established and a renewed focus on education and training in complex systems, WICI will more specifically support and enable cross-faculty, cross-institutional, transdisciplinary collaborations in complex systems research and education in Canada, thereby improving access to interinstitutional funding opportunities and attracting top complex systems scholars to University of Waterloo.

WICI's Vision 2021-2025: Supporting transdisciplinary collaborations in Canadian complex systems research and education for global impact in addressing society's most pressing complex challenges.

WICI's mission has been "to facilitate and undertake rigorous, transdisciplinary, collaborative research that promotes innovation and resilience within the complex adaptive systems at the core of human well-being in the 21st century." Through both of WICI's 2015 and 2019 Member Surveys, it was identified that education and training should be added as key WICI focus over the next five years.

WICI's Mission 2021-2025: Facilitate complex systems collaboration, research and education within University of Waterloo and across Canada to equip students and professionals to address complex challenges at the intersection of society, environment and health.

While capacity to become a larger centre clearly exists, it is likely a process to be developed over the next five years. WICI's prime concern is not simply to grow, but rather to prioritize the most impactful resources and services that we can offer in areas where it is most needed: facilitating interdisciplinary research around grand challenges at the intersection of society, environment, and health; and education and training for the students and community members who need it. In order to accomplish these goals, WICI must also establish a viable long-term resource base.

2. SCIENTIFIC DIRECTION: GRAND CHALLENGES

As noted by incoming President Goel, Waterloo is more than just a technical university. It has deep strength also in the environmental, social, and health sciences, and is well positioned to address major societal challenges in these areas. In the University of Waterloo 2020-2025 Strategic Plan, the University commits to align its research strengths to address the following important global challenges:

Quantum science, nanotechnology, connectivity and telecommunications

Water, energy and climate: sustainability, security, infrastructure

Information technology and its impact, including intelligent systems, human–machine interfaces, cybersecurity, privacy and data science

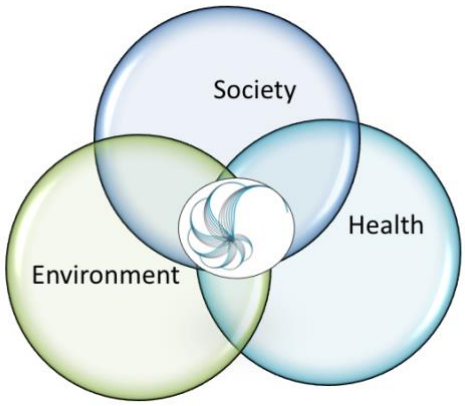
Robotics and advanced manufacturing

Health technologies

Each of these global challenges involves cross-scale and networked interactions within human-environment systems, thus each is inherently a complex systems challenge. We believe that complex systems science should be viewed as one of the University of Waterloo's research strengths, a strength that provides the core scientific foundations for investigations into each of these thematic areas. WICI has strong and/or developing connections with complex systems researchers in all of these areas.

In its interdisciplinarity, WICI's thematic research foci can be very broad. Branding WICI's foci around grand challenges at the intersection of **society, environment and health** encompasses the majority of our existing and desired research foci while providing clarity of purpose and function and aligning closely with the global challenges of the University of Waterloo Strategic Plan through 2025.

Figure 1: WICI at the Intersection of Society, Environment and Health



Some examples of current and future areas of exploration that both support the University of Waterloo's research alignments **and** fall under the umbrella of society-environment-health challenges are summarized in Table 1 on the next page (this is not an exhaustive list).

Table 1: Complex Systems Society-Environment-Health Questions that Support UW Research Alignments

UW Research Strength Alignments	Examples of **past/current** WICI research priorities that both support UW research alignments *and* intersect with society-environment-health	Examples of **potential** complex systems questions that both support UW research alignments *and* intersect with society-environment-health
Water, energy and climate: sustainability, security, infrastructure	• Building a circular Bioeconomy to ensure sustainable Cradle-to-Cradle Biomass Value Chains (T. Charles) • Identifying leverage points to address global systemic risks (T. Homer-Dixon, V. Schweizer) • Implementation science to create healthy cities, with a focus on food (D.C. Parker, S. Kirkpatrick) • Nutrition and its intersections with equity, health, and sustainability (S. Kirkpatrick); • Housing innovations for sustainable cities (D.C. Parker); • Collaborative social innovation, financing and design to support sustainable development (S. Geobey) • Solving complex societal-technological-environmental issues using innovative systems thinking methods (K. Hipel, V. Schweizer)	• Structural economic inequality and economic instability • Green finance innovations to support a sustainability transition
Information technology and its impact, including intelligent systems, human–machine interfaces, cybersecurity, privacy and data science		• Ensuring equitable and affordable access to computing technology • Balancing attention demands vs. productivity enhancement of a digitally enabled world • Reimagining human-computer interaction for an aging population
Health technologies	• Policy interventions to control pandemic disease spread (C. Bauch)	• Addressing structural inequalities in health service access • Reimagining human-computer interaction for an aging population

3. STRATEGIC GOALS AND OBJECTIVES THROUGH 2025

To fulfill our new mission, WICI will prioritize the most impactful resources and services we can offer in the areas where it is most needed. Below, we elaborate on how we will facilitate interdisciplinary research and deliver education and training for students and community members. To accomplish these goals, WICI must also establish a viable long-term resource base.

GOAL 1: FACILITATE INTERDISCIPLINARY COMPLEX SYSTEMS RESEARCH AT THE INTERSECTION OF SOCIETY, ENVIRONMENT, AND HEALTH

Research in complex systems is inherently interdisciplinary and is well aligned to large interdisciplinary grants, especially those associated with grand challenges at the intersection of society, environment, and health. Our growing network of experienced senior research collaborators across Canada will enable us to succeed in such grant competitions. WICI will continue to support and enhance our current network of complex systems researchers while providing services and activities that promote research collaboration and networking.

Objective 1A - Continue to support new and ongoing core complex systems research projects.

There is a high amount of interdisciplinary collaboration energy and potential across existing WICI and WISIR core research projects. WICI will offer grant-writing assistance, in-kind support and matching grant opportunities when applicable, in support of these and other large shared complex systems research projects, to facilitate their success.

Objective 1B - Continue to develop and grow a Canadian Network for Complex Systems (CNCS).

Over its next five years, WICI will continue its development and growth of a Canadian Network for Complex Systems, enabling complex systems researchers at the University of Waterloo to expand their inter-institutional collaborative network across Canada. This network has tremendous potential to enhance research capacity for inter-university and international collaboration as well as training/employment opportunities for students.

Objective 1C - Provide and support interdisciplinary networking opportunities and activities, including a bi-annual conference to bring researchers together around grand challenge themes.

WICI will continue to offer informal networking opportunities such as ‘mixers’, ‘open house’ events, and seminar receptions. We will build on the successes of previous conferences and branch out to our growing Canadian Network for Complex Systems to host biennial conferences on relevant research themes as an opportunity to highlight the revolutionary complex systems research our members are engaged in and bring our diverse complex systems researchers together for networking and collaboration opportunities.

Objective 1D - Actively promote current work and member achievements through regular seminars, WICI newsletters, social media, and media outreach.

WICI will continue to host relevant seminars, distribute bi-weekly newsletters, and engage with social media followers and local media to highlight the impact of ongoing member research, strengthen existing connections, and raise the profile of WICI, WISIR, and University of Waterloo.

Objective 1E - Utilize dynamic web-based content to facilitate searching and connecting with complex systems researchers across all disciplines.

WICI will seek to integrate an interactive member database, such as AirTable, with our existing website, to enable user-friendly member and research topic searches that facilitate impactful, high-caliber collaborations to strategically respond to funding opportunities.

GOAL 2: PRIORITIZE COMPLEX SYSTEMS EDUCATION INITIATIVES

WICI members have made it clear that a substantive focus on complex-systems training in the science behind complex systems targeted to students, research staff, and faculty is a missing piece on campus. Both internal members and external partners are requesting training in systems thinking and methods. As the University of Waterloo looks to support flexible education pathways (University of Waterloo Strategic Plan 2020-2025, p.4), WICI will prioritize initiatives targeted to highly qualified personnel in complex systems applications.

Objective 2A - Explore professional development offering(s) in collaboration with Professional Development, Co-operative Education and the Problem Lab.

Building on the recommendations in WICI's *Proposal for Training Program* (Dordi, 2020) and *Business Plan Notes for WICI's Complexity Professional Development Program* (Comeau, 2021), WICI will work with Professional Development, the Problem Lab, Co-operative Education, faculties and deans to implement a professional development course and/or micro-credentialing program, with the aim of engaging workforce professionals in solving relevant, applied complex problems, while exploring opportunities to promote University of Waterloo talent to the workforce.

Objective 2B - Pursue collaborative training grants around interdisciplinary complex systems training.

Due to its inherent interdisciplinarity and growing membership of top complex systems researchers in Canada, WICI is uniquely positioned to apply for strong interinstitutional training funds. In addition to the funded CIHR-NSERC-SSHRC Healthy Cities Research Training Platform (HCRTP), there is potential for a strong NSERC-CREATE application around modelling and simulation of coupled human-natural systems.

Objective 2C - Host regular WICI workshops and support working groups that bring complex systems researchers together from multiple disciplines.

WICI supports working groups that enable students and faculty to actively engage with a larger network while learning relevant complex systems content. Following successful workshops offered in previous years, WICI will organize annual workshops with a focus on skill development and collaboration.

Objective 2D - Work with University of Waterloo and/or potential partner institutions to develop graduate and/or undergraduate complex systems programming by 2025.

Building on exploratory discussions in 2020, WICI will engage University of Waterloo faculties and departments as well as partner institutions in discussions and plans to leverage its existing curricula and resources, identified in WICI's *Proposal for Training Program* (Dordi, 2020), to develop formalized cross-faculty complex systems programming for graduate and/or undergraduate students.

GOAL 3: ESTABLISH A VIABLE, LONG-TERM RESOURCE BASE

During its next five years, WICI will develop a business plan working with the faculties, the University and our internal and external partners to pursue hybrid funding options that will allow us to establish and support the activities, services and complex systems research integral to WICI and to the University of Waterloo.

Objective 3A - Identify and harness potential revenue through Professional Development offering(s).

WICI has begun and will continue to explore the market for applied complex systems education, working with University partners such as WatSPEED and potential community partners to determine what revenue opportunities exist in this area. A professional workshop with scale-up potential is planned for the 2021 Annual Meeting of the Society for Risk Analysis.

Objective 3B - Partner with faculty and university advancement offices to identify potential sources of endowment funds for WICI.

WICI will actively engage with advancement offices at both the University and faculty levels to identify promising sources for WICI Institutional support.

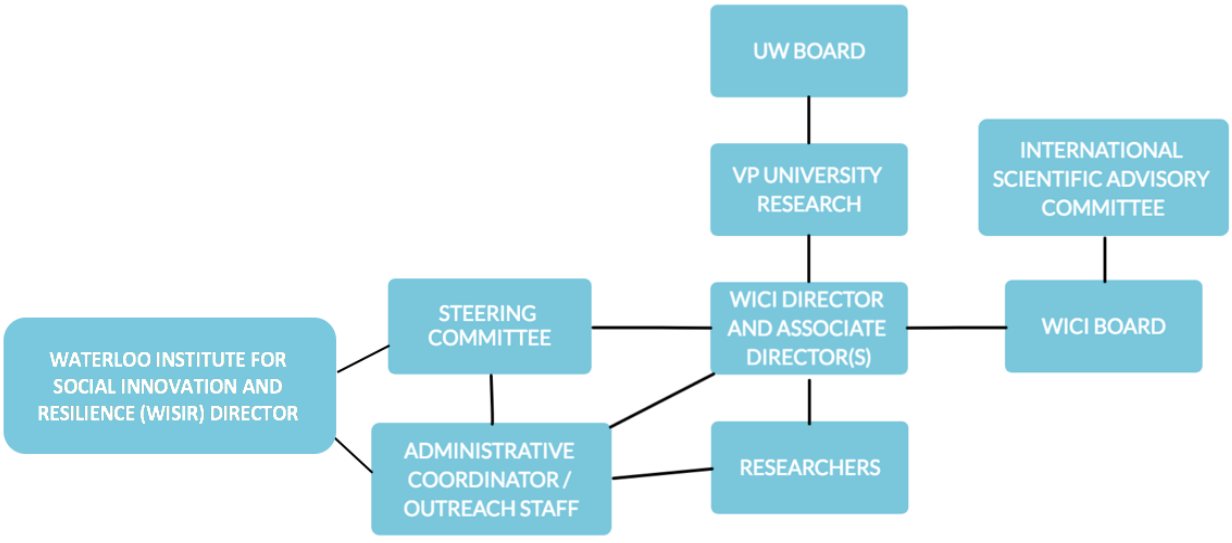
Objective 3C - Seek regular opportunities for collaboration and/or resource-sharing with deans, departments and other research centres and institutes, as well as external nodes of a Canadian Network for Complex Systems (CNCS).

As the University streamlines its vision for university research centres, WICI will seek to collaborate with deans, departments, and other research centres to find creative ways of sharing resources and improving cost efficiencies.

4. CONSOLIDATION WITH WATERLOO INSTITUTE FOR SOCIAL INNOVATION & RESILIENCE (WISIR)

WICI and Waterloo Institute for Social Innovation and Resilience (WISIR) have a long history of complementarity, with strong overlap in membership, and the work that WISIR leads is inherently complex. Going forward, WISIR will align strategically with WICI as a sub-centre that focuses on social innovation and social resilience research. WISIR will maintain autonomy over its research and funding, but benefit from select administrative support from the WICI Administrative Coordinator and continued collaboration with WICI on activities and core projects related to complexity, social innovation and resilience. WICI will request a member of WISIR to join the Board, Steering Committee and International Scientific Advisory Council in 2021/2022, pending senate approval of this motion.

Figure 2: WICI's Governance Structure with WISIR as a Sub-Centre



5. PROJECTED BUDGET

It is imperative that WICI has a sustainable budget model in place to fulfill the research and training objectives defined in this plan. While many WICI members have strong industry partner research portfolios, with complex systems science's strong focus on novel basic science, interdisciplinarity, and high-risk/high-gain research, industry partnership funding opportunities are not currently a primary funding source for WICI. As a shift away from central university funding is encouraged, WICI must consider alternate options. Thus, WICI will continue exploration of partnerships, collaborations, and alternate funding models over the next five years, with the aim to develop a funding model that could also be applied to other mid-sized centres at University of Waterloo whose focus lies beyond industry contracts, but includes substantial network-building, tri-council research, and educational activities.

There is much to be determined as to how WICI may directly capture funds from external sources, such as net revenues from professional development courses and training workshops, or donor and foundation funds identified in partnership with faculty and university advancement teams. Until a viable model can be fully developed, the budget proposed in Table 2 on the next page is based primarily on faculty deans' support with augmentation from Office of Research and carryover from the 2020/21 fiscal year. Funding commitments have been confirmed from the faculties of Environment, Mathematics, Science and Engineering, while the faculties of Health and Arts have indicated that they will consider financial or in-kind resource requests for specific WICI initiatives over the next five years. The WICI Steering Committee and Board will continue quarterly and annual reviews of financial statements, and annual funding requests will be adjusted (as required) as developments are made toward the goal of establishing a viable funding model.

A viable financial model for WICI must include core funding for administrative support, not only to manage its public-good workshops, conferences, seminars, and student activities, but also to support large core-member grants. In the next five years, the WICI Administrative Coordinator role is projected to shift priorities with a focus on management of a growing network of members, implementation of a dynamic member database, enhanced grant application support for WICI members, financial administration for consolidated research centre(s), and potentially managing external sources of funding and/or a training program if these options prove viable.

In anticipation that WICI collaboration for multidisciplinary grants will be increasing over the next five years, WICI has budgeted for research grant support (i.e., administrative support with grant preparation, matching funds where helpful) for funding applications such as the New Frontiers competitions and Waterloo Interdisciplinary Trailblazer, and others that may be applicable. Additionally, WICI has budgeted to provide qualified complex systems graduate students with opportunities to expand the impact of their research through a WICI Graduate Research Assistant (GRA) position each year, based on the significant impact GRA research projects have made for complex systems research and education over the past few years. Additional GRA positions may be funded via the conference and workshop budgets as appropriate.

Table 2: Projected Budget 2021-2026

Income	2021-2022	2022-2023	2023-2024	2024-2025	2025-2026
Projected Budget Carryover	$52,120	$54,336	$43,980	$29,016	$16,727
Office of Research Contributions	$12,000	$12,000	$12,000	$12,000	$12,000
Faculty Funding from UW Deans & Departments	$48,000	$48,000	$48,000	$48,000	$48,000
Funding from Engineering Members	$1,000	$1,000	$1,000	$1,000	$1,000
Conference Fees/Co-Sponsorships Income	*n/a*	$5,000	*n/a*	$5,000	*n/a*
Grant Overhead for WICI from CIHR Grant (Parker)	$9,000	$10,000	$9,500	$10,000	$9,500
External Funding from Cascade Institute (Royal Roads)	$10,000				
TOTAL INCOME	**$132,120**	**$130,336**	**$114,480**	**$105,016**	**$87,227**
Expenses					
Salaries*					
Administrative Coordinator (18 h/wk)	$25,937	$26,451	$27,490	$28,042	$28,604
Graduate Research Assistant (10h/wk)	$8,300	$8,465	$8,634	$8,807	$8,983
Events					
Speaker Series (Travel, Accommodation & Catering)	$1,255	$7,000	$7,000	$7,000	$7,000
Biennial Conference	$0.00	$10,000	$0.00	$10,000	$0.00
Graduate Student Workshops (1 per year)	$0.00	$0.00	$8,700	$0.00	$9,000
Promotion and Marketing	$600	$900	$600	$900	$600
Research Funding					
Stipend for WICI Director	$9,000	$9,000	$9,000	$9,000	$9,000
WICI Members Research Grant Supports	$2,500	$2,500	$2,500	$2,500	$2,500
SC Members Research Grant Supports (up to 7 SC members @ $500 ea)	$3,500	$3,500	$3,500	$3,500	$3,500
Additional support for Associate Director	$500	$500	$500	$500	$500
Additional support for Associate Director of CNCS	$500	$500	$500	$500	$500
Student Research Grants and Awards	$5,000	$5,000	$5,000	$5,000	$5,000
Map the System Co-Sponsorship	$1,000	$1,000	$1,000	$1,000	$1,000
Office Expenses	$1,516	$1,540	$1,540	$1,540	$1,540
Course Funding (BSIA GGOV 622)	$9,175	$0.00	$0.00	$0.00	$0.00
TOTAL EXPENSES	**$77,783**	**$86,356**	**$85,464**	**$88,289**	**$87,227**

**2% inflation year over year*

5.1 METRICS FOR SUCCESS

To ensure WICI is supporting the University faculties and departments in a valuable and measurable way, a clear understanding of which metrics, and what levels thereof would constitute "success" need to be agreed upon. WICI will seek a better understanding with University of Waterloo research leaders on this matter and will work to improve its own metrics going forward. Initial ideas for enhanced metrics include:

- With modified options on cover sheets, including a "complex systems" keyword, WICI could track and attribute applications that benefited from WICI administrative or matching support and provided directly funded or in-kind WICI activities. Applications could be given additional points 1) if funded 2) if external institutions are involved 3) if the grant has international partners 4) if it includes multiple WICI members and 5) if members are in different faculties. While administrative support for grant preparation is provided within some faculties, no unit provides it for cross-faculty complex systems grants and contracts.

- The bibliometric framework provided by the *Mapping Canadian Complex Systems Scholarship* project (Piereder, 2020) provides a means to track and attribute a subset of complex systems publications (those published in Scopus). Points could be granted for (and/or) 1) Meeting the query, 2) "Complex systems" as a key word 3) Acknowledgement for WICI support and/or membership 4) Bonus for more than 1 WICI author 5) Bonus for one or more international co-authors.

- Although manual tracking of co-supervisions would be a challenge, with sufficient administrative support, this information could be tracked manually for core members and student members via WICI's Airtable database or through a query of graduate and committee members in consultation with the Graduate Studies office, on an annual basis.

- Current metrics, including seminar attendance and views, workshop and conference attendance, website views, and external contacts, could also continue.

6. CONCLUSION: SUPPORTING UNIVERSITY OF WATERLOO'S STRATEGIC PLAN

Since WICI was established in 2010, it has covered an impressive span of services and activities. WICI has continued to support and grow a solid network of complex systems researchers at University of Waterloo, in Canada, and beyond. The research accomplishments of core members, as well as our strong reputation attracting national and international attention, show that we have made substantive, high-impact scientific progress in the area of complex systems science.

Looking forward, WICI members have identified a need for WICI to focus more specifically on the key directions outlined in our new strategic plan, and WICI's activities, network and goals are clearly aligned to support the strategic commitments of the University of Waterloo through 2025.

Specifically, Waterloo has stated a commitment to use its **disciplinary and interdisciplinary strengths to solve increasingly complex, real-world problems**. WICI is one of the University's leaders in this pursuit, not only because of our solid interdisciplinary network, but also because our research foci include the development and application of tools and knowledge in complex systems approaches to real-world problems. WICI has carefully reviewed its research priorities for the next five years and is confident that they are aligned with the University's new strategies for **advancing research for global impact** nationally and internationally, in an environment of free expression and inquiry.

APPENDIX A: LETTER OF SUPPORT AND COLLABORATION FROM PROBLEM LAB

UNIVERSITY OF WATERLOO

PROBLEM LAB®

February 9, 2021

Senate Graduate and Research Council
With respect to Review of Waterloo Institute for Complexity and Innovation

Letter of Support

I write in support of the work of the Waterloo Institute for Complexity and Innovation [WICI]. As Director of the University of Waterloo's Problem Lab, let me first note that the Lab and WICI have complementary goals and general orientation. The Lab is North America's only university-based facility whose sole mandate is to understand important problems. In order to do full justice to problem analysis, the Lab does not attempt to formulate solutions. By concentrating on problem analysis as the first step of successful innovation, our ultimate goal is to encourage high-impact solutions.

WICI's focus on both complexity and innovation are fully consistent with the Problem Lab. We both agree that innovation must be a high social priority and that rapid change is making innovation ever more challenging. The Lab's methodology emphasizes a comprehensive understanding of the problem in question. The complexity of the problem is clearly part of that understanding, as is an interdisciplinary approach.

However, even though it is generally recognized that innovation is important and difficult, many organizations do not take the time or care to fully understand the problems they are trying to solve. Both WICI and the Lab directly contribute to that deeper understanding.

The Problem Lab has found a renewed commitment by a variety of players to a more thoughtful approach to innovation. As a result, the Lab has provided problem analysis to Cisco Systems, and is currently working with Canada Mortgage and Housing Corporation, Treasury Board of Canada Secretariat and Rogers Communications. This suggests that WICI has the potential to serve external players, as do we.

In addition, we are part of the collaboration of other units of the University in order to assist all our students to become better innovators, no matter their core discipline.

We are participating in active discussions with WICI to develop professional training courses for external audiences. And we anticipate potential collaboration on other educational initiatives.

Simply put, WICI's mandate is vital to innovation, and its basic methodology is indispensable to a thorough understanding of any complex problem. We expect to be active collaborators with them on an ongoing basis.

Larry Smith
Director of the Problem Lab
Adjunct Associate Professor, Economics and the Conrad School

PROPOSAL FOR TRAINING PROGRAM

Waterloo Institute for Complexity & Innovation
University of Waterloo

Truzaar Dordi, Vanessa Schweizer, Brenda Panasiak

Working Internal Document

EXECUTIVE SUMMARY

The Waterloo Institute for Complexity Innovation at the University of Waterloo is examining opportunities to incorporate a teaching element to their existing offerings, in line with their mandate develop a formal education program on complex systems. This report summarizes the proposed recommendations.

Summary of Recommendations

- Through an exploratory review of similar program structures at the University of Waterloo and beyond, along with several consultations with program leads, we considered six program structures and ten program offerings.
- Recommendations were assessed based on criteria such as ease of implementation and potential for multiplier effects.
- Favored program recommendations include a certificate program targeted to working professionals and a collaborative program for graduate students.
- Favored program offerings include graduate electives, project based courses, summer institutes, and graduate internships graduate internships.

Summary of Implementation

- We recommend that WICI take a phased approach to the development of a complexity program, which will span a five year period.
- The Professional Development office highlights that a certificate offering is a revenue generating stream, with the potential to earn the institute upwards of $100,000 per year.

Summary of Course Offerings

- A systematic review of over 7,500 courses offered at the University of Waterloo, found that 166 courses references complexity and systems thinking.
- Text analysis of course descriptions indicate that the University of Waterloo takes a clear focus on tools to address complexity, but is also applied across both technical solution oriented topics, like mathematics and qualitative process based topics like environment and management.
- Topic modelling was applied to delinate latent fields of instruction on complexity and systems thinking. Topics on healthcare, managenement, engineering were notable topics of interest.

MOTIVATION

The Waterloo Institute for Complexity Innovation at the University of Waterloo is examining opportunities to incorporate a teaching element to their existing offerings, in line with their mandate develop a formal education program on complex systems. WICI's 2019 annual report states 'members have strongly emphasized that training in the science behind complex systems targeted to students, research staff, and faculty is a missing piece on campus' (p 7) and thus, a Graduate Research Assistant was hired to explore avenues to incorporate a teaching element into WICI's offerings.

Various models have been discussed including cross-university core courses, a certificate, workshops, and/or summer schools. One option being strongly considered is a certificate in complexity, which targets working professionals looking to acquire the increasingly sought technical and strategic competencies required to incorporate 'big picture' thinking into organizations. Another option being considered is a collaborative complexity program, which is a cross-disciplinary graduate program offering a suite of master's and doctoral program with a specialization in complexity and systems thinking. A certificate in complex systems that targets working professionals could be a precursor to a multi-disciplinary graduate program in complex systems, laying the foundations of course offerings, which could be translated into a collaborative program for current graduate students. This training would be the first of its kind offering in Ontario.

Our training will take a multidisciplinary approach, with course offerings that target quantitative and qualitative analysts and decision makers across industries. WICI currently spans several key departments and faculties across the University of Waterloo. Our steering committee encompasses several departments including planning, knowledge integration, environment and resource studies, systems design engineering, public health, and psychology. Thus the steering committee incorporates voices of four of the seven faculties.

There is a compelling case for WICI to offer training in complex systems. WICI members have emphasized that complex systems training for students, research staff, professionals, and faculty is a missing piece on campus. There also appears to be demand for training that targets working professionals who desire technical and strategic competencies to incorporate 'big picture' thinking into organizations. In the past year, the Waterloo Institute for Complexity & Innovation (WICI) has been approached independently by two professionals working on community development projects (one an international development fund, the other an American professional based out of Washington, DC) for advice, collaborative opportunities, and/or professional development training in complexity that might make poverty alleviation efforts more successful. Finally, other Universities such as the University of Texas, University of Arizona, and University of Michigan have begun offering executive, professional development, and continuing education courses to meet this increasing demand. Both internal members and external partners are specifically requesting training in systems thinking, problem identification, and complex-systems appropriate methods for program evaluation.

EXPLORATORY REVIEW

Our exploratory review began by identifying select programs and offerings from other institutes at the University of Waterloo and complexity related offerings from other institutions in North America. Notably, this is not an exhaustive list of offerings at the University, but rather some illustrative examples of different options to consider when developing a complexity program. The table below summarizes some exemplary programs and offerings identified.

Program	Type	Multi-disciplinary	Course Offering	Seminar Participation	Internship	Experiential Education	Summer Institute
Collaborative Water Program	Collaborative Program						
Theoretical Neuroscience	Diploma						
SWaGUR	Graduate Program						
Climate Risk Management	Diploma						
Bioengineering & Biotechnology	Graduate Program						
CSCS	Graduate Certificate						

The ***Collaborative Water Program***, co-ordinated by the Water Institute offers 15 interdisciplinary Master's offerings and 9 interdisciplinary PhD offerings, in partnership with 11 academic units across the University of Waterloo. The academic units span all 7 faculties at the University. Graduate students in the collaborative water program are required to take two "WATER" courses. The first, WATER 601 provides an overview of current issues and challenges across a variety of disciplines, such that students have a broad knowledge base of theories, concepts, and terminologies from various water-related fields. This is taught collaboratively by faculty members and professionals from multiple disciplines. The second, WATER 602 course includes a 6-8 day field trip to the Grand River Watershed, to learn about watershed issues and management approaches first hand by water practitioners, managers, scientists, volunteers and others concerned with watershed health. Finally, students will present their respective research at a Water Institute organized research seminar, intended to develop the student's ability to communicate their research. This approach of mandatory course and seminar requirements encourages graduate students from multiple faculties to collaborate across disciplines.

The ***Center for Theoretical Neuroscience***, offers students enrolled in one of the select Masters of PhD programs to receive a diploma in Theoretical Neuroscience. Students working with one of 12 supervisors associated with the center are eligible for the diploma. The associated members span 8 departments, including psychology, applied math, systems design engineering, statistics, computer science, biology, philosophy, and applied health sciences. The diplomas are offered in conjunction with a graduate degree, adding an additional, usually interdisciplinary, qualification to the higher degree. Students are required to complete 4 courses, including one mandatory research seminar, one of two offerings in systems design engineering, and two courses from a cross-disciplinary list of recommended courses. The mandatory course, TN 700 consists of attending and reporting on 10 seminars presented by the center, including presentations from students, faculty, and visiting researchers. SYDE 556/750 subsequently ensures all

students have a base level understanding of the topic. Finally, students select 2 of a list of 24 approved courses, providing disciplinary expertise across the student's respective field of study.

SWaGUR is an interdisciplinary program co-ordinated by the Games Institute for students completing a Master's or PhD degree at either the University of Waterloo or the University of Saskatchewan. Students in the fields of computer science, English, psychology, management sciences, and systems design engineering may apply through one of 11 potential supervisors across the two universities. In addition to the degree requirements, Masters and PhD students will take an additional 4 to 5 courses to meet the SWaGUR requirements, including a foundation level course, and related courses of interest. Graduate students must also complete a mandatory internship.

The ***Climate Risk Management diploma***, coordinated by the Interdisciplinary Center on Climate Change is an offering for early- to mid-career professionals interested in integrating climate risk management within their field of work. The program is offered fully online and part time through the department of Geography and Environmental Management. Students in this program are required to take one mandatory course and 3 of 4 additional offerings. The mandatory course, GEMCC 600 ensures all students have a base understanding of global climate challenges. The other courses offer students knowledge in a range of competencies, from analytics, business, community planning, and carbon accounting.

The ***Center for Bioengineering and Biotechnology*** was recently awarded the NSERC CREATE grant to develop a biomedical technology graduate program. The proposal prioritizes building competencies in both the research side and the business side of the industry, by partnering with the Grand River Hospital, Starfish Medical, and Synaptive Medical. The curriculum will include clinic and industry partnerships, commercialization courses, international exchanges, and professional skills workshops. Each student will be part of a team that includes a research supervisor, a clinician, and the manager of a biomedical engineering company. Before they begin their research, students will need to prove that they've spent time with clinicians and patients in settings relevant to their area of research. This will help ensure that the solutions they develop are viable and easier to commercialize.

The **Center for the Study of Complex Systems (CSCS)** at the University of Michigan is a multi- and interdisciplinary program designed to encourage and facilitate research in the general area of nonlinear, dynamical and adaptive systems. Affiliated researchers apply cross-disciplinary techniques, incorporate models, measures, and insights from traditional disciplines (physics, biology, computer science, economics, and mathematics) in novel ways, to identify properties that hold across a wide range of complex systems. The center currently has eight core members and 32 affiliated members across nearly every college of the University. The Complex Systems Graduate Certificate allows students from different fields to integrate the rich paradigms and useful analytic and modeling techniques of complex systems into their own research. The program is accessible to students who are simultaneously enrolled in a graduate degree program or who have a Bachelor's degree or higher from any University and are U.S. citizens. Students are required to take five courses, including 2 core courses, 1 of 4 core electives, and 2 additional approved electives. Below is a brief look at each core course. In addition to the undergraduate and graduate programs, the CSCS offers additional activities, including an annual workshop in partnership with the Santa Fe Institute, which features a keynote presentation that is open to the public with other sessions by invitation only.

CONSULTATIONS

Following our review of program offerings we consulted with leads for two program offerings at the University of Waterloo; the Diploma program in Climate Risk Management and the Collaborative Water Program. These meetings were intended to provide a more detailed understanding of the program development process at the University of Waterloo. We finally consulted with the core WICI committee, providing a brief update on the exploratory review conducted to date and to garner input on which programs and offerings were favored for deeper study.

Graduate Diploma (GDip) in Climate Risk Management

We consulted with Johanna Wandel and Daniel Scott about the Geography and Environmental Management department's Graduate Diploma (GDip) in Climate Risk Management. This online diploma is available to individuals with an undergraduate degree in a related field and requires that students complete four courses on a part time basis.

In developing the GDip program, a business case was prepared and sent to the Dean of Environment. However, a multi-department approach might need the approval of multiple deans. Completing a statement of interest, including details on program type, structure, outcomes, enrolment, and tuition expectations would be the first step in this process. If required, Amanda McKenzie director of Academic Integrity and Quality Assurance, can provide more guidance on this process. To gain support, prepare a clear marketing strategy that demonstrates an interest in the course and obtain letters of support from instructors that teach related courses. Fundamentally, the program must demonstrate how it will be cost neutral to the Deans. Other notable discussions revolved around the need to obtain an open time slot for online courses (which may be difficult given current circumstances), that in-house instructors are strongly preferred to industry experts, and that the Center for Extended Learning can support with online course development.

Collaborative Water Program

We also consulted with Kevin Boehmer, Managing Director of the Water Institute. The Collaborative Water Program, co-ordinated by the Water Institute offers 15 interdisciplinary Master's offerings and 9 interdisciplinary PhD offerings, in partnership with 11 academic units across the University of Waterloo, spanning all 7 faculties at the University. It is notable that Institutes do not have academic status in supporting and facilitating education (refer to Policy 44).

The Water Institute and Collaborative Water Program was initially funded from a financial gift from CBR, which compensated instructors so departments would not have to contribute financially. The program was built from the bottom up, where key faculty committed to supporting the program approached their own departments and ultimately the senate and the province. The collaborative program was prepared as traditional new graduate program, using the same statement of interest templates mentioned above. However, the program went through the multiple various departments for comment and 'conditional approval' before being approved by faculties, provost, and senate.

Now, the Water Institute works closely with Deans to estimate funding and teaching contributions from each department. A joint committee governs the program, however there is a lead academic unit which rotates every two years under the reporting structure. Currently, engineering, environment, and science are the three main contributors to the Collaborative Water Program, however the institute is responsible for promoting the program.

Core WICI Committee

The WICI committee were provided with a summary document that delineated potential program structures and offerings based on what has been identified by our exploratory review of programs at the University of Waterloo and beyond. We identified 6 programs and 10 offerings that we proposed as recommendations to the core committee. The table below highlights the programs and offerings considered, however, the Appendix at the end of this report presents a detailed description of each along with relevant examples.

Programs	Offerings
A Undergraduate Minor	A Graduate Elective
B Graduate Certificate	B Undergraduate Elective
C Graduate Diploma	C Project Based Course
D Graduate Specialization	D Seminar Attendance
E Graduate Program	E Research Seminar
F Professional Accreditation	F Graduate Internship
	G Undergraduate Internship
	H Experiential Education
	I Summer Institute

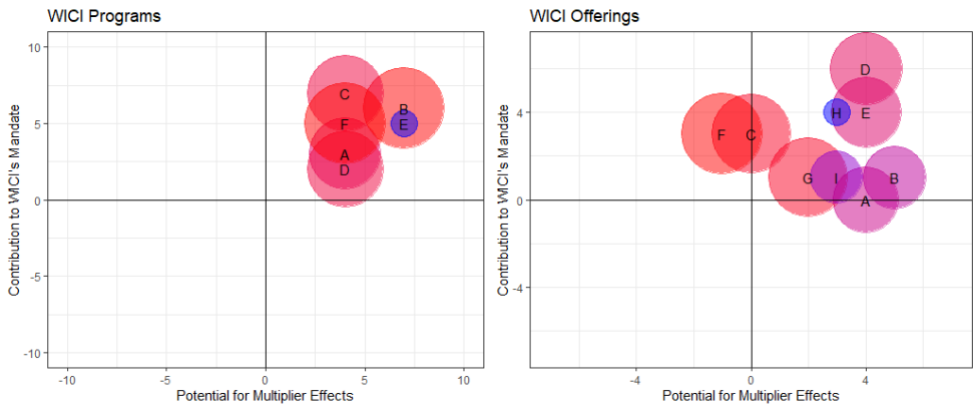
We asked the core WICI committee to consider the feasibility of each program and offering through a short online survey. The committee was asked to rank each recommendation on five criteria:

1. *Contribution to WICI's mandate*: Does the structure or offering advance the institutes mandates of complex-system training, the development of a Canadian network for complex systems, or the institute's brand?
2. *Potential for multiplier/spillover effects*: Would the structure of offering have longer term benefits - or spillover effects - for the institute? Consider the benefits that may be realized by the students, faculty, the institute, and the Canadian Network for Complex Systems (CNCS).
3. *Ease of implementation*: How quickly could this structure or offering be undertaken? Are there existing offerings that can be capitalized or will new material need to be developed? Consider whether the undertaking may face regulatory or administrative barriers. Examples of barriers may arise from financing, policy, reporting, human resources, competing offerings, and collaboration with other agencies and universities.
4. *Overall desirability*: There would be an expectation that WICI's members will need to contribute to the success of the program. This may come in the form of making formal connections with your faculties, developing course content, or co-delivering courses. How likely would you provide

support in the form of advocacy or program development if this structure or offering was implemented by WICI?

5. *Time Horizon*: How long would it take to implement this program or offering? Consider for example, administrative barriers that may arise in its development.

We concede that there are some methodological and statistical limitations to collecting the committees input through an online survey, such as a small sample size (6) and missing benchmarks. In aggregating the survey responses, we allocated greater weight based on the frequency of scores. For example, if a recommendation was rated (1, 1, 0, 1, 2, and 1) it would have a mean of 1 and a frequency weighted score of (4x1 + 1x2 = 6). Due to the simple exploratory nature of our examination we feel confident that the survey gave us a clear understanding of how the committee perceives each program and offering. We plot the perception of each recommendation based on its contribution to WICI's mandate, potential for multiplier effects. The size of the circle is proportional to its ease of implementation, whereby a smaller circle is more difficult to implement. A graduate certificate and collaborative program are both ranked highly on contribution to WICI's mandate and potential for multiplier effects. However, the graduate certificate would be easier to implement in a shorter time horizon. On offerings, graduate electives, project based courses, and a summer institute are ranked relatively high on both contribution to WICI's mandate and potential for multiplier effects. Graduate internships are also ranked highly for potential multiplier effects. The aggregated scores are presented in the appendix.



RECOMMENDATION

Through our exploratory review and consultations we recommend that WICI take an iterative approach to developing a complexity program at the University of Waterloo, beginning with a single offering to a fully developed collaborative program over the course of 5 years. The timeline below presents a stepwise process to achieve this goal.

Aug 2020 **Exploratory Report** This initial report positions WICI to develop a complexity program highlighting the steps required to achieve that goal.

Sep 2020 **Initiate Proposal for Certificate** In partnership with Professional Development at the University of Waterloo, prepare a proposal for one introductory course on complexity.

Oct 2020 **Market Research** Conduct early market research, identifying the target audience and their interests in complexity.

Jan 2021 **Course Offering** Offer an initial 'Introduction to Complexity' course. Use this course to gauge interest and conduct additional market research.

Apr 2021 **Revise Strategy** Following the success of the introductory course, identify avenues of future teaching.

Sep 2021 **Establish Certificate in Complexity** Offer a complete certificate through Professional Development.

Sep 2022 **Extended Courses to Graduate Students** Offer complementary in-class or online offerings to current graduate students.

Sep 2023 **Extend Certificate Pathways** Consider opportunities to create pathways for future teaching, whereby certificate holders can progress toward a graduate program.

Jan 2024 **Develop Collaborative Complexity Program** Begin the process of approval and design of a collaborative program.

Sep 2025 **Launch of the Collaborative Complexity Program** Offer a collection of graduate degrees in Complexity across the University of Waterloo.

Certificate

Faculties do not offer certificate programs at the University of Waterloo. Rather, certificates are offered through or in partnership with a University Office; the most prominent being Professional Development, Centre for Teaching Excellent, and the Student Success Office. The appendix below highlights a list of certificates offered through the University along with a brief description of certificate requirements. Of the University offices, Professional Development is most aligned with the type of certificate WICI is considering, targeting professionals (non-students) interested in learning applicable and in-demand skills.

To offer a certificate through the Professional Development office, begin the process by completing the 'Professional Development & Lifelong Learning Program Proposal' (attached). Justify the program, through examining the demand for this offering and how it ties to lifelong learning. WICI is also expected to propose a course design, including select topics, learning outcomes, and assessments. WICI can work in collaboration with Professional Development to strengthen the proposal, prior to the formal approval process through the Professional Development Advisory Committee.

Professional Development offers both single course offerings and multi-course certificates. It is recommended that WICI begin with a single introductory course offering, which will be easier to develop and can be used to conduct additional market research on the target audience, demand for content, and future offerings. Iterative and agile pathways of progress are favored when developing a certificate, however, long term pathways for learning are equally important.

The formal Complexity certificate will follow a similar structure to current in-class and online offerings through Professional Development, at approximately 28-30 contact hours. This can include courses content on complexity theories, methods, and applications. Learners will be required to have completed a bachelor's degree from an accredited institution, to meet the rigor of this training and by the end of the training, learners will have gained technical competencies in the theory and application of systems thinking in organizations and for partnerships, leadership competencies in effective management, and strategic competencies in adaptive capacity and operational efficiency.

For greater impact, incorporate pathways for lifeline learning. This may include additional specialized courses that target specific industries (such as healthcare), technical capabilities (such as software), or select audiences (analysists or executives). Pathways for lifelong learning can contribute to improved participation, diversity in training, and better skilled individuals. Pathways may also lead to a graduate program, where individuals who have completed the certificate program may continue their education through a graduate degree.

Capitalizing on the resources developed over the course of the certificate program, begin the process of developing a collaborative complexity program. Seek approval letters from department leads and faculty deans. Formalize the cost and reporting structure. Seek support from the Water Institute with regards to the development process.

Collaborative Program

In line with the collaborative water program, a collaborative complexity program may be designed with a combination of required courses, electives, and a research seminar. Below is a sample program structure that incorporates elements of proposed programs and offerings. The Collaborative Complexity Program may span academic units and may be offered to all current graduate students at the University, however admission into the program may be competitive. Students may be required to take three additional courses in addition to their program requirements, including a combination of core courses and approved electives; however, the select courses may count towards their elective requirements.

CMPLX601 – Seminar. In the Complexity Research Seminar Course, students must attend 10 to 12 seminars offered by WICI or affiliated institutions on a discretionary basis. Students are requred attend and prepare a two page written deliverable for each seminar they attend, summarizing the main ideas of the seminar and how the topic relates to complexity research. Students may also be required to attend at least two seminars that adopt qualitative research methods and two seminars that adopt quantitative research methods, to expand their understanding of how complexity research is applied. Students may complete these course requirements over the period of three academic semesters.

CMPLX602 – Introduction to Complexity and Complex Systems. After successfully completing the research seminar course, students attend an in-class or online graduate course on complexity studies. This course will span one academic semester. Course content will include aspects of traditional learning as well as student centered learning and active learning. Topics covered include 1 a brief outline of complexity studies, 2 theories of complexity studies, 3 quantititative and qualitative methods, and 4 applications of complexity studies across disciplines. This course will have four deliverables, including two essays on applying theories and methods of complexity studies in their field of research, one guest lecture in an undergraduate course, as selected by the student or assigned by the instructor, and the preliminary design of a capstone project and identification of a potential WICI affiliated research collaborator.

CMPLX603 – capstone. In the capstone course, students apply their expertise in complexity systems by applying to one of two national competitions. Student must partner with one current WICI affiliated researcher that is not their supervisor and submit an application to either the Map the System or the RSA student design award. The final deliverable for this course is a successful application to either competition.

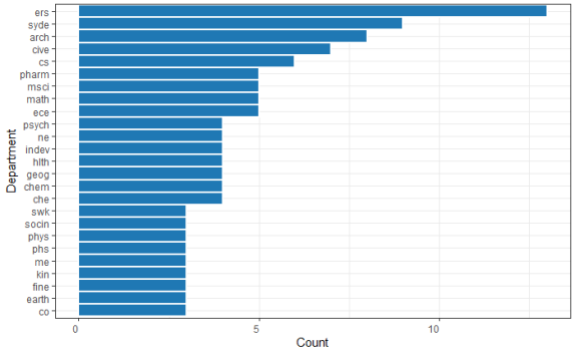
Students who complete the collaborative complexity program gain 5 core competencies. First, students gain a comprehensive understanding of the qualitative and quantitative complexity research currently undertaken at the University of Waterloo and through affiliated partners. Second, students will share a base level understanding of what complexity studies entail across disciplinary lines. Third, students will be able to apply theories and methods of complexity studies into their own field of study. Fourth, students will learn and practice articulating complexity related topics to other students, researchers, and practitioners. Finally students will apply expertise in complexity studies through the successful involvement in one of two international complexity competitions

COURSE OFFERINGS

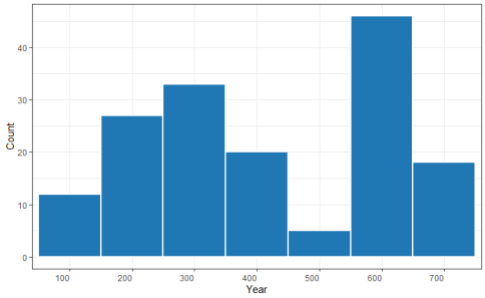
The final contribution of this report is a systematic analysis of complexity and systems thinking course offerings at the University of Waterloo. With thanks to the Office of the Registrar, we were given access to 7,533 undergraduate and graduate course offerings at the University of Waterloo, including the course code, title, description, and instructor. Of those offering, 166 reference either complexity or systems thinking. We examine these 166 courses is greater detail.

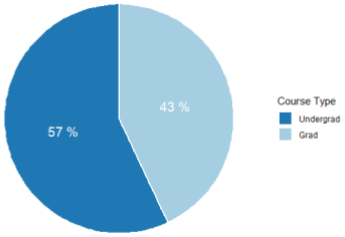
Descriptive Analysis: Complexity offerings by department and year

We begin with a descriptive analysis of complexity courses by department and year. At first glance, there is an even mix of technical and social science offerings on complexity and systems thinking Environment and Resource Studies for example, offers 16 courses on this topic. Other relevant fields include systems design, architecture, civil engineering, and computer science.

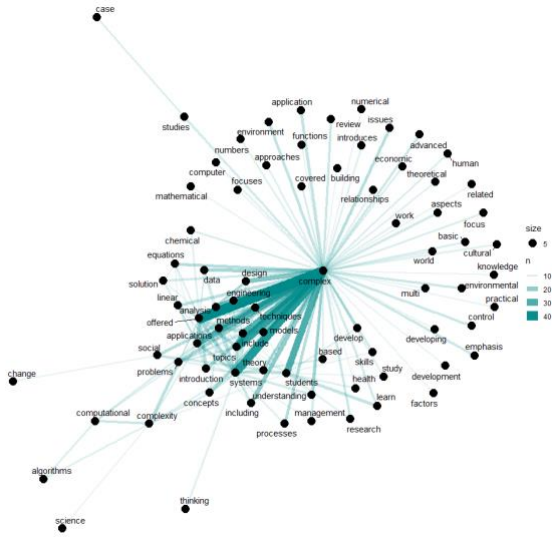


Complexity related courses are more prevalent in upper year courses, however, 57 percent of identified courses are taught at the undergraduate level.

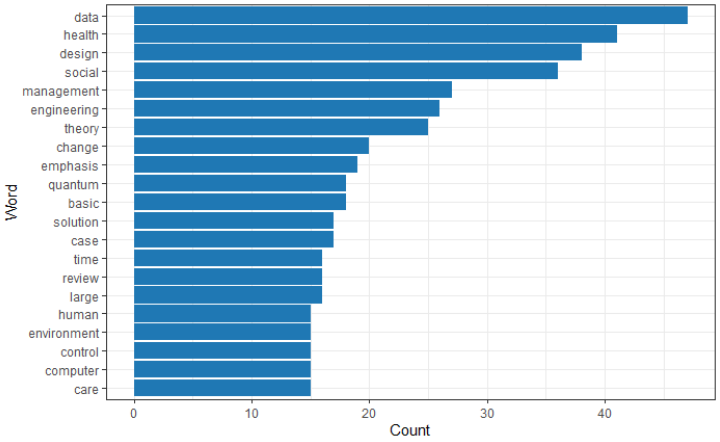




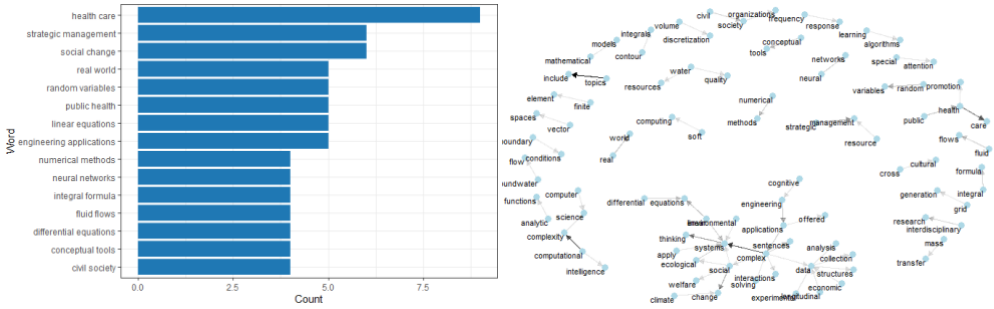
Our analysis turns next to the course descriptions. What do we mean by complexity here at the University of Waterloo? Complexity studies are most associated with words like theories, techniques, methods, and analyses, suggesting a clear focus on tools to address complexity. However, this graph also tells us that complexity is applied in various ways, from the more technical and solution oriented topics of mathematics, science, and computation, to more qualitative and process based topics of environment, development, management, and culture.



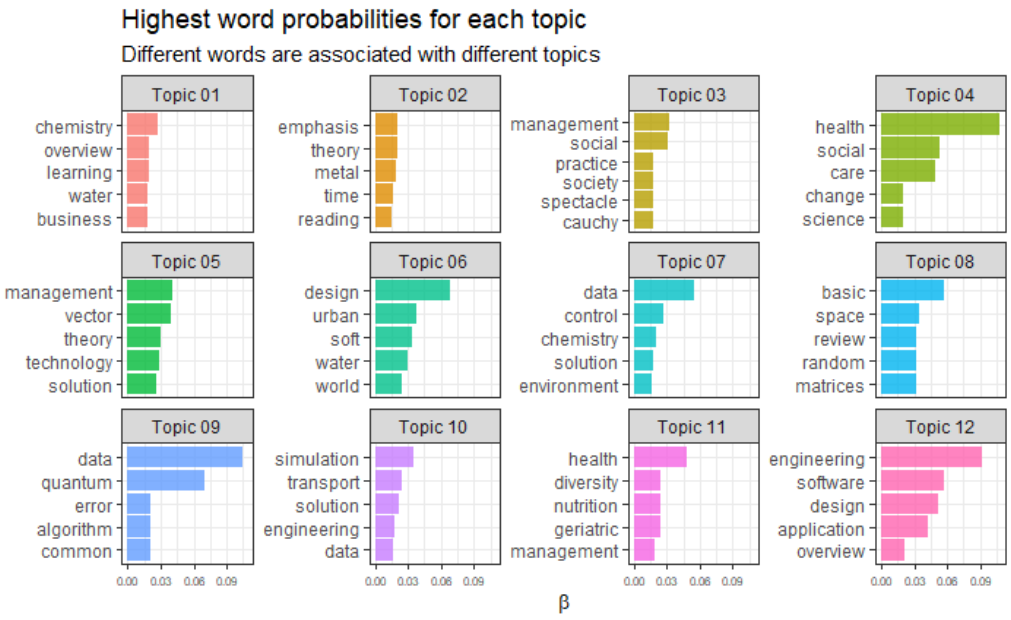
By frequency, words like data, health, and design are among the commonly used in course descriptions that reference complexity or systems thinking.



However, looking at frequent phrases gives greater context about how complexity studies is applied. Healthcare is the most common application of complexity studies at the University of Waterloo, followed by topics related to strategic management and social change. The associated word combination networks maps adjacent words based on how frequently they appear. This first gives greater nuance on complexity related topics. We see for example that water in complex systems often refers to water quality or water resources. It also infers more complex combinations, such as social ecological systems, cognitive engineering applications, or complex data analysis.



We finally run a topic model analysis on the course descriptions. This method identifies latent topics on complexity studies as well as identifies courses that fall into each topic. This may be particularly useful in developing a list of approved electives based on select areas of interest. Some notable topics include those on healthcare in the context of social change (topic 4) and in the context of nutrition (topic 11). Topics on management take a technological (topic 5) and social lens (topic 3). Topics related to engineering software, application, and design (topic 12) and quantum studies (topic 9) are also notable fields of study. Most courses fit into one of these topics; the appendix below highlights the top 3 courses in each bucket as illustrative examples of courses with similar fields of study.



Appendix – Programs and Offerings Considered for Recommendation

Programs

A. Undergraduate Minor. All undergraduate students at the University of Waterloo can enroll in the Complex Systems Minor, provided that the student has declare a major. Students may be required to take up to five courses, including a combination of core courses and approved electives.

Example: Complex Systems Minor at the University of Michigan

B. Graduate Certificate. A graduate certificate can be offered to students who are not enrolled in a graduate degree program at the University of Waterloo but have completed an undergraduate degree or equivalent from an accredited Canadian institution. Students may be required to take up to five courses, including a combination of core courses and approved electives.

Example: Complex Systems Graduate Certificate at the University of Michigan

Example: University of Toronto Policy on Certificates (For Credit and Not-For-Credit)

C. Graduate Diploma. In contrast to a graduate certificate, graduate Diplomas are designed to prepare students for employment. The typical duration is one to four semesters at the Master's level and one to six semesters at the doctoral level. Requirements are integrated throughout the program, and may include an experiential learning component and four to six graduate courses.

Example: Diploma in Theoretical Neuroscience, University of Waterloo

D. Graduate Specialization. A collaborative specialization is an intra-university graduate program that provides an additional multidisciplinary experience for students enrolled in and completing the degree requirements for one of a number of approved degree programs. A specialization is achieved at the University of Waterloo by successfully completing a set of courses defined by the academic unit that collectively contain the necessary depth of material to ensure a student's level of mastery.

Example: Master of Engineering (MEng) Specializations, University of Waterloo

E. Collaborative Graduate Program. Collaborative programs can span academic units or Universities. Students may be required to take up to three additional courses, including a combination of core courses and approved electives across disciplinary boundaries. By completing the requirements of the collaborative program, students may receive a specialization or diploma from the associated institutes.

Example: Collaborative Water Program, University of Waterloo

Example: Waterloo-Laurier Graduate Program in Geography

Example: Biotechnology Technician, University of Waterloo / Conestoga College

F. Professional Accreditation. Though structured like a graduate certificate or diploma, a professional certificate targets early- to mid-career professionals interested in integrating complexity within their field of work. The program may be offered fully online and part time and students are required to take a combination of core courses and approved electives.

Example: Climate Risk Management Diploma, IC3, University of Waterloo

Example: Masters of Environment and Business, SEED, University of Waterloo

Offerings

A. Undergraduate Internship. Undergraduate students affiliated with WICI may be directed towards partner organizations or researchers to support the advancement of complexity thinking.

Example: SWaGUR (Games Institute) Undergraduate Internship, University of Waterloo

B. Graduate Internship. Graduate students affiliated with WICI may be directed towards partner organizations or researchers to support the advancement of complexity thinking. Students are required to take one or more four-month internships related to a topic related to their program and accredited through WICI.

Example: PhD Computer Science Internship, University of Waterloo

C. Seminar Attendance and Documentation. Students may be required to attend and document their participation on a select number of seminars presented by the institute or across campus that would be relevant to their research, including presentations from students, faculty, and visiting researchers.

Example: TN700, Theoretical Neuroscience Research Seminars, University of Waterloo

D. Introduction to Complexity Undergraduate Elective. The University of Waterloo may offer an existing or new course for undergraduate students on complexity and systems thinking. This course may be available to all students across the university.

Example: SYDE332, Introduction to Complex Systems, University of Waterloo

E. Project based course / Capstone. Students may be required to participate in a project based course, perhaps related to the Map the System competition or the RSA student design awards.

Example: Water 602, Collaborative Water Program, University of Waterloo

Example: Capstone Design, Engineering, University of Waterloo

F. Research Seminar (Poster Presentation). Students may be required to present their respective research at an organized research seminar, intended to develop the student's ability to communicate their research. This approach encourages students from multiple faculties to collaborate across disciplines.

Example: Research Seminar, Water Institute, University of Waterloo

G. Summer Institute. An annual workshop between the University of Waterloo and an affiliated institution. This event may be limited to doctoral candidates and accessible by invitation only. A keynote presentation may be open to the public.

Example: Annual U-M-SFI Workshop, University of Michigan.

Example: Summer Institute, Water Institute, University of Waterloo

H. Experiential Education. Graduate students affiliated with the institute may partner with a researcher and practitioner in the field to conduct research on a topic that is relevant to practitioners.

Example: Biomedical technology graduate program, University of Waterloo

Appendix - Aggregated Results from WICI Consultation

Raw Data

ID	Name	Type	Contribution to WICI's core Mandate	Potential for Multiplier Effects	Speed/Ease of Implementation	Overall Desireability	Time Horizon (short/long)
A	Undergraduate minor	Program	3	4	-2	4	1
B	Graduate Certificate	Program	6	7	0	5	-2
C	Graduate Diploma	Program	7	4	-1	4	-2
D	Graduate Specialization	Program	2	4	-1	-1	0
E	Collaborative Graduate Program	Program	5	7	-6	2	0
F	Professional Accreditation	Program	5	4	0	1	0
A	Undergraduate Internship	Offering	0	4	0	-2	-1
B	Graduate Internship	Offering	1	5	-1	0	-1
C	Undergraduate Elective - Introduction to Complexity	Offering	3	0	6	4	0
D	Graduate Elective - Introduction to Complexity	Offering	6	4	3	6	0
E	Project based course / Capstone	Offering	4	4	2	2	0
F	Seminar Attendance and Documentation	Offering	3	-1	7	2	-2
G	Research Seminar (Poster Presentation)	Offering	1	2	6	1	-2
H	Summer Institute	Offering	4	3	-7	-2	0
I	Experiential Education	Offering	1	3	-4	-1	0

Appendix – Certificate Offerings at the University of Waterloo

Issuing Body	Certificate	Description
Professional Development	In Class Certificates	Each certificate is comprised of 3-5 courses which are offered at various times throughout the year. Some offer a selection of courses to choose from, so you can tailor your certificate to your personal needs and interests.
Professional Development	Online Certificates	Each certificate is comprised of 3 or 4 courses which are fully online and are offered every month. There are no admission requirements, and no required time to complete the certificate.
Center for Teaching Excellence	Certificate in University Teaching	Students must successfully complete three Graduate Studies (GS) courses (GS 901, GS 902 and GS 903) and have one year to complete each course. GS 901 is a pre-requisite for GS 902. Note: These courses may only be applied for credit towards the Certificate in University Teaching and may not be counted towards any degree.
Center for Teaching Excellence	Certificate in University Language Teaching	CTE and the Department of Germanic and Slavic Studies jointly offer the Certificate in University Language Teaching (CULT). CULT is tailored to language instruction and is open to all currently enrolled Waterloo doctoral students in languages. Learners are required to attend teaching workshops on language teaching and participate in three microteaching sessions.
Student Success Office	Leadership Certificate Program	Workshops are free to any current UWaterloo student (you must be registered in the term). You can complete the 12 workshops in any order and at your own pace throughout your university career. By completing all 12 workshops, you are eligible to receive the leadership certificate. This program does not qualify for university credit
Student Success Office	Global Experience Certificate	Undergraduate students are required to submit an application and a GEC milestone plan outlining how they will complete the following GEC requirements: Three for-credit courses (1.5 units), specifically two sequential language courses and one Global Studies course. One international experience for a minimum 6 consecutive weeks. One cross-cultural volunteer experience for a minimum of 20 hours during one term. Reflection piece (e.g. written reflection, photo journal, or journal entries) about your international experience or cross-cultural volunteer experience.
EDGE	EDGE	Students complete six milestones as part of the EDGE certificate: a skills identification and articulation workshop, in which students practice recognizing their skills and expressing them to employers in a confident, concise fashion; a career development course, in which students develop core career-seeking skills and align their career goals with their values, skills and interests; three work or community experiences, in which students explore a wide variety of opportunities both inside and outside of the classroom and reflect on their personal growth; and a capstone workshop, in which students

		tie everything together and develop an action plan for post-graduation success.
Sustainability	Sustainability Certificate	Waterloo's Sustainability Office, in collaboration with Organizational and Human Development, is excited to offer a free Sustainability Certificate for employees of the University. To receive the certificate, an employee must: Complete all seven sessions (can be completed over multiple terms); Come to all session having read the pre-reads and be ready to engage with colleagues; Complete the short multiple choice quizzes after each session (5 minutes each)
Economic Development Program	Certificate in Economic Development	The Economic Developers Association of Canada (EDAC) and University of Waterloo have partnered to offer a suite of professional development programming. Our courses and seminars are accredited by EDAC and will help you get your Certified Economic Developer designation (EcD). It consists of two courses, Year 1 and Year 2. Year 1 includes a 1-2 page reflection and Year 2 includes a 15 page research paper.

Appendix – Topic Modelling of Top Courses by Topic

Code	Title	Description	Topic	Score
earth621	Aqueous Geochemistry	a) Basic thermodynamics and activity-fugacity relationships. Chemical equilibria, ion association and complexing, oxidation-reduction reactions. Models for aqueous equilibria in high concentration solutions. b) Interaction of groundwater with porous media; mineral dissolution/precipitation reaction kinetics, ion exchange, surface ionization of oxides. c) Use of computer codes such as PHREEQE and GEOCHEM to simulate mass transfer in geochemical systems. Examining and modelling chemical evolution in groundwater flow systems.	1	0.9518491
enbus602	Introduction to Sustainability for Business	This course reviews the history of global environmentalism; societal expectations and business responses; and the emergence of corporate social and environmental responsibility. It systematically presents environmental (climate change, air pollution, water quality and quantity, energy and resource consumption, etc.), and social (human rights, health, poverty, ethics, fair trade, etc.) issues, their science, status and priority; technological, regulatory and policy responses; and implications for business. This course introduces concepts for business sustainability, including systems thinking, complexity and resilience, corporate responsibility, materials and energy flows and transformations, economic and market mechanisms, and relates these to business operations, marketing and strategic management.	1	0.9505613
enve275	Environmental Chemistry	Overview of risk, biosphere compartments and contaminant fate. Composition of water. Electroneutrality and activity. Reactions and speciation including reaction kinetics, mass transfer, vapor pressure, equilibrium, and chemical thermodynamics. Equilibrium chemistry including Log-concentration diagrams, titration and buffering intensity, dissolution/precipitation, carbonate system, hardness, and complex formation. Classification, nomenclature, physical/chemical parameters and partitioning of organic compounds. Basic redox chemistry including: half cell reactions, Faraday and Nernst equations, and pE-pH diagrams. Four labs. [Offered: W]	1	0.9740412
avia204	Professional Pilot Program Course IV	This course continues from AVIA 203 and provides the required Preparatory Ground Instruction to prepare students for the air exercises to be completed during in-aircraft instruction that is conducted as part of the course. Students will complete a dual cross border flight to the United States as well as a dual flight into high density controlled airspace (CYYZ). Students also complete a check-out in a complex aircraft and acquire additional cross-country pilot-in-command time. Students will have acquired approximately 110 hours total flight time by the end of the course. This course also includes the g	2	0.9729775

		round school required to prepare the student to write the Transport Canada Commercial Pilot Licence - Airplane examination.		
chem717	Advanced Transition Metal Chemistry	Magnetochemistry of transition metal compounds. Electronic spectra of complex ions including applications of molecular orbital and ligand field theories. Stabilization of unusual oxidation states and coordination numbers. Bonding, structure and reactivity of certain important classes of metal complexes, e.g. metal hydrides, metal-metal bonded species, biologically-significant model systems such as macrocycles.	2	0.9555927
syde292	Circuits, Instrumentation, and Measurements	Active and passive circuit elements, Kirchhoff's laws, mesh and nodal circuit analysis, principle of superposition; step response of first and second order networks; sinusoidal steady state analysis using complex impedance phasors; input-output relationships, transfer functions and frequency response of linear systems; operational amplifiers, operational amplifier circuits using negative or positive feedback; diodes, operational amplifier circuits using diodes; analog signal detection, conditioning and conversion systems; transducers, difference and instrumentation amplifiers, active filters, A/D and D/A conversion. [Offered: F]	2	0.9723240
ers622	Biosphere Reserves as Social-Ecological Systems	The Georgian Bay Biosphere Reserve is one of 16 UNESCO biosphere reserves in Canada, and is used as a setting to learn about sustainable community development, adaptive resource management, and social and ecological resilience. The main objective is to link practical experience "on the ground" with some of the theoretical concepts related to sustainability and complex social ecological systems.	3	0.9476866
indev308	Introduction to Social Entrepreneurship	This course uses the case study method to examine the challenges of starting, funding and operating an early-stage social change venture in a developing country. The focus is on ventures that address urbanization and poverty. Students explore the complexities of managing and sustaining growth, the role of governing boards, and the role of private sector partnerships and resources. Innovative public/private partnerships are examined. The challenges and opportunities associated with engaging diverse partners with differing agendas are considered from the perspective of the entrepreneur, investor/donor, local community leaders and legal counsel.	3	0.9500156
pacs603	Building Civil Society	This course explores operational aspects of civil society organizations such as visionary leadership, goal setting, evaluation, report writing, financial management, applied research skills, and human resource management. Students will also examine codes of conduct and practice, including rules, laws and customary understandings that guide the work of civil society organizations. Students will research contending views of civil society organizations and their complex relationships with governme	3	0.9584211

		nt and business, thereby developing a philosophical and ethical framework for evaluating civil society action.		
bme364	Engineering Biomedical Economics	This course examines key economic issues in health care and biomedical industries. Topics include the market for medical care, health insurance, various models of healthcare delivery and competition and the role of government in policy, financing and delivery of health care. This course will train students to use economic analysis to model and understand the complex interactions between health care delivery, insurance markets, health innovators, governments, and firms. [Offered: F]	4	0.9534436
indev603	Global Health	This course explores aspects of the distribution, diffusion, determinants and delivery of health and health care in a global context. Building on foundational skills (i.e. basic understandings of epidemiology; the social determinants of health) the course will review a range of case studies (e.g. infectious disease; water; access to care; global environmental change) from a variety of regions around the world. Students will gain an appreciation for the complexity of the issues, as well as science-policy bridging.	4	0.9462965
swk602r	Social Work Practice in Health	This course examines practice models and multi-level methods of intervention for effective social work practice in health care, including health promotion, disease prevention, assessment, treatment, rehabilitation, continuing care, and discharge planning within the context of social, economic, environmental, and cultural variations. The distribution, determinants, as well as psychological and behavioural aspects of health and disease across the life span are addressed. Practice models incorporate competence and empowerment as central themes. New models of care are considered, including primary health care, the impact of socio-cultural factors on health and well being, the significance of family relationships and resources in the management of chronic and complex health conditions, and interventions that support individual and family capacity to adapt to acute health crises or chronic health conditions. (Note: This is an online course).	4	0.9713270
cive774	Advanced Numerical Methods for Environmental Applications	The analyses of natural and/or manmade environmental systems commonly lead to quantitative descriptions, or mathematical models, of the underlying chemical, biological and physical processes. Numerical models are used for complex situations that may involve spatial variability of material properties, non-uniform geometry, and transient boundary conditions. The objective of this course is to introduce you to theoretical and practical aspects associated with numerical methods for environmental applications. Topics include: review of field equations, conservation laws, and continua; classification of PDEs; types of boundary and initial conditions; finite difference method, error analysis and stability; equation solvers; weighted residual techniques; finite element method; introduction to the finite volume	5	0.9439308

		method; techniques for advective dominated flows; sensitivity methods; and the solution to coupled non-linear equations.		
dm766	Strategic Management of Technology	This course focuses on the strategic management of technology and innovation established firms. We take an evolutionary process perspective. The fundamental ideas underlying the perspective are: (1) that a firms technology strategy emerges from its technological competencies and capabilities, (2) that the technology strategy is shaped by evolutionary external (environmental) and internal (organizational) Forces. The course draws on strategic management, economics and organization theory for analytical tools to address important challenges faced by senior and middle managers in technology based firms. The course is practice oriented. Case studies of various real life situations will require in-depth analysis to be complemented with specific action recommendations. * To develop an awareness of the range, scope and complexity of the issues and problems related to strategic management of technology and innovation * To develop an understanding of the state of the art of strategic management of technology and innovation * To learn how to practically apply theoretical concepts in strategic management of technology and innovation.	5	0.9663449
socin602	Design Thinking for System Change	This course covers the history of design thinking as a tool for supporting system change at local and broad scales - from designers like Bruce Mau, who uses this approach to describe what he calls "massive change", to complexity thinkers like Brian Arthur who explores the nature of technological innovation. The course also investigates the methodological implications of design thinking approaches to strategy development and implementation.	5	0.9279703
ece457b	Fundamentals of Computational Intelligence	Introduces novel approaches for computational intelligence based techniques including knowledge-based reasoning, expert systems, fuzzy inferencing and connectionist modeling based on artificial neural networks. The focus is on the use of soft computing approaches to deal effectively with real world complex systems for which their mathematical or physical models are either non-tractable or are difficult to obtain. The main thrust is on designing computationally intelligent systems with human like capabilities in terms of reasoning, learning and adaptation. Tools of computational intelligence could be used in a wide range of engineering applications involving real world problems such as in planning problems, intelligent control, autonomous robotics, speech understanding, pattern analysis, network design, face recognition, communication systems to name a few. [Offered: W]	6	0.9635278
ece657	Tools of Intelligent Systems Design	Conventional approaches for tackling complex systems are usually implemented under the assumption of a good understanding of the process dynamics/functionalities and its operating environment. These techniques fail, however, to provide satisfactory results when applied to ill-defined processes (for which analytical and experimental modeling may	6	0.9691933

		not be easily obtained) that may operate in unpredictable and possibly noisy environment. Recent developments in the area of intelligent systems and soft computing have presented powerful alternatives for dealing with the behavior of this class of systems. This course outlines fundamentals of soft computing based design approaches using such tools as approximate reasoning, fuzzy inferencing, neural networks, evolutionary algorithms, and neuro- fuzzy systems. Fundamentals and advances on these procedures are outlined along with their potential applications to various real world applications in virtually most fields of engineering including pattern recognition, system planning, classification, power generation, intelligent transportation, systems and control, intelligent mechatronics, optimization, communication, robotics and manufacturing, to name a few.		
indev612	Introduction to Water Resources	This course presents a broad survey of water resources processes and issues. How much water does the world need to support growing human populations? What factors influence water quality, droughts, floods, and waterborne diseases? What are the potential effects of climate change on the world's water resources? This course presents a thorough introduction to the complex world of water resources. The fundamentals of the science of water, aquatic ecology, geomorphology and hydrology, chemistry, and biology of lakes, rivers, and wetlands are covered. Major disease issues, worldwide water quality and quantity problems, and potential solutions are examined.	6	0.9614134
enve231	Inorganic Environmental Process Principles	Atomic theory, bonding, stereochemistry and transition metal chemistry as related to catalysis and pollution abatement. Some thermodynamic aspects of inorganic chemistry, stability of metal complexes and complex ions in solution. Principles and applications of atomic and molecular structure to environmental chemistry and engineering (e.g. ozone, CFCs, NOx, and SOx). Selected inorganic chemical processes of industrial importance, e.g. sulphuric acid, nitric acid, ammonia, phosphate, caustic, iron ore, uranium. Impact of process design and chemistry on the environment. [Offered: F, S]	7	0.9567571
hlth706	Advanced Epidemiological Methods	Building on HLTH 606, this course provides an in- depth survey of theory and methods in epidemiology, focusing on answering complex research questions using epidemiologic methods. Course topics include modeling multinomial, count, rate, and survival data and disease transmission; infectious disease dynamics; assessing the reliability/validity of measurement instruments; an in- depth examination of various study designs (e.g., case control, nested case control, case- cohort, randomized controlled trials, panel studies, and hybrid study designs); critical appraisal of the medical literature; and systematic reviews and meta-analysis.	7	0.9600246

span218	Parallel Revolutions in a Nascent Continent	This course provides a broad foundation to the varied and complex geographical, ethnic, social, and historical forces that have shaped contemporary Latin American nations from the early 19th-century independence period to current affairs. Students will be introduced to the diverse regions of the continent: Mexico, Central America, the Caribbean, the Bolivarian republics, and the Southern Cone. Students will analyze and discuss nation-building factors such as European-African-Asian-New World interactions, ethnic mixtures, military takeovers, revolutions, U.S. interventions in the region, and migratory experiences. Discussions will also be aimed at contrasting and comparing the contemporary and diverse cultural manifestations of the peoples living in Latin America and the cultural transformation of Latin Americans who have emigrated to other parts of the world, as well as the perceptions of Latin Americans in other cultures.	7	0.9601018
econ221	Statistics for Economists	This course introduces students to describing economic data and drawing inferences from features of economic data. Starting from fundamental axioms of probability, students will learn about the calculation of probabilities of basic events and the features of random variables, the most important tool for representing the outcomes of complex economic phenomena. Students will describe discrete and continuous random variables via their probability distributions and summary statistics such as means and standard deviations, as well as the relationships between two random variables in terms of covariance, correlation, and simple regression models. The concepts of hypothesis testing and confidence intervals, and the fundamentals of statistical inference are discussed for basic features of random variables and for comparing the features of more than one random variable.	8	0.9324412
sds326r	Philosophy and History of Social Welfare	Social welfare from the 18th century to the present. The effects of religious, political, economic and cultural factors on social welfare, development, and the continuing influence of inherent attitudes, philosophies, and values on this complex institution. Focus on the Canadian social welfare system.	8	0.8974880
stv303	Cross-Cultural Change, Technology and Society	The course will examine the concept of cross-cultural change as more than a consequence of contact between ethnic and national groupings. Technological change and the mutual interaction between technology and culture produce new cross-cultural change and challenges. The purpose of the course is to help students understand and identify the complex interaction between technology and culture and its impact on design and the choice of technology. Students will be expected to use this knowledge as a decision-making tool.	8	0.9354966
amath871	Quantum Information Processing	Review of basics of quantum information and computational complexity; Simple quantum algorithms; Quantum Fourier transform and Shor factoring algorithm: Amplitude amplification, Grover search algorithm and its optimality; Completely positive trace-preserving maps and Kraus representation; Non-	9	0.9754438

		locality and communication complexity; Physical realizations of quantum computation: requirements and examples; Quantum error-correction, including CSS codes, and elements of fault-tolerant computation; Quantum cryptography; Security proofs of quantum key distribution protocols; Quantum proof systems. Familiarity with theoretical computer science or quantum mechanics will also be an asset, though most students will not be familiar with both.		
co481	Introduction to Quantum Information Processing	Basics of computational complexity; basics of quantum information; quantum phenomena; quantum circuits and universality; relationship between quantum and classical complexity classes; simple quantum algorithms; quantum Fourier transform; Shor factoring algorithm; Grover search algorithm; physical realization of quantum computation; error-correction and fault-tolerance; quantum key distribution. [Offered: W]	9	0.9626394
earth458l	Field Methods in Hydrogeology	This course exposes students to a wide variety of field and laboratory techniques for collecting hydrogeologic data and to gain experience in interpreting the data. Advantages and limitations of various measurement and data reduction techniques for evaluating groundwater flow systems are demonstrated in a set of field exercises carried out at the groundwater demonstration facility located on the university North Campus. These exercises illustrate the complexity of natural systems and the need for good data collection and interpretation skills when characterizing such systems . [Offered: F,S]	9	0.9550141
cive755	Micromechanics of Soils	The theory of application of statistical mechanics to explain engineering behaviour of soils as discrete assemblies of particles. The introductory topics include mathematical descriptions of soil fabric, fabric tensor, definition of stress tensor in terms of average intergranular forces and characteristics of fabric, evolution of fabric due to shear deformations. Effects of particle shape and stiffness on macroscopic properties. Applications of micromechanics to constitutive models of granular materials. Drained and undrained response, behaviour under complex states of stress and effects associated with principal stress rotation.	10	0.9609528
earth651	Advanced Groundwater Modelling	This course covers advanced numerical modelling topics in groundwater flow and contaminant transport in the subsurface. Topics to be explored include two- and three-dimensional transport in groundwater systems, density/ heat-dependent flow/transport, flow in the vadose zone, immiscible flow of non-aqueous phase liquids, multiphase dissolution and mass transfer processes, transport of biodegrading or chemically interacting contaminants, transport in fractured systems, transport in the vapour phase. The focus is on the use of models to obtain insight into the complex coupled processes that control groundwater contamination and remediation problems. Students will work with their own as well as existing models.	10	0.9666450

me663	Computational Fluid Dynamics	This course presents the concepts and details required to develop computer codes for the simulation of complex multidimensional fluid flows. The following topics will be covered: the finite volume discretization method, discretization schemes for diffusive fluxes, iterative solution algorithms, multigrid acceleration techniques, first and second order bounded discretization schemes for advective fluxes, special treatments for the coupled momentum and mass conservation equations, pressure redistribution techniques, velocity- pressure solution techniques, and extensions to multi- dimensions. Enrichment topics will be chosen from the following research areas: grid generation, turbulence modelling, and emerging discretization and solution algorithm technologies.	10	0.9575737
bet580	Consulting	This course is useful for anyone considering working as a consultant, either for a consulting firm, as an independent entrepreneurial consultant, or as an internal consultant to large organizations. Some of the competencies skilled consultants have include understanding business needs from a holistic perspective, developing innovative ideas, expert people skills, influence, and change management. Course topics may also include key stages in the consulting process, issue diagnosis, managing difficult clients, consulting frameworks, analytical approaches to solving complex problems, engagement management, building a consulting toolset, change management processes, negotiation, and advanced presentation techniques. We will also cover aspects of the business of consulting. [Offered: F]	11	0.9524371
kin146	Introduction to Human Nutrition	An introductory course on human nutrition. Students will be introduced to core topics in nutrition including function of nutrients, nutrient requirements, diet assessment and planning, food composition and the complex interrelationships between food, nutrition, and health. Factors that affect the human diet such as biology, psychology, sociology, environment and political policy will also be examined, as well as key areas of nutrition focus for life stage groups.	11	0.9531987
swk600r	Diversity and Health	This course studies the impact of diversity on health in Canada and across nations. It provides an understanding of the complex interaction among aspects of diversity. The course examines and critiques the methods used in the study of these concepts and issues related to the measurement of health among diverse groups. The ultimate goal of this examination is to help students develop an appreciation of the impact diversity has on assessments and study of health, health status, and health promotion in Canada and other nations. The course is designed to integrate different sources of information about diversity by utilizing critical thinking skills for the consumption of health information. (Note: This is an intensive on campus course with an online component).	11	0.9594509
arch677	Survey of Digital Design Tech	This course provides an overview of the software and hardware technologies to support the design of an architecture that is more holistically conceived on cultural, social, health, technical and formal grounds that would otherwise be possible. What is taught facilitates an integrated design process where all disciplines collaborate through all phases of a p	12	0.9594797

	nologies for Architecture	roject to achieve a sustainable design. There will be an exploration of software applications including the generation of landscapes and vegetation, energy analysis, acoustics, lighting, structure, people movement, air flow analysis, microclimate analysis and various types of three-dimensional modelling software, particularly, packages that facilitate interfacing with rapid prototyping and allow complex form generation. Rapid prototyping techniques will include laser cutting, three-dimensional printing and CNC 3-axis machining. The course format is a seminar in which each student will explore some of these technologies in depth by means of a small design example and presentations to the class while obtaining an overview from the course lectures and presentations by other students on other applications.		
ece457a	Cooperative and Adaptive Algorithms	The course starts by addressing the ill-structured problems and need for computational intelligence methods. It introduces the concepts of heuristics and their use in conjunction with search methods, solving problems using heuristics and metaheuristics, constraints satisfaction. The course also introduces the concepts of cooperation and adaptations and how they are influencing new methods for solving complex problems. The course starts by illustrating how the concepts of cooperation and adaptation are manifested in nature and how such models are inspiring new types of solutions methods. Topics to be covered include: search algorithms, game playing, constraints satisfaction, meta-heuristics, evolutionary computing methods, swarm intelligence, ant-colony algorithms, particle swarm methods, adaptive and learning algorithms and the use of these algorithms in solving continuous and discrete problems that arise in engineering applications. [Offered: S]	12	0.9311148
syde642	Cognitive Engineering Methods	This course examines the fundamentals of modern perspectives on interface design for complex systems using current methods in cognitive engineering. We discuss Cognitive Work Analysis, Brunswick's' Lens Model, Goal Directed Task Analysis, Situation Awareness Oriented Design, Naturalistic Decision Making, Contextual Inquiry, Macro-cognitive Methods, Activity Theory, Concept Mapping, Cognitive Task Analysis, Social Network Analysis and their application to different types of human engineering problems. Students in this course will learn multiple methods in cognitive engineering with an emphasis on knowing the differences in foundation, assumptions and appropriate application of the methods. Students will be expected to apply the methods in a realistic research context, applying for ethics clearance and working with actual participants. Examples of appropriate topics may include understanding how people work with complex or automated systems models. Finally this course discusses aspects of the current research environment in cognitive engineering, with the objective of developing successful future researchers in this area.	12	0.9581234