UNDERGRADUATE RESEARCH GUIDE

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Introduction

The University of Toronto's Department of Computer Science thrives on research. We have over a hundred faculty members working in over a dozen different research areas. Most of the CS research at U of T is conducted by faculty members and graduate students. However, undergrads do research too!

In fact, there are a lot of different ways for CS undergrads to get involved in research. On the one hand, this is a good thing – there are research opportunities for students who have a wide variety of personal backgrounds and academic interests. On the other hand, the task of finding these opportunities can seem daunting and confusing.

At the Review of Undergraduate Computer Science (RUCS), we believe in the importance of undergraduate research. We put together this document in the hopes of making the process a little less confusing. We hope that you enjoy reading it.

If you have any questions, don't hesitate to reach out to us! Send us an email at rucsuoft@gmail.com or message us on Slack.

What is Undergrad Research?

When you picture a researcher in computer science, there's a good chance you don't picture an undergraduate student. Undergrads often lack in-depth subject-matter expertise, and the research programs and courses available to them tend to have very rigid timelines. However, despite these constraints, undergrads often undertake ambitious research projects and are capable of making real contributions to computer science.

Types of Undergrad Research Projects

Generally speaking, most undergrad research projects fall into one (or more) of these categories:

- experimental research
- software development
- exploratory research

Experimental research generally involves designing an experiment, collecting data, testing a hypothesis, and doing statistical analysis.

Software development, on its own, is not research. However, a lot of research projects in CS involve software development. For instance, you may find yourself writing software that you or another student will use in order to run experiments and test hypotheses. Or, you may be writing software that implements the results of someone else's research.

Exploratory research is what we typically think of as computer science research: you look at a scenario or an idea, you wonder about it, you figure out the right questions to ask, and then you answer those questions, by thinking really hard, talking to your peers, trying out a bunch of strategies, and doing a lot of reading!

As you might imagine, of those three categories, exploratory research is a lot harder for undergrads to undertake. If you want to do research but you have a limited amount of background knowledge and experience, consider starting out with research that is more focussed on experiments and software development. This will provide you with an excellent foundation to pursue more exploratory research later on, and will help you create connections with faculty members.

For more experienced undergrad students, it is absolutely possible to undertake exploratory research. This is more challenging, both for the student and the supervisor. Unfortunately, a single semester is often not enough time to do meaningful work. Different profs have different ways of dealing with this time constraint. Sometimes, your supervisor will simply give you a problem and you will spend the semester solving it, much like you would a homework problem. Other times, you and your supervisor might decide on a more open-ended approach.

The Day-to-Day

Your daily activities will depend a lot on your particular circumstances, i.e. the field you're working in, the topic you're working on, the preferences of your supervisor, your time constraints, etc. You might be going in to a lab 9 AM to 5 PM, Monday to Friday, just like you would at a real job. Or, you might be working largely from home, with the occasional check-in with your supervisor. Sometimes, you'll be working with other undergrads or with grad students; other times, you'll be working alone. There is a lot of variety.

Examples

Here are a few examples of research projects that undergraduates have undertaken. These examples are all drawn from papers that students have submitted to RUCS. They were selected to demonstrate the range of types of projects that undergraduates have worked on. Some of these projects required relatively little background knowledge and expertise.

1 - **PREDICTING EXAM RESULTS IN AN INTRODUCTORY LEVEL COMPUTER SCIENCE COURSE** (link)

Sihan Zheng and Emmanuel Ifemade

In this project, students investigate the correlation between performance on online exercises and final grades in an introductory computer science class. The authors use statistical analysis to predict final scores based on the number of attempts taken for practice problems.

2 - **EFFICIENT IMPLEMENTATION TO IDENTIFY DISEASE MECHANISMS** (link)

Ekansh Sharma

In this paper, students consider a method proposed by other researchers for identifying causal genes for complex human diseases. They propose a more efficient implementation of this method in software by using a different

programming language and applying several heuristics to the existing method.

3 - **DEVELOPMENT OF DYNAMIC AND CUSTOMIZABLE VOICE-TO-CODE SOFTWARE** (link)

Christopher Koehler

The author developed software using a free speech-recognition engine in order to help programmers write code using their voices. The student then evaluated their software by asking a group of programmers to use the software and provide feedback.

4 - **N-WAY MODEL MERGING GAME** (link)

Christina Chung

The author created a game to enable humans to perform N-way Model Merging, an NP-hard problem. Existing efficient algorithms generate only approximate solutions; however, humans appear to perform this task easily and accurately. The purpose of the study was to get insight into how accurately humans perform this task depending on properties of the models that they are merging.

5 - **USER CUSTOMIZATION OF CAREGIVING ROBOTS THAT SUPPORT OLDER ADULTS WITH DEMENTIA** (link)

Zehui (Joyce) Zhou

The author improves upon a caregiving robot by allowing the behaviour of the robot to be customized to patient needs. This is accomplished by furnishing the robot with a customizable knowledge base that can be updated and which modifies the robot’s behaviour.

Courses

CSC 49* Courses

U of T's CS Department offers four courses that are geared towards open-ended and self-directed projects. The department website has some info about them here.

I. CSC490H and CSC491H - Capstone Design Project

"This half-course gives students experience solving a substantial problem that may span several areas of Computer Science. Students will define the scope of the problem, develop a solution plan, produce a working implementation, and present their work using written, oral, and (if suitable) video reports. Class time will focus on the project, but may include some lectures. The class will be small and highly interactive."

The topic for these courses is determined every year by the department and announced on the CS bulletin board or the department website. Here is the 2018 posting, which lists the project descriptions and application instructions. These projects are likely to be centered around software engineering. However, sometimes they also have a research component.

You can also take CSC491 via a "Business of Software" program - read more here. This program has little to do with research but might be interesting nonetheless.

II. CSC494H and CSC495H - Computer Science Project

"This half-course involves a significant project in any area of Computer Science. The project may be undertaken individually or in small groups. The course is offered by arrangement with a Computer Science faculty member."

These courses are generally undertaken on a one-on-one basis, as a result of an arrangement that the student personally makes with a faculty member. However, sometimes there are more structured options. For instance, here is a 2018 posting which lists a few collaborative projects with engineering students and industry partners.

Graduate Courses

Undergrad students may take graduate courses, provided that they have permission from the instructor. Although most graduate courses will not directly involve research, these courses are a great opportunity to get to know a faculty member and dive deeper into an interesting topic.

If you see a grad course that you find interesting, you can email the instructor to get more info about what kind of background they expect you to have or – if you're planning ahead – what undergrad courses you should take now to prepare you for for taking the grad course in the future.

Research Opportunity Program (ROP)

ROP is Faculty of Arts and Science initiative. Every year, a set of ROP courses are announced online with instructions on how to apply. The course code are ***299Y and ***399Y. They are intended specifically for students entering their second or third year.

Unfortunately, there usually are not very many computer science courses offered via ROP. However, you can apply to an ROP in another department, if you think you have the skills that are listed in that ROP's description. Often, projects in fields such as economics and biology are looking for applicants who are skilled programmers.

ROP courses are generally a full credit, unlike most CSC49* courses. There are ROP courses during the school year as well as over the summer. You can read more here.

Other Relevant Courses

If you are considering applying to grad school or pursuing a career in computer science research, you will surely benefit from a strong foundation in statistics and mathematics. This includes areas such as discrete mathematics, calculus, linear algebra and algebraic theory. This is especially true if you are interested in pursuing machine learning, numerical analysis, or theory of computation.

Regardless of your specific interests, we strongly recommend that you take more than the bare minimum math courses required for your degree. Doing so will help you stand out when it comes time to apply for research positions and grad school.

If you're interested in fields such as machine learning or if you would like to do experimental research – research that involves designing experiments, collecting data, and analysing data – you might consider taking courses such as:

STA302H Methods of Data Analysis I
STA314H Statistical Methods for Machine Learning I
STA304H Surveys, Sampling and Observational Data
STA305H Design and Analysis of Experiments
MAT245H Mathematical Methods in Data Science

If you're interested in fields such as cryptography and theory of computation, consider taking courses such as:

MAT347Y Groups, Rings and Fields
MAT315H Introduction to Number Theory
MAT332H Introduction to Graph Theory
MAT344H Introduction to Combinatorics
APM461H Combinatorial Methods

Those are just a few examples. Don't hesitate to ask faculty members for their input on what courses you should take to achieve your goals.

Undergraduate Summer Research Program (UGSRP)

A great way to get started in CS research at U of T is by applying to UGSRP. You can find the info about the summer 2019 projects here.

UGSRP is a CS department initiative. Every year, CS faculty members are asked to propose UGSRP projects. Students applying to UGSRP indicate on their application which projects they're interested in working on. A committee then selects which students/projects will receive funding. The recipients are awarded funding by either NSERC USRA (Natural Sciences and Engineering Research Council of Canada - Undergraduate Student Research Award) or UTEA (University of Toronto Excellence Award).

Students who apply but are not selected to receive funding may still have the opportunity to work on a UGSRP project. This sometimes happens when the faculty member has an alternate source of funding (via one of their own grants or an industry partner). You might also work on the UGSRP project without funding and receive a course credit instead. There are many other possible arrangements.

In any case, the student would be making these alternate arrangements directly with the faculty member. Sometimes, these arrangements come about because faculty members choose to directly contact students who have applied to work on their UGSRP projects. In other cases, the student took initiative and contacted the faculty member.

It is always a good idea to reach out directly to faculty members before applying to a UGSRP project – this will greatly improve your chance of being selected or of having the opportunity to make an alternate arrangement with a faculty member.

Other Options

UGSRP and CSC/ROP courses are not the only way to get involved in research. To give just a few examples, you could:

- Be a research assistant in a researcher's lab
- Get a research-oriented job or internship at a company
- Do a summer research program at a not-for-profit or government agency
- Do a summer research program abroad at another university via their own in-house research programs
- Do research independently, on your own time (yes – this does happen!)

Finding these opportunities can be tough. The number one place to start is a faculty member's office hours. They often have – or know about – opportunities for undergrads that are not advertised online. For example, a faculty member may run a lab that currently needs a new research assistant.

You can also sometimes find opportunities online. You might consider checking out the following:

- Facebook pages for student course unions (e.g. CS, CogSci, Math)
- The research catalogue
- CS bulletin board (Discourse)
- The DCS newsletter (subscribe)
- Websites for labs/groups that are affiliated with U of T (E.g. TAGLab, Dynamic Graphics Project, Vector Institute)
- PEY job portal - some jobs are research-oriented. These may be described as R & D positions.

Beyond U of T

Finding opportunities outside of U of T can be a little more work. Consider checking out:

- McGill's research opportunities listing
- The JYI's undergrad summer research listing (some of these are for Americans only)
- Other universities' websites – many major American universities such as Stanford and Harvard have summer research programs that are open to foreigners
- Hospitals (such as SickKids)
- Tech companies' websites - many major tech companies do R&D

- U of T's Summer Research Exchange Program (SREP)

Perspectives

We spoke with several U of T CS undergrads who are currently doing research. In this section, you can read about a few of them.

Qiongsi Wu found an unconventional path to research. After graduating with a degree in math and statistics from UWaterloo, he worked in industry for a few years developing financial software. While there, he discovered a problem that he just could not get his mind off of: improving the performance of compute-intensive modelling applications. This led him to returning to school to tackle the problem of compiler optimization.

Qiongsi began approaching professors regarding research early on during his time at U of T. At the Welcome to the PoST event, Qiongsi spoke to Professor Angela Demke Brown about who to talk to in order to get involved with systems research and was recommended to speak to Professor Gennady Pekhimenko. Using this valuable face-to-face interaction, Qiongsi e-mailed Professor Pekhimenko and immediately hit it off. Qiongsi believes his strong motivation and clear research interest greatly aided him during this process. They collaborated part-time over the school year, which eventually developed into a full-time UTEA opportunity this summer. In terms of courses, Qiongsi believes that the fundamental 2nd year CS courses have been quite useful, especially CSC209. Interestingly, due to the increasing AI workloads that are being requested, Qiongsi recommends taking CSC421 just to familiarize oneself with the lingo. Now in 3rd year of undergrad computer science at U of T, Qiongsi is looking to continue his research in grad school with Professor Pekhimenko's group to work on optimizing compilers for parallel and heterogeneous processors.

Christina Chung is a senior in computer science who is a big believer in the collaborative aspect of research. Her motivation for doing research is in advancing the collective frontier of human knowledge and improving our world. Her experience with undergrad research actually began outside of computer science: in 2nd year, she saw a posting in a Facebook group looking for lab assistants in a psych lab. Having wanted to try research and see what it is like (since it sounded cool), she decided to just apply for it and got the position. This kicked off an illustrious career as an undergrad researcher; she has received two NSERC awards, worked on multiple projects with different professors, published papers, and presented at conferences.

Despite all this success, Christina stresses the importance of maintaining a good work-life balance, which can be difficult for a researcher. Unlike a 9 to 5 job, research can always be on your mind, even outside of the lab. This is, in fact, her motivation for her current research into the mental health crisis at U of T.

For undergrads just looking to get started with research, she reassures that professors are not expecting or looking for a lot of experience! All professors need help with something, and are even happy to provide training. In terms of courses, Christina believes that beyonds fundamental programming skills, most of what is important can be learnt on the job. She plans to attend graduate school and plans to work in industry as a researcher.

Alex Chang and **Abhishek Sai Moturu** are fourth year undergrads who worked with Professor Ken Jackson in Scientific Computing this summer. Their work was on developing synthetic lung tumour X-ray data in order to train neural networks and was featured on U of T's website. However, their research faced challenges and adversity at many points. They both demonstrate the importance of perseverance when pursuing a research position.

Abhishek became familiar with Professor Jackson after taking several of his courses. After applying for the research project, Abhishek received his NSERC award only after getting off the waitlist. Alex was initially rejected for the project, but followed-up in person where he found Professor Jackson was very receptive and still interested in taking him on. Alex thus quickly sent Professor Jackson a CV and reference letters, thus securing a spot in a research course covering this project. During the actual research, they received lots of negative results and failed experiments, but stuck at it, incrementally improving and refining their work little by little until it achieved good results.

In terms of courses, they found that surprisingly their work did deal with low-level programming.; hence courses like CSC209 really helped. Aside from that, general knowledge of data structures and algorithms from CSC236 and CSC263 was also quite useful. Alex would like to continue doing research in medical school, while Abhishek plans on continuing research in graduate school.

Faculty

In putting together this guide and organizing several events this year, I have spoken to many faculty members. My biggest takeaway from this experience is that faculty members *want* to work with undergrads. Well, they don't want to work with *all* undergrads *all* the time, but undergrads can – and do – add value to faculty members' research projects.

The best way to find out if a faculty member is currently seeking out undergraduate researchers is to ask them.

Who should you approach?

You can find a list of all CS faculty and all CS research areas on the department website. Each of those research areas has its own website with a faculty listing as well. Most faculty members also have their own personal website, where they'll link to their publications, share biographical info, etc. So, there is no shortage of resources for finding a faculty member who does research in an area you find interesting.

Some faculty members are "teaching stream", meaning that they aren't primarily researchers. Those faculty members shouldn't be your go-to when looking for research positions. However, many teaching stream faculty also do research.

Note that you do not need to limit your search to faculty members who have taught courses you've taken: it's perfectly acceptable to reach out to faculty members who you've never met. If you send a sensible email from your U of T email address, most faculty members will respond to you, and most of the ones who respond will agree to meet with you.

What should you say?

Often, your first contact with a faculty member will be via email. Your email should

- be polite and well formatted,
- contain some info about yourself,
- explain how you know the faculty member,

- and contain a reasonably specific question, such as “Are you available to meet with me next week?”

If your emails are not personalized, or you’ve sent the same email to multiple professors, there is a good chance your emails will be be ignored. So, do not spam faculty members – they can often tell and many faculty members consider it disrespectful.

You might also consider skipping the email altogether and simply stopping by the faculty member’s office. The recipe for writing a polite email applies to in-person introductions as well. However, if you decide to approach them in person, you should start by asking them if they have time to speak with you, and offer to come back at a more convenient time.

Your chances of having a successful encounter are much higher if you go into the meeting prepared. You should prepare by reading a bit about the faculty member’s background and by reading – or attempting to read – some of their published work. Try to communicate to the faculty member what exactly you find interesting about their research, and how it is related to your research interests.

What are they looking for?

Not every faculty member has the same idea about what makes a good undergraduate student. For the most part, however, it seems that they want evidence that you are

- smart and motivated to do research,
- passionate about the topics that they research, and
- pleasant to work with.

Show that you’re smart

Most faculty members agree that your grades *do* matter. However, if you have a weak academic record, you are not doomed. That is because your grades are just one of many ways you can demonstrate that you are smart and motivated. You can also demonstrate this by having

- letters of reference from other profs,
- awards,
- extracurricular activities – they don’t need to be directly related to research,

- some evidence of self-directed learning outside of the classroom – club membership, blog posts, hackathons, etc.

Show that you're passionate

You can show that you're passionate about the topics that they research by

- reading the faculty member's research papers (or at least trying)
- taking classes that are relevant to their research area, including classes in other departments (e.g. taking a language course is relevant to pursuing computational linguistics)
- doing self-directed learning, having relevant job and club experience, etc.

Show that you're pleasant

It is very tricky to demonstrate that you would be pleasant to work with. However, this is mostly taken care of by being polite and respectful.

Improve your chances

Some faculty members - especially the more established ones – are simply not taking on any new students, while others – especially the ones who have joined the department recently – may have much more relaxed criteria, and have a big unmet need for students. So, if you're really concerned about not being an ideal candidate, you might want to start by approaching someone who has joined the department recently.

Student Groups

A lot of research opportunities and projects arise organically, by going out into the world and talking to other people who share your interests. Participating in student groups and attending student-run events is a great way to accomplish that.

UAIG - Undergrad AI Group. In 2018, they hosted a conference called StartAI. (link)

RUCS - Review of Undergraduate Computer Science. Publication and student group that aims to promote undergrad research at U of T. (Creators of this guide!) (link)

TURCS - Similar to RUCS, but without the journal or publication aspect. Mastermind behind the 2018 Undergrad CS Research Conference. (link)

UHCIC - Undergraduate HCI Club. A new club devoted to undergrads who are interested in Human-Computer Interaction (HCI) (link)

Galbraith Society - Engineering undergrad research club. Also publishes a journal, like RUCS. Has a professor-student matching program for student researchers. (link)

ASSU Research Conference - Research conference that happens in January, featuring research from all around U of T in every subject. (link)

MSURJ - McGill version of RUCS! A well run and very professional undergrad research journal at McGill. (link)

FAQ

How much experience do I need?

It really depends. Sometimes, none! Everyone has to start somewhere. Even if you are concerned that you do not have enough experience, you should still get in touch with a faculty member who does research in an area that you find interesting – they will be able to provide you with some guidance.

What do I do if a faculty member ignores my email?

Often, faculty members will simply forget to respond to an email. After 5-10 days, you should send a follow up email to remind them. You could also try directly stopping by their office.

What do I do if they say no?

Try again with someone else! You could also ask them if they have any recommendations regarding other faculty members you could speak to, or things you might do to improve your resume.

How can I start doing research if I don't have a lot of experience in CS?

You are trying to solve the classic bootstrapping problem: you need a job to get experience, but you need experience to get a job. Here are a few ways to gain research-related experience before seeking out a position as a researcher:

- Volunteer in a research lab. You'll likely start out doing administrative work or software development.
- Volunteer to work on software projects such as MarkUs or work on some side projects.
- Join clubs related to research such as RUCS, TURCS, UHCIC, or UAIG.
- Read up on topics that you find interesting and write blog posts about them.

Don't forget that you don't necessarily need a faculty supervisor or a course credit in order to do research – some undergrads have undertaken successful research projects without any faculty involvement.

What time of year should I approach a faculty member if I want to work with them during a certain semester?

Talk with them as soon as possible. It is never too early to start asking.

Resources

- Department of Computer Science (DCS) page about undergraduate research: link
- DCS newsletter: link
- CS bulletin board: link
- Graduate Courses: link
- The research catalogue: link
- The Galbraith Society: link
- RUCS: link
- U of T's Summer Research Exchange Program (SREP): link