QN
QUAESTIONES NATURALES

VOLUME 4, 2016

UNDERGRADUATE RESEARCH IN SCIENCE

Lakehead UNIVERSITY
Faculty of Science and Environmental Studies
lakeheadu.ca

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"Quaestiones naturales" is a Latin term referring to investigations into the natural world, or today what we call scientific research, especially those studies of a multidisciplinary nature. The term was originally used by the Roman philosopher Seneca the Younger for a series of books on meteorology and other natural processes.

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Welcoming Remarks from the Dean

This is the fourth issue of *Quaestiones Naturales*, our annual publication of the research achievements of undergraduate students in the Faculty of Science and Environmental Studies at Lakehead University. Student engagement is a top priority in our faculty and involvement of our students in exciting research projects is central to our focus. This year in *QN*, we feature nine students from across Lakehead's two campuses whose research interests range from the applied to the pure sciences and who use field-, laboratory and computer-based approaches. Subjects range from the possible reduction on CO_2 emissions through novel concrete additives to assessing human influences on water quality in a North Western Ontario lake, and from developing strategies for on-site composting in Canada's northern climates to modeling HIV infection progression using computer-based algorithms. These are just a sampling of pure and applied research projects undertaken by students in our 10 academic departments each year. We take pride in being able to offer motivated students meaningful opportunities to work with leading scientists on projects that are current and of real interest to the student. In a typical year, our faculty's researchers spend close to half a million dollars from individual grants to support students on research projects throughout the summer. Research inspires learning and this magazine allows us to showcase just a fraction of the great work being done by some of the future generation of science alumni at Lakehead University. Enjoy!

Todd A. Randall, PhD, P.Geo.

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Interim Dean of Science and Environmental Studies

Quaestiones Naturales
Undergraduate Research in Science

Featuring research performed by undergraduate students in the Faculty of Science and Environmental Studies at Lakehead University.

Ideally, science is a method by which information is gathered using evidence and physical models. It may then also extend to developing that knowledge for beneficial purposes. Part of the mandate of every university is the creation of new knowledge, and part of the educational experience for science students is the study of new knowledge and how it is gained. As part of this training, many students have the opportunity to take part in research projects under the direct supervision of a professor. As you will see, these projects are truly scientific – the students are creating new knowledge while they learn the skills to become researchers themselves.

In this magazine, we profile nine students and their projects. They performed the research when they were undergraduate students; you will see they made interesting and significant contributions to their areas of research.

Researcher	Program	Hometown	Supervisor
Jessica Allingham	Biology and Chemistry	Oakville ON	Wely Floriano wely.floriano@lakeheadu.ca
Pierfrancesco Cervellini	Computer Science	Milan, Italy	Vijay Mago vmago@lakeheadu.ca
Katelynn Crawford	Environmental Sustainability	Severn Bridge, ON	Christopher Murray cmurray1@lakeheadu.ca
Trevor Kavalchuk	Geography	Thunder Bay ON	Todd Randall todd.randall@lakeheadu.ca
Justin Kulp	Mathematics	Thunder Bay ON	Hubert de Guise hubert.deguise@lakeheadu.ca
Brandon Luu	Chemistry	Thunder Bay ON	Stephen Kinrade stephen.kinrade@lakeheadu.ca
Ashley Powers	Geography with Concurrent Education	St. Thomas ON	Rosario Turvey rturvey@lakeheadu.ca
Ryan Stevens	Environmental Sustainability	Oro-Medonte ON	Nandakumar Kanavillil nkanavil@lakeheadu.ca
Kyle Wright	Water Resource Science	Thunder Bay ON	Rob Stewart rob.stewart@lakeheadu.ca

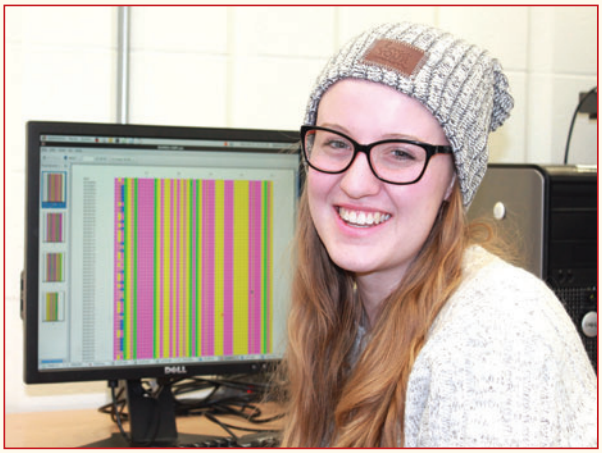
Izumo Investigation

Determining variation in coding for fertilization proteins

Even as early as Grade 4, Jessica Allingham's favourite subject was science. "That year, my teacher Mrs. Smith got us all to do a project. Mine was making a bicycle out of gears and other pieces," she says. "That year and through the rest of school, science was my favourite subject." Her specific interest eventually narrowed to Biology and Chemistry, which made Lakehead a natural choice for her, given that it was the only school to which she applied that offered a combined Biology-Chemistry degree. Although the Thunder Bay campus is a fair distance from her hometown of Oakville, Ontario, she continues to be happy with her choice: "I know it's not for everyone right out of high school, but I wanted to get out on my own. I've learned so much coming to Lakehead, not only in my courses but also those things you don't learn until you're living on your own. It's been a great experience for me."

> "When you do research, you have to find the solution for yourself."

When it came time to pick a 4th-year research project, Jessica was again led by her twin interests in Biology and Chemistry. Her project, under the supervision of Chemistry professor Wely Floriano, is related to the mammalian proteins Izumo and Juno. Izumo is located on the surface of sperm and its recognition by Juno on the surface of the egg is a key step in the fertilization process: no recognition, no fertilization. Jessica explains in more detail: "Like with all genes, there is variation from species to species and even within a single species. We are using gene-sequence



Jessica Allingham

data from the 1000 Genomes Project database to determine the variation in the human sequences that code for these two proteins." Ultimately, Jessica hopes to determine if there is any significant variation in these sequences, and if such a difference could lead to a molecular form of infertility. A further application might be in contraception. "Normal hormone-based birth control pills have many side effects because they affect multiple body systems," she explains. "If we alter production of either of these proteins, it should only affect the ability of the sperm and egg to combine, and hopefully would not affect other biochemical systems in the body."

Jessica has been enjoying her research experience. "In previous years, if you had a problem or didn't understand something you could find an expert to explain the solution to you. When you do research, nobody knows the answer, so you have to find the solution for yourself. At the same time, it's exciting to be working with things that are so new. For example, the function of the Juno protein was only determined a couple of years ago." ■

Quantum Contemplations

Using mathematical models to understand subatomic particle behaviour

Justin Kulp

Initially, Justin Kulp's research in Mathematical Physics sounds a bit esoteric. "Much of what I did was coding in *Mathematica*, developing ways to solve equations and matrices that my supervisor, Dr. de Guise, was interested in. My most important contribution was coding a method for calculating the immanant for large matrices." (Students of introductory linear algebra will recall the concept of the determinant, which is a special case of the immanant.) On closer inspection, the work has an important physical basis, since the matrices were designed to describe physical systems at the smallest level. "If you want to develop, for example, a quantum computer, you need to understand the underlying quantum physics. My project was to use math to verify the validity of the models we were using, which in turn would lead to a more complete understanding of the system." The tools he coded with *Mathematica* were the keys to being able to test and verify the hypotheses; he was rewarded for his efforts with a scientific publication in the *International Journal of Physics A: Mathematical and Theoretical*.

Justin says the preparation for his research project started in high school. "I did a science fair project that happened to involve some coding. It opens a lot of doors if you know at least a little bit of coding: all my summer research projects so far have involved that skill." He also credits his high school physics teacher (and Lakehead alumnus) for instilling an interest in science and an understanding of the intellectual rigour required to succeed in research and in university in general. "He expected a lot of us, but it meant that we were well prepared for university, and while I wouldn't say 1st-year was easy, it was certainly easier for me than it would have been if I'd not had such a demanding high school experience in Physics."

> "If you want to build a quantum computer, you need to understand the underlying physics."

Working on a research project early in his academic career – starting in the summer after his first year – gives more direct benefits, such as one-on-one interactions with faculty members. "It's a lot easier to get a good reference letter if you've done summer research in a lab. Better than a generic 'they did well in my course' form letter, which is probably the best you can hope for from the prof of a class of 100 students or more." Another benefit is the confidence it builds: "A research supervisor expects high quality results, so if you can impress him, you have nothing to worry about when it comes to succeeding in your class work." ■

Pining for Knowledge

Studying how forest management techniques affect tree growth

The path to Ryan Stevens's degree program started in a Grade 11 course called Outdoor Education. "It was a course studying environmental issues combined with recreational aspects like mountain biking and skiing," he explains. "I found I was really good at the hands-on stuff... and maybe not so much at the book learning." Therefore, Ryan looked for a program of study that would allow a similar learning experience at university. Having talked to friends who had already started programs at Lakehead University Orillia, he chose to go there and enroll in the Environmental Sustainability program.

> "Growth rate was significantly higher after thinning the tree stand"

Fast-forwarding to his final year, Ryan teamed with Dr. Gerardo Reyes and Sustainability Sciences Prof. Nanda Kanavillil to study sustainable forestry practice. "We studied the growth rates of Red Pine trees in stands that had been planted on public land in the last 35 to 50 years, all across Simcoe County" he explains. When planting the stands, the trees were planted in regular rows, which were later thinned by harvesting every fourth row. Ryan took core samples from the remaining trees to investigate the effect of the thinning. "We had stands that had been thinned in 2007, 2012, and stands that had not been thinned at all," he says. "In total, I ended up with 397 core samples, each 5 mm in diameter taken at a height of 1.3 m above the ground." After sanding down the samples and securing them to a board with glue, Ryan could start his analysis. "I used a microscope with a reticule to carefully measure the growth lines for each tree," he says.

Ryan Stevens

Next came the data analysis. Using his growth measurements, climate data from Environment Canada, and soil characteristics from Agriculture Canada, Ryan compared the growth rates for the trees. Although he is still in the preliminary stages of his analysis, he has found some statistically significant results: "The thinned sites experienced higher growth than the control (unthinned) sites," he explains. "In addition, for the 2012 sites, at least, the growth rate was significantly higher after the thinning than it was before." Ryan is going to continue his analysis to investigate other effects like initial planting density and soil types. "There's lots of variables, some may not be significant but we want to make sure we check all of them so we can better understand how trees grow, and therefore create best practices for sustainable use of this renewable resource." ■

Concrete Example

Additives for improving cement and concrete strength

Brandon Luu

Concrete is a composite material made from the three basic ingredients of cement, water, and aggregate (gravel, sand, etc.). Chemical additives can also be added as required by the specific building requirements, e.g., setting time or durability. Brandon Luu is working with Professors Stephen Kinrade and Lionel Catalan on a new natural additive (sourced from forest product waste) that improves the compressive strength of the resulting concrete. "The additive strengthens the concrete up to 40%, which means you could either have stronger concrete or use less cement to get the same strength," Brandon says. He goes on to explain that since a ton of carbon dioxide (CO_2) is released for every ton of cement manufactured, concrete use accounts for nearly 10% of anthropogenic CO_2, a greenhouse gas. "If we could reduce the amount of cement, it will make a significant impact on global CO_2 reduction goals."

Brandon is using various instruments to determine exactly how the additive works. "Previous students have eliminated certain mechanisms," he explains. "Right now I'm using SEM [scanning electron microscopy] to zoom in on the cement-aggregate interface." Using a greyscale comparison technique, he evaluates the difference in microstructure and composition between samples that have the additive and those that do not. "Because the magnification on an SEM is so large, you have to make a lot of measurements to get a meaningful statistical result," he says. While he admits that doing the same kind of measurement many times can get repetitive, he keeps the end goal in mind: "With this kind of practical project, it's great to see exactly how your input leads to progress in the project, and how that leads to a real-world result." Thus, Brandon is also working towards implementing the use of the additive at local concrete manufacturers.

> "It's easy to see how your input leads to progress in the real world."

Combining theory with practical application fits Brandon's learning style. "The best thing about chemistry is the labs – they are hands-on and that helps me learn the material. I don't fully absorb the information just sitting and listening to it in class." He also likes the fact that chemistry is foundational, echoing the catchphrase that, "Chemistry really is the 'central science' because it gives you the theoretical underpinning for how all matter works." He admits, though, that he might have been biased early on: "My mother is a high school chemistry teacher, so she's been showing me chemistry experiments my whole life!" ■

Algal Bloom Blues

Eutrophication in a lake in Northwestern Ontario

No matter what the environmental issue is, there will be a component that deals with water. Thus, the Water Resource Science program at Lakehead University has a multidisciplinary and broad subject matter, which appeals to Kyle Wright. "When I was pondering my major in high school, I wanted to do something environmental, which is a rapidly expanding field," he says. "I realized that this program covered everything from biological systems to drinking water to mining processes, and that was very attractive to me." Another advantage of the program that Kyle chose was that in four years, he obtains both a Science degree from Lakehead University and an Environmental Technician Diploma from Confederation College. He explains, "The combination of the two means that I am qualified to work at the day-to-day practical aspects of water treatment and testing, while also understanding the theoretical and policy background, which would be useful in method development and optimization."

"Where there are humans, there will be phosphorus and therefore eutrophication"

Doing a 4th-year research project is optional in his program, but Kyle wanted to take advantage of the opportunity. "The project sounded interesting, and having seen the practical side in my year at the College, I wanted to see what the research side was like," he says. Working with Geography Professor Rob Stewart, his project involved changes in the quality of the water in a small lake south of Thunder Bay. Kyle continues, "Cloud Lake has about 80 homes and cottages with frontage on the water. At the same time, it is isolated by geological features that make the watershed quite contained. Therefore, changes in the water quality are likely the result of local human activity." Landowners at the lake have noticed increases in the amount of algae in the lake, including periodic blooms of activity, which is indicative of the process of eutrophication, caused by an overabundance of nutrients in the lake water. Kyle explains, "Phosphorus is often the limiting nutrient in the growth of bacteria. Human activity – farming fertilizer, animal waste, etc. – tends to increase the amount of phosphorus in the environment. Therefore, where there are humans, there will be phosphorus, and where there's phosphorus, you'll get eutrophication." He goes on to further point out that water quality declines as a result of the process, including decreasing fish population and potability.

Kyle Wright

Kyle's part in the study was to qualitatively evaluate the shoreline around the lake. "We'd go out in a boat and take pictures and evaluate the nature of the shoreline – I'd evaluate the species of plants, for example, while the grad student would measure the amount of turbidity in the water. A lawn reaching all the way to the water's edge is obviously not natural in what used to be a forest environment and gives an indication of the level of human influence on the shoreline." When analysing the data, Kyle and his lab-mates are looking to supply landowners with strategies to mitigate the effect of their presence around the lake, and in fact held a symposium to present their results. "Growing up I loved camping and fishing and other outdoor activities," Kyle says. "The people who live around Cloud Lake value these kinds of activities as well, and therefore are looking for information they can use to help keep their lake healthy." ■

Company Compost

Finding ways for large organizations to arrange for on-site composting

Although recycling of packaging items (glass, plastic) and paper is well-established throughout Ontario, most organic waste still ends up in landfills. Upon arriving at Lakehead Orillia, Katelynn Crawford immediately saw the need for a campus-wide composting system. Collaborating with Sustainability Sciences professor Chris Murray, she set about investigating how composting might be implemented in a climate where much of the year is spent below the freezing point. "Obviously most of the compostable material will be generated when classes are in session," she explains, "Which, unfortunately, coincides with the coldest months of the year."

> "Institutions will only adopt a new composting system if it is inexpensive"

Using reactor sizes varying from 0.5 to 200 litres, Kate measured physical constants like pH and temperature in the reactors under various conditions. She also changed conditions in order to compare the effects on the composting process. For example, some reactors were completely filled at the start (batch processing) while others had small amounts of material added over many days (continuous processing). Other variations included subjecting certain reactors to freeze-thaw cycles, starting some indoors then taking them outdoors after a certain amount of time, and varying the amount of gas-exchange in the reactors. "As the bacteria degrade the compost, they generate heat, but bacterial metabolism stops when the ambient temperature is too cold," she says. "We wanted to see how long the heat generated by the degradation could

Katelynn Crawford

hold off the cold weather in the large reactors." While the temperature inside the reactors did, indeed, stay warmer than the ambient on cold days, it was not enough to sustain the decomposition process. "We use uninsulated reactors because large institutions will only adopt a new system if it is inexpensive," Kate explains. "Fortunately, even if the composter freezes through, the reaction will readily restart as soon as it warms up enough, so if you have enough capacity to store compost, you can just wait for the warm weather."

Kate was especially interested in discussing her project for this magazine because she is combining her Environmental Sustainability program with courses in Media Studies. "The program at Orillia was the only one I found where you could add in a Media Studies component without increasing the number of years in the degree, so that was very attractive to me." She continues, "After all, environmental action and policy requires everyone to work together, and that requires using the media to get messages out." ■

Cells in Cells

Modelling the progress of an HIV infection

Pierfrancesco Cervellini

Having already graduated with a degree in molecular biology, Pierfrancesco Cervellini is not a typical undergraduate Computer Science major. "My wife got a position in Thunder Bay, so I used the opportunity to study a new subject that's really interesting to me," he says. His life growing up could be similarly described as unconventional. He continues, "My mom was a diplomat, so we lived in a few different places in Europe and eventually in Ottawa, where I did my first degree." With such a background, it is perhaps unsurprising that he would take an interest in cybersecurity. What is less obvious is that the combination of his molecular biology background and current interest in security are interrelated. He explains, "Security is problem domain rather than a solution domain, which means you need to use experience and concepts from other disciplines and then apply them to the security problem. One of the current trends is towards adaptive computer algorithms, which take their inspiration from molecular biology." Thus, he can combine his interests in computer science and molecular biology, applying them to create new tools for a cybersecurity toolbox.

Specifically, Francesco is studying medical informatics with Computer Sciences Professor Vijay Mago. As part of a multidisciplinary and multi-university research team called *cHeal*, Prof. Mago's team is using computational modelling to study the progression of diseases. Francesco is focussed on the human immunodeficiency virus (HIV), studying the progress from cellular infection to AIDS. "We represent the human body with a grid," he explains. "Each grid cell represents a piece of the human body, like a (biological) cell. Each grid cell has a state – healthy, infected, or dead – which then influences the cells around it. As time progresses, we use an algorithm to determines the chance of each such cell changing state, for example from healthy to infected. The algorithm is based on real medical science studies on HIV infection spreading in the body." He goes on to acknowledge that these kinds of simulations have been studied before, but his research goes much further, both in medical and computational requirements. "Viruses mutate all the time, and there are many strains of HIV," he explains, "So our research adds these levels to make a far more realistic model." Such a model will ultimately help physicians combat mutating diseases so they can plan for different drugs to meet the changing nature of the infection.

> "Adaptive computer algorithms take their inspiration from biology"

Doing applied projects are a vital part of the experience in computer science. While the degree gives you a firm background in the material, Francesco points out that, "In the workforce, people aren't interested in a program's code, for example, they just care about getting the result they want." Thus the ability to do a research project that applies a computer-based solution to a real-world problem was an attractive option. He continues, "With my background in Biology and Computer Science, it was great to be able to have a project at the interface between those disciplines." ■

Pictures of Progress

Evaluating the evolution of land use in urban settings

Looking out the airplane window as a boy, the seeds of Trevor Kavalchuk's future career path were germinated. "I would look down and see how the grids of houses were laid out, and the malls and industrial parks," he muses. "I'd wonder why things ended up just that way." When it came time to choose his high school courses, Geography was a natural choice. "Unfortunately, the subject doesn't get the credit it deserves," he says. "Fortunately, my school offered International Baccalaureate Geography, which was advanced and allowed me to do an independent project, which I really enjoyed."

> "You have all these downtown revitalization projects, but how do you determine how effective they are?"

Trevor went on to major in Geography and when it came time to select courses for his fourth year, he decided to do a research project. He chose to work with Geography professor Todd Randall because of the overlap between their interests in urban development. "Recently, the City of Thunder Bay has undergone a waterfront redevelopment project of the downtown North Core. This kind of work is common," he says. By definition, redevelopment requires change in the use of space. He explains, "We look at buildings and we know (from a previous project) their functions in 2010 – be it a single-family dwelling, a restaurant, a store – and now I'm looking at them in 2015 to determine if there was a change." To do this, he does a visual survey of the area and classifies each building by the North American Industry Classification System (NAICS) code, which

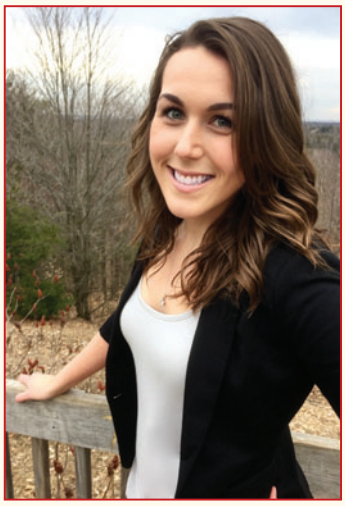
Trevor Kavalchuk

is the way Stats Canada classifies use of a building. The codes go into an interactive map, so the location and use of each building is specified, both in 2010 and 2015. Trevor continues, "The NAICS codes are very specific, and allow a high degree of precision – for example, a fast-food restaurant can be differentiated from a family restaurant – but we've grouped these codes into categories by usage, and then we can track the land usage over time." Using this kind of analysis, the program also takes into account turnover within a category, for example if a restaurant changes owners, if a large house is subdivided into several apartments, or if new development has occurred.

Ultimately, the goal of the project is to quantify changes in land use, and to attribute those effects to a cause, *e.g.* city planning. Trevor explains, "The City of Thunder Bay has labelled the North Core downtown area as an 'entertainment district.' So if we see an increase in restaurants, for example, can that be attributed to an aspect of the City's plan?" Trevor stresses, though, that his research is more about creating a tool to evaluate and quantify the change rather than to critique any specific plans. "You have all these downtown revitalization projects, but how do you determine how effective they are or their long-term effects?" he asks rhetorically, "We're designing the tools that urban planners need in order to answer these questions." ■

Fuels and the Future

Are biofuels a legitimate alternative to dwindling fossil fuel stocks?



Ashley Powers

At the current rate of consumption and the estimated amount of crude oil available on Earth, fossil fuels as an energy source will run out sometime in the next century. A number of alternatives exist; for example, Brazil mostly uses biofuels, which are compounds derived from plant or algal sources that serve the same purpose as traditional fossil fuel-derived gasoline and diesel. Unfortunately, the current thinking is that biofuels are themselves unsustainable. Ashley Powers, a Geography student doing research in the area, explains, "For first generation fuels like corn ethanol, there will always be a competition for arable land, that is, between food security and fuel production." Second generation fuels, such as biodiesel produced from switchgrass, are better but still problematic in the long term. Ashley continues, "Switchgrass is an invasive species, which means it will grow anywhere so it needn't use valuable arable land. On the other hand, it is invasive and will destroy biodiversity as it spreads."

Working with Prof. Rosario Turvey in the Department of Sustainability Sciences, Ashley investigated research studies on biofuels more closely, and came to a modified conclusion. "Most of the studies look at the long-term sustainability of biofuels," she explains. "I wanted to determine the short-term viability, for use as a bridging technology." Since current infrastructure is designed to support spark/combustion engines (gasoline/diesel, respectively), it is impossible to change to another type of transportation fuel overnight. "Therefore, short term use of biofuels is feasible and even necessary to give time to bridge the gap to whatever the new technologies will be." She goes on to conclude that there is still research to be done: "We will need to use GMOs as part of the process if we are going to make even short-term use viable."

> "Short-term use of biofuels is necessary to bridge the gap to new technologies."

The combination of this project and the small-town feel of the Orillia campus especially appeals to Ashley, an environmental thinker who enjoys farming, hunting, and other outdoor activities. "I went to open-houses at big universities in cities, and they felt wrong," she says. "When I saw the Orillia Campus, it immediately felt like 'home'." She is also concurrently completing her BEd degree, although classroom teaching is not necessarily her career goal. "I love teaching, but I think I'd be more effective working with an NGO like Ducks Unlimited," she says. "These kinds of organizations have education of the public at their cores, including teaching kids about environmental issues." ■

“The scientist is not a person who gives the right answers, he’s one who asks the right questions.” – Claude Lévi-Strauss

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955 Oliver Road | Thunder Bay, Ontario | P7B 5E1 | (807) 343-8110
500 University Ave. | Orillia, Ontario | L3V 0B9 | (705) 330-4008
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