THE WALK OF LIFE

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The Walk of Life

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Edited by Amir A. Aliabadi

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... the pure mathematician who wants to set up all of his work with absolute accuracy is not likely to get very far in physics.

—Paul Dirac

Dedication

Hossein Modarresi

Preface

The essays in this volume result from the Fall 2021 offering of the course *Control of Atmospheric Particulates* (ENGG*4810) in the Environmental Engineering Program, University of Guelph, Canada. In this volume, students have written about Bernhard Riemann, Paul Dirac, Shiing-Shen Chern, and Muhammad Ibn Zakariya al-Razi. Students have accessed valuable literature to write about these figures. I was pleased with their selections while compiling the essays, and I hope the readers will feel the same too.

Amir A. Aliabadi

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I am indebted to my brother, Reza Aliabadi, a life-long mentor and inspirer for my ideas and directions in life, who also designed and executed the cover page for this volume. At last, I am thankful to each individual student author, without whom this project would not have been possible.

Amir A. Aliabadi

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The Man Responsible for the Turning Point of the Conception of Mathematics

By Myles Street, Julia Leith, and Liam Dunnett

1.1 Early Years and Opportunities

Bernhard Riemann, in full Georg Friedrich Bernhard Riemann, was born on September 17th, 1826 near Dannenberg in the kingdom of Hanover and was the second of six children. Riemann's father, Friedrich Bernhard Riemann was a poor Lutheran pastor, and his mother, Charlotte Ebell died in Bernhard's teenage years (Narasimhan, 2010). Bernhard was a shy and introverted child, however he exhibited strong mathematical skills from an early age. Riemann's early school teacher recognized his acute mathematics skills and lent him advanced math concept books that quickly caught his attention. Bernhard attended the gymnasiums in Hanover from 1840 to 1842, and then continued studies at the Universities in Göttingen (1846-1847, 1849-1851) and Berlin (1847-1849) (Laugwitz, 2008). During Riemann's initial stint in Göttingen, he quickly exhausted the resources available to him and became quite withdrawn from university life and his studies (du Sautoy, 2012). Looking beyond for greater intellectual stimulation, Riemann moved to the University of Berlin that had been greatly influenced by Ecole Polytechnique, a French research initiative created by Napoleon that revolutionized Universities at the time (du Sautoy, 2012).

After interacting with the likes of Augustin-Louis Cauchy in Berlin, Riemann became fixated on "pure mathematical" ideas that Cauchy exposed him to, soon becoming a recluse because of his fixation with these exciting new ideas. In 1849, Riemann returned to Göttingen and worked under Carl Friedrich Gauss who focused on prime numbers. This interest would soon be passed along to Riemann who would build upon these ideas in his first groundbreaking theory. Gauss died in 1855 and Peter Gustav Dirchlet succeeded him. Riemann continued to work under Dirchlet becoming an associate professor in 1857 and a full professor in 1859 after Dirchlet's death (Narasimhan, 2010).

1.2 The Riemann Hypothesis

Throughout history, many mathematical discoveries have been hypothesized and validated through a proof. While Riemann made several contributions to the field of mathematics, the hypothesis that gained his namesake is a rather interesting one. In 1859, Riemann was made a corresponding member of the Berlin Academy (Derbyshire, 2003). This was a considerable achievement for a relatively young mathematician (ages 32 years old). Such an achievement was typically followed by the publishing of a work from the mathematician (Derbyshire, 2003). It was at this time that Riemann published *On the Number of Prime Numbers Less than a Given Quantity*. This paper detailed Riemann's development of a formula that can give the number of prime numbers less than a given number (Derbyshire, 2003). For example, when considering the number 20, the prime numbers up to 20 are 2, 3, 5, 7, 11, 13, 17, and 19. Riemann's formula would be able to determine the number of primes less than 20 without having to manually count them, or in the case of higher numbers, even know which ones were prime.

While Riemann's prime numbers work was an incredibly important discovery, along the way Riemann made an important assumption that he did not prove (Derbyshire, 2003). In his paper Riemann writes, "One would, of course, like to have a rigorous proof of this, but I have put aside the search for such a proof after some fleeting vain attempts because it is not necessary for the immediate objective of my investigation" (Derbyshire, 2003). Riemann assumed that the real part of all nontrivial zeros of the zeta function had a real part equal to one half (Derbyshire, 2003). This was an important assumption in Riemann's formula. To this day, over 160 years later, this hypothesis has not been formally proved. This is by no means a result of disinterest. Many people have attempted to both prove or disprove the theory throughout the entire 20th century (Derbyshire, 2003). In fact, it is considered one of the most important and well known hypotheses that remains a mystery. It is so sought after that the Clay Mathematics Institute has offered a million dollar prize to anyone who can prove the theory, while the American Institute of Mathematics has addressed the hypothesis with several full-scale conferences (Derbyshire, 2003).

Solving this hypothesis is more important than it originally appears. What is the big deal with finding massively large prime numbers? Why invest so much time in discovering them? Prime numbers are actually the most important numbers in number theory (Mazur and Stein, 2016). Prime numbers are often referred to as the 'atoms' of number theory. This comparison is because as elements are the building blocks of all molecules, prime numbers are the building blocks of all numbers. Every number that is not a prime number can be made by multiplying other prime numbers together. From a computational standpoint, it is incredibly easy to multiply multiple prime numbers together. However, it is significantly harder to factor a number down to its prime building blocks (Mazur and Stein, 2016). This principle is important in the field of cryptography. Encryptions are made based on the idea that it is incredibly hard to factor massive numbers into their prime numbers (Mazur and Stein, 2016). Proving the Riemann hypothesis would have massive impacts on number theory if massive prime numbers were easily detectable.

It is hard to say when or if the Riemann hypothesis will be solved. Such a proof has fascinated mathematicians for the last 160 years and will continue to do so. It is amazing what would essentially result from one man's intuition. Perhaps it will take centuries for another mind like his to finally prove his hypothesis and solve a great mathematical mystery.

1.3 Personal Challenges

Despite his enormous contributions to the advancement of mathematics, Riemann faced his own challenges in personality and character. From an early age, Riemann struggled with socialization and was known to be quite introverted. This can be attributed to his upbringing, as until the age of fourteen Riemann lived within the circle of his family, virtually isolated from all other social interaction. Once he began attending the gymnasium in Hanover, another characteristic came to light. Riemann suffered from extreme perfectionism and his teachers became concerned that he was unable to submit any school work that was less than perfect (du Sautoy, 2012). However, this perfectionism is also what drove Riemann to escape into the world of mathematics and he found solace amongst the perfection of formulas and rules (du Sautoy, 2012). These challenges continued to follow Riemann, and his perfectionism paired with his weak social skills, affected Riemann throughout his years in the German university institutes. Riemann struggled to associate with people both as a student and docent. He never sought contacts with people and avoided greater connection with his colleagues (Laugwitz, 2008). It is also known through the memoir of Riemann's closest associate, Richard Dedekind, that as an adult Riemann was a hypochondriac and often suffered from depressive periods, especially following the death of his father, whom he greatly admired (Derbyshire, 2003). In addition, due to his inability to publish work that had not yet been fully proven, much of Riemann's work has remained unseen and following his death countless unpublished papers from his study were destroyed (du Sautoy, 2012). It may be questioned that perhaps Riemann could have published much more of his work had he not been plagued by his desire for perfection; these published works could have been extremely influential to the field of mathematics. However, without his perfectionism Riemann might never have been driven to pursue mathematics, and so his unique and peculiar character may be exactly what made him such a brilliant mathematician.

1.4 Europe's Changing Landscape

Throughout Riemann's lifetime many changes were taking place both socially and politically. The ever changing landscape of the 1800s greatly influenced the opportunities that Riemann was exposed to and helped him achieve his status as a prominent mathematician. An important aspect of Riemann's early life in Hanover was the changing educational system. In 1809, 17 years prior to Riemann's birth, Wilhelm von Humboldt became the education minister of Prussia (du Sautoy, 2012). Humboldt was an advocate for the pursuit of knowledge for its own sake and sought to divert from the old educational scheme which was geared towards producing civil servants (du Sautoy, 2012). This shift is what brought about the creation of the Gymnasiums, new schools which aimed to produce graduates who would go on to study at the universities and polytechnics (du Sautoy, 2012). At the same time, many of the universities were beginning to adopt the French École Polytechnique form of learning that would allow for students to study mathematics ideas instead of their implication in the real world (du Sautoy, 2012). This branched into Berlin and later Göttingen, as a result of Riemann's influence, which revolutionized the University setting.

On top of this, hard times swept over Europe in the late 1840s and transformed widespread frustration in the German Confederation into a full-blown revolution (Laugwitz, 2008). By the middle of the decade, a severe economic depression left many suffering from unemployment and halted industrial expansion (Laugwitz, 2008). Riemann moved to Berlin in 1847 and remained there for 2 years, during this time the revolution found its way to the streets of Berlin (du Sautoy, 2012). This time had a profound impact on Riemann, and this was noted as one of the few times in his life that he joined in with those around him when he enlisted in the student corps to defend the Berlin palace (du Sautoy, 2012). The economic depression affected Riemann financially as well, whose income from tuition fees was extremely limited. On top of this, when Riemann's brother died in 1857 he had to provide for his three surviving sisters, at which point he became associate professor and was extremely grateful for an increased yearly salary of 300 thaler (Laugwitz, 2008). Riemann saw many changes occurring in the world around him during his short lifetime. Financial troubles and political unrest may have contributed to stress and difficulties in his life. However, some of these changes had a positive influence such as the ever growing support for academics and research, which greatly aided in his pursuit of mathematical advancements.

1.5 Tragic End to a Brilliant Mind

After becoming a full professor and working at the University in Göttingen for some time, Riemann was on a stretch of good fortune which amounted to his marriage to Elise Koch in 1862 (du Sautoy, 2012). But just over a month later Riemann contracted pleurisy in the fall of 1862 which resulted in permanent lung damage (Laugwitz, 2008). From this point onward, Riemann was plagued with ill health and often traveled to the Italian countryside for refuge. In 1863, his daughter was born in Pisa. This stretch of extended stays in Italy was refreshing and rejuvenating for Riemann as the Italian mathematical community was the most receptive of his ideas, and the change in scenery seemed to uplift the mathematician's moral spirit (du Sautoy, 2012). In 1866, Riemann took his final trip to

Italy from Göttingen when the armies of Hanover and Prussia clashed in Göttingen. Riemann escaped to Italy however soon died on the shores of Lago Maggiore at the age of 39 (Laugwitz, 2008; du Sautoy, 2012). With his escape being so quick, his study was left a mess. The housekeeper destroyed many of his unpublished scribblings before she was stopped by members of the University. Many of these notes were said to have held keys to his theories that were never to be found again. Mathematicians have tried for centuries to solve these problems, however the answers to these questions were probably lost for eternity in the fireplace of his study (du Sautoy, 2012).

Bernhard Riemann was a revolutionary mathematician in his time and paved the way for others to build upon his revolutionary work with imaginary numbers. The likes of David Hilbert and Kurt Gödel revolutionized logistics but attributed Riemann with being one of the forefathers that birthed this new stream of mathematics. Although he struggled with expressing these great ideas, Riemann was revolutionary in the ones he shared. However, his obsession with perfectionism did roadblock his ability to portray these groundbreaking ideas. Questions must be asked about the possibilities that Riemann could have achieved if he had the confidence of Einstein or Hawking.

2 Paul Dirac (1902-1984)

The Quantum Mastermind

By Tyra Jamieson, Alexander Urtheil, Cassidy Morgan, Maia Ruscitti, and Kayla Pollock

2.1 Miserable Beginnings

On Aug. 8, 1902, while the eyes of most in Bristol in southwest England were turned to London for the coronation of King Edward VII the next day, the eyes of Florence Hannah Dirac and Charles Adrien Ladislas Dirac were on a newborn, healthy, six-pound son, Paul Adrien Maurice Dirac (Farmelo, 2009). He grew up with an older brother, Felix, who later committed suicide, and a younger sister, Betty (Farmelo, 2009). Because his mother thought Paul did not eat as much as other youngsters, his parents nicknamed him 'Tiny' (Farmelo, 2009). Florence was the daughter of a ship's captain and worked at the Bristol Central Library as a librarian, which is also where Paul's parents first met Bristol Central Library. Charles had come to England from Switzerland at 20 and settled in as a French teacher at the Merchant Venturers School in Bristol (Mehra, 1972). The parents were something of an unusual pairing because their religious faiths were different. Florence was raised a

Methodist who disliked alcohol, while Charles grew up in a Roman Catholic family who enjoyed a glass of wine at mealtimes (Farmelo, 2009).

Paul would later describe his boyhood as unpleasant, even hostile, because of tensions between his parents and his father's intimidating manner. Living in the Dirac household as a child would have been unusual and difficult for him and his siblings (Farmelo, 2009). There were no visitors and few opportunities to mingle with people beyond immediate family. Paul's father spoke only French in the house, while his mother only spoke English. This led a young Paul to briefly believe that men and women spoke distinct languages (Farmelo, 2009). Another unpleasant memory that emphasized separation and parental tension over family cohesion was the family's dining arrangements. Paul would sit alone with his father, while Felix and Betty would eat with their mother in the kitchen. It was an enduring puzzle to the young boy why his father chose him above his siblings for attention (Farmelo, 2009). Paul's father insisted on giving him French lessons during meals. One of Charles Dirac's more cruel teaching methods was a rule that Paul could only converse with him in French. If he made any mistakes, he would not be allowed to leave the table. Consequently, when Paul did not know how to explain himself in French, he would simply remain silent (Mehra, 1972). Paul's parents also made him eat every single bite of food on his plate, even when he was unwell or not hungry, which caused him to vomit occasionally at the table (Farmelo, 2009).

His first exposure to formal education and interaction with children outside his family was at Bishop Road Primary School. Despite this opportunity to socialize, Paul made little attempt to talk with the others. He would only speak when he was spoken to. He would often withdraw into his own thoughts due, it is believed, to the difficulties of his home life and the strain of his relationship with his father. Later in life, Dirac lacked crucial social and emotional skills, and had little ability to make normal small talk with others (Farmelo, 2009).

2.2 The Academic Journey

After Bishop Road Primary School, Paul moved on to secondary school at the age of 12. He attended the school where his father taught French, Merchant Venturer's Technical College. This only added to the trauma that Paul had from his father's strict, abusive teaching methods, though it is also where he began to find the beauty in science. Later in life Paul recalled that his secondary school was a great place to learn science and modern languages and he was relieved that no Latin or Greek was required since he "did not appreciate the value of old cultures" (Pais, 1998). During his time at Merchant Venturer's School, he played soccer and cricket, though he did not have a talent for either. Paul did find though that he had a great interest in science that was greatly encouraged and stimulated in school (Pais, 1998).

Combining his passion for science with his father's wish for his sons to have practical professions, Paul moved on to study electrical engineering at the University of Bristol at the age of 16. At first, he struggled with the inexact solutions found to "solve" engineering problems, but he grew to tolerate the approximations found. He stated later in life that "the pure mathematician who wants to set up all of his work with absolute accuracy is not likely to get very far in physics" (Pais, 1998). He contributed a lot of his success to his training as an engineer even though he did not continue that path. He even said toward the end of his life that "[he] continued in [his] later work to use mostly the non-rigorous mathematics of the engineers" (Pais, 1998). After graduating from the University of Bristol with first class honours in 1921, Paul struggled to find a job and was offered free tuition for two years at the University of Bristol in their mathematics program (Pais, 1998).

After completing his study of mathematics, Paul enrolled at the University of Cambridge with a maintenance grant from the Department of Scientific and Industrial Research to begin his Ph.D. thesis (Pais, 1998). Though he never had a true teacher at Cambridge, his advisor Ralph Fowler was the only professor there who was well versed in the new quantum theory being developed in Denmark and Germany. It was Fowler in 1925 who showed Paul an unpublished paper by Werner Heisenberg regarding the transition to new quantum mechanics, inspiring Paul to develop those ideas in his thesis. This thesis led Paul to earn his Ph.D. in 1926.

From there he went on to lecture on quantum mechanics as a Fellow of St John's College where he was described to deliver his lectures with exceptional clarity. Despite this, he devoted much more of his time to research where he made many impressive discoveries .

2.3 Quantum Mechanics

Early quantum mechanics models were successful but failed to provide accurate theories backed by first principles. In 1925, Dirac first met Niels Bohr and attended his lectures on the fundamental problems and difficulties of the quantum theory of atoms (Debnath, 2013). He made an attempt to improve Bohr's quantum theory but was unsuccessful (Debnath, 2013). The

1925 paper by Heisenberg shown to Dirac in advance of publication would attempt to formulate a quantum mechanics that instead of using atomic orbitals, used observable characteristics such as position and momentum for an oscillator (Larsson and Balatsky, 2019). Later that year Dirac would successfully develop his own mathematical formulation of Heisenberg's quantum mechanics (Larsson and Balatsky, 2019). Dirac would take the step to explain the origin of electron spin, a concept that was not explainable by the theories developed by other physicists working on quantum mechanics, such as Heisenberg and Schrödinger. He was successful in developing a wave equation that accurately predicted electron spin and magnetic moment, an equation known as the "Dirac equation" which is still used in physics today. Dirac's equation incorporated Einstein's theory of special relativity with wave mechanics (Larsson and Balatsky, 2019).

The Dirac equation predicted antiparticles that corresponded to negative-energy solutions, which was considered undesirable physics at the time. Some physicists were not satisfied with this idea since it had not been confirmed. However, in 1932 US physicist Carl Anderson would publish his discovery of the positive electron, confirming Dirac's equation and the discovery of antiparticles and antimatter, one of the biggest discoveries of 20th century physics (Larsson and Balatsky, 2019). The positive electron, or "positron", is an antiparticle with the same spin as an electron but an opposite charge of $+1e$. Positron Emission Tomography (PET) is a medical technology used commonly to detect cancer, demonstrating one of the engineering applications developed thanks to the work of Paul Dirac.

In 1926 Dirac visited Bohr at the Institute of Theoretical Physics in Copenhagen where he worked out the theory of canonical transformations in quantum mechanics, introduced the Dirac delta, or unit impulse function, and formulated the foundation of quantum electrodynamics (Debnath, 2013). In 1927 he visited Göttingen, Germany, where he completed a paper that formulated the second order perturbation theory, leading him to discover the quantum theory of dispersion. In 1930 Dirac published his treatise *The Principles of Quantum Mechanics*, summarizing the concepts of quantum mechanics and compiling discoveries he had made himself (Debnath, 2013). In following years, he would publish newer editions that expanded and introduced new ideas, many of which he had developed. His treatise was celebrated for its precise logic, and correct physical explanations (Debnath, 2013). In 1933, the same year he would be awarded the Nobel Prize in Physics, Dirac published his work on Lagrangian quantum mechanics, which would become the foundation for Richard Feynman's approach to quantum electrodynamics, Feynman being another important figure of quantum mechanics (Debnath, 2013).

Paul Dirac was a wonderfully gifted physicist. His groundbreaking work led to many breakthroughs and revolutionized the world of quantum physics. While it would take many years to understand Dirac's work and the science of quantum mechanics without familiarity of the topic, the importance of his mind and his legacy in the field is immediately apparent. His works have led to theories still accepted and used in the present day and inspired other physicists within his field.

2.4 Notable Partnerships

Most scientists, in any field, do not achieve success on their own. Collaboration within research and experiments leads to more efficient discovery of theories, and thus can propel the knowledge of a scientific field at an accelerated rate. Paul Dirac was no exception. He engaged in numerous partnerships throughout his career, which helped him achieve success in his own life as well as contributions to the field of quantum physics.

His research supervisor, Ralph H. Fowler, was a well-known physicist and lecturer at Trinity College, Cambridge. The opportunity to conduct experimental research under the successful thermodynamics and statistical mathematician provided an environment that promoted quality work, precise technical equipment, and overseeing expertise. Here, Fowler and Dirac studied white dwarf stars. Fowler, with his knowledge of quantum mechanics, and the Fermi-Dirac model of statistical mechanics were able to quantify the statistical distribution of particles in white dwarf stars based on the theory that no two electrons can occupy the same state (Hoddeson and Bayrn, 1987). Fowler went on to supervise fifteen Fellows of the Royal Society and three Nobel Laureates and connected Dirac with Werner Heisenberg and Niels Bohr.

Werner Heisenberg, a German physicist, was awarded the Nobel Prize in Physics a year before Dirac for the creation of quantum mechanics. Although a key pioneer in quantum theory, Dirac and Heisenberg worked closely starting in 1928 after Dirac had derived his realistic wave equation. Heisenberg questioned Dirac's model, thinking of it as classical physics, diving deeper into the idea of positrons, positive electrons, by comparing it to electromagnetism (Segrè, 1980). Dirac's original experimental research on the idea of positive electrons lead Heisenberg to "create" an entirely new field of science, which has progressed the societal understanding of electrons (positrons) movement, position, behavior, and formation/destruction. Carl Anderson observed a positron in 1932 by studying cosmic ray particle tracks in a cloud chamber (Anderson, 1933) further finding evidence for Dirac's theories.

Dirac then used Heisenberg's mathematical matrices and Erwin Schrödinger's wave mechanics to formulate an interpretation to describe the operators for movement in the physical state. This building block relationship Dirac had with Heisenberg and Schrödinger brought the three of them to receiving the Nobel Prize in Physics in 1932 and 1933, respectively (Beller, 1983). An integral part of scientific understanding is the ability to reproduce results and have one's theories supported by other scientists. While one scientist was finding formulas for subatomic particles matrices, the other scientist was focusing on combining these theories toward understanding of particle position and velocity distributions.

One of Dirac's most famous books, *The Principles of Quantum Mechanics* (1930), was the standard textbook used during his lectures and is commonly used today in modern understanding of quantum mechanics. Dirac, among other scientists including Fowler, Bohr, Schrödinger, Heisenberg, and Anderson, were able to progress the fields of quantum mechanics and quantum electrodynamics. Although these partnerships may have appeared competitive at times, their successes in finding theories, formulas, and concepts resulted in the expedited understanding of quantum particles and their behaviors. Though Paul Dirac has since passed, his contributions to quantum mechanics have still enabled the partnerships of some of the most famous physicists to continue researching and theorizing today.

2.5 Accomplishments, Honours and Death

Paul Dirac is undeniably one of the most influential physicists of the 20th century. His contributions earned him a myriad of awards, appointments, and fellowship positions throughout his life. His first notable appointment was to Sir Isaac Newton's previous position of Lucasian Professor of Mathematics at Cambridge University in 1932 (Debnath, 2013). Dirac ended up holding this position for 37 years. In the same year, Dirac was elected a Fellow of the Royal Society, London (Debnath, 2013). The following year, Dirac was awarded a shared Nobel Prize in Physics for his findings in relativistic wave mechanics. This came as a surprise to some since there had been controversy and uncertainty surrounding the award for several years.

In the early 1930s the Nobel Prize was not awarded for several years due to the committees' uncertainties about theoretical discoveries and quantum mechanics (Larsson and Balatsky, 2019). The controversy over Dirac's award first started in 1931. At the time most of the committee believed that the prize should have been awarded to Schrödinger and/or Heisenberg. Notable committee members who agreed with these original nominations were the "Founding Fathers" of quantum mechanics, Bohr and Einstein (Larsson and Balatsky, 2019). The reasoning behind voting for Schrödinger and Heisenberg was because most felt as if they should be the first two to be recognized for the development of quantum mechanics (Larsson and Balatsky, 2019). Because of this, Dirac only received one vote in 1931. Fortunately for Dirac, that year's prize was never awarded since the committee could not come to an agreement. The following year, Schrödinger and Heisenberg were once again the front runners for the prize with Dirac receiving only two votes (Larsson and

Balatsky, 2019). Again, the prize was not awarded in its designated year due to the inability of the committee to come to a decision. This gap allowed Dirac to further develop his experiments and gain support from several committee members. As a result, Dirac was awarded the prize in 1933 to be shared with Schrödinger for his work in relativistic wave mechanics (Larsson and Balatsky, 2019).

After Dirac was awarded the Nobel Prize in physics, he began to gain more notoriety. In 1939, he was awarded the Royal Medal by the Royal Society of London (Debnath, 2013). Following this, Dirac was elected as an Honourary Fellow of the American Physical Society in 1948 and was awarded the Copley Medal of the Royal Society and the Max Planck Medal for his work in 1952 (Debnath, 2013). Moreover, he was elected to be an Honourary Fellow of the Institute of Physics in 1971 and was selected to become member of the Order of Merit in 1973 (Debnath, 2013). Dirac was also offered the honour of being knighted but turned it down due to his fears of too much publicity (Debnath, 2013).

Paul Dirac died in 1984 at the age of 82 in Tallahassee, Florida. He had been teaching and continuing his research at Florida State University for the last 12 years of his life and was said to have enjoyed the informal American way of life (Debnath, 2013). After his death, Dirac was recognized by old friends and colleagues as one of the world's greatest mathematical scientists and his impact is still felt throughout the scientific community today.

3 Shiing-Shen Chern (1911-2004)

A Poet in Differential Geometry

By Ronak Patel, Matthew Terry, Jacob Shantz, and Nathan Martin

3.1 Introduction

Dr. Shiing-Shen Chern was a Chinese-American mathematician who is considered one of the founding fathers of differential geometry. Dr. Chern is the recipient of numerous awards in the field of mathematics including the Wolf Prize in 1983 and the inaugural Shaw Prize in 2004 for his leadership and contributions to topology and algebra in the field of differential geometry. Dr. Chern's contributions to the field of mathematics via the Chern classes and the Chern-Gauss-Bonnet Theorem have laid the groundwork for current-day mathematics and physics. Dr. Chern's contributions to the world extend further than his work in mathematics through his role in unifying the scientific communities in China and the United States.

3.2 Early Life and Education

Dr. Shiing-Shen Chern, son of Bao Zheng Chern and Mei Han, was born on October 28th, 1911, in what is now known as the province of Zhejiang, China. Chern had one brother and two sisters. Chern had a strong passion for reading and solving arithmetic operations that were first introduced to him by his father. Chern was originally home schooled by his aunt until the fifth grade but his passing of the enrollment examination with ease, indicated the beginning of the mathematical marvel's brilliancy.

In 1922, Chern's father moved the family to Tiajin, where Chern later went on to enroll in his undergraduate studies at Nankai University in 1926 at just fifteen years old (Cheng et al., 1996). At the time, Nankai University only had one professor in their mathematics department, Li-Fu Jiang, a PhD graduate from Harvard University. Chern used this opportunity to deepen his understanding of mathematics by closely shadowing and learning from Jiang by taking up the role of his assistant. Once graduated from Nankai University, with a Bachelor of Science degree, Chern decided he wanted to study overseas like Professor Jiang (Meng, 2014). Due to financial reasons Chern first needed to attend Tsinghua University, where those who received impeccable grades would be considered for government funding to study abroad.

In 1932, while at Tsinghua University, Chern became deeply inspired by professor Wilhelm Blaschke, from Hamburg University in Germany, and his guest lectures and published literature on differential geometry. After graduating Tsinghua University, with a Master's of Science degree, Chern decided to use his government funding to study at Hamburg University as a student of Blaschke's. Under Blaschke, Chern worked on applications of Cartan's methods in differential geometry. In 1936, Chern graduated from Hamburg University with his Ph.D. and went off to Paris to work under the founder of his most recent studies, Elie Cartan.

In Paris, Chern performed his postdoctoral research. Chern used biweekly meetings arranged by Cartan to further improve his understanding of differential geometry and published three different papers over this period (Cheng et al., 1996). After Chern's two years in Paris he decided to return to China as a professor in mathematics before heading to the United Sates in 1943 to Princeton University. It was at the Princeton University that Chern developed his iconic work on characteristic classes and curvature.

3.3 Contributions to Differential Geometry

Chern went to the United States in 1943 to work at the Institute for Advanced Study (IAS) at Princeton to continue his research on characteristic classes in differential geometry. Chern immediately impressed Hermann Weyl and Oswald Veblen, who were both well-known mathematicians at the time. It was also at the IAS where his work on the theory of characteristic classes (a way of associating each principal bundle of X a cohomology class of X) was recognized as Chern classes which are associated with complex vector bundles. Chern classes are quite feasible in practice, as in differential geometry (sometimes algebraic geometry), Chern classes can be expressed as polynomials in the coefficients of the curvature form which describes curvature of a connection on a principal bundle (Chern, 1946). Overall, in topology, differential geometry, and algebraic geometry, it is important to count how many linearly independent sections a vector bundle has, proving Chern's work to be extremely valuable to the field of mathematics. The Atiyah-Singer Index Theorem in differential geometry on how the "twisting" of vector bundles can be measured by certain cohomology classes is one major theory, for which the foundation would not be possible without Chern classes (Shanahan, 1978). Chern Classes are one of the four characteristic classes that provide the framework to this theorem.

In addition, his work culminated at the IAS in his publication of the generalization of the famous Gauss-Bonnet theorem (is a relationship between surfaces in differential geometry for a 2D manifold/surface) to higher dimension manifolds and is now known as the Chern theorem (Chern, 1946). In mathematics, the Chern theorem states that the Euler Characteristic of a closed even-dimensional Riemannian manifold is equal to the integral of a certain polynomial of its curvature. This theory was founded by Chern in 1945, connecting global topology with local geometry. Chern made history as this was the first time that the formula was proven without assuming the manifold to be a hypersurface manifold embedded in Euclidean space. The Chern theorem can be seen as a special instance in the theory of characteristic classes. The Chern integrand is the Euler Class, which is a characteristic class of oriented, real vector bundles. Like other characteristic classes, it measures how "twisted" a vector bundle is (Chern, 1946). Chern's theorem has also been found in many applications of physics, including: adiabatic phase processes, string theory, condensed matter physics, topological quantum field theory, and the topological phases of matter. Overall, Chern considers the Chern theorem his greatest work, as it was able to reshape the fields of geometry and topology.

3.4 Later Life

Chern eventually settled with his family in the United States in 1949 as a professor at the University of Chicago before moving to the University of California Berkeley in 1960 . Shiing-Shen officially retired from UC Berkeley in 1979, after an illustrious 29 years of research and professorship.

As with most things in Shiing-Shen Chern's life, retirement did not mean stepping away from mathematics. His love for mathematics is an example that shows how mastery of a subject is a lifelong ambition. It was because of this that Chern did not rest in his retirement and in 1981, he founded the Mathematical Sciences Research Institute (MSRI) at Berkeley where he served as the director until 1984. In 1985, Chern founded the Nankai Mathematical Institute, but remained as the honorary director of the MSRI. Chern advised many impressive Ph.D. students during this time, including Shing-Tung Yau, who later won the Fields Medal, Jim Simons, who became a billionaire by mathematically cracking the secrets of the stock market, and Chen-Ning Yang, who won a Nobel Prize.

3.5 Contributions to Mathematics in China

Although it was not where Chern spent most of his life, Shiing-Shen had a deep love for his home country of China. During Shiing-Shen's life, China was in a deep state of turmoil, undergoing several cultural revolutions. The Sino-Japanese war, and subsequently World War II (WWII), had forced him to America, and the preceding violence and instability kept him away. After the initial violence of Mao Zedong's cultural revolution

(1965-1976), Chern began to make regular visits to China in 1972. China had lost a whole generation of mathematicians, and with them the tradition of mathematical research. This had a profound effect on Shiing-Shen, who returned with the purpose of training mathematicians and re-igniting these traditions.

In 1985, Chern furthered these ideals by overseeing the opening of the Nankai Mathematical Research Institute. The Institute was loosely modelled after the Institute for Advanced Study in Princeton, where established mathematical figures could interact with doctorate students, all while fully focused on research. Chern's work on restoring and progressing mathematical traditions in China strongly influenced a new era of Chinese math.

Chern believed that China had the power and responsibility to become a world leader in mathematics. However, he believed that two things were required for this to happen: the existence of people within the Chinese mathematical community that wish to advance human understanding of mathematics and enough support for excellent library facilities, space for research and communication with the worldwide mathematical community. Chern felt these resources were as essential for mathematicians as laboratories are for experimental sciences and the Institute at Nankai University played an important role in this vision.

3.6 End of Life

Chern finally moved to China in 1999 to spend his final years in Tianjin, where the Institute had been set up. Chern's wife, Shih-Ning, died in 2000. After her passing, Chern would write, "Through war and peace and through bad and good times we have shared a life for forty years, which is both simple and rich. If there is credit for my mathematical works, it will be hers as well."

Chern continued to work on mathematical theorems while in China, attempting to recast the results of Riemannian geometry of the last several decades in the Finsler context. Chern passed away in 2004 at the age of 93, in his home in Tianjin.

3.7 Legacy

Chern's impact on modern mathematics cannot be understated. Chern took differential geometry, a dormant field, and turned it into a vibrant and exciting area of study, eventually merging with the study of algebraic geometry and topology.

His expansion on Cartan's insights on the equivalence problem, which he published papers on for 20 years, explained and reformulated the problem with such clarity that it is now found in all geometric textbooks.

The Chern-Gauss-Bonnet theorem was a monumental study that connected differential geometry to topology, forever linking the two subjects together. His work is at the foundation of gauge theory, one of the cornerstones of modern theoretical physics. When speaking about Chern in a mathematical context, he is described as having "absolute mastery of the techniques of differential forms and artful application of the techniques in solving differential geometric problems."

Although Chern's work had such an impact on the global scale, his legacy is defined by his ability to figure out the local problems like no one else could. Chern was of the philosophy that one cannot explore the global context if the local is unknown, which has significant meanings beyond mathematics. Of the many awards that Chern won, notable achievements include: the 1984 Wolfe Prize, the 1975 U.S. National Medal of Sciences, the 1982 Humboldt Prize, the 1970 Chauvenet Prize, the 2004 Shaw Prize, and more.

Perhaps more important than the numerous awards and honours bestowed upon Shiing-Shen Chern is his lasting impact on the social dynamics between the United States and China. In 2002, he convinced the Chinese government to host the International Congress of Mathematicians in Beijing.

In his opening speech, he said, "The great Confucius guided China spiritually for over 2000 years. The main doctrine is ... the human relationship. Modern science has been highly competitive. I think an injection of the human element will make our subject more healthy and enjoyable. Let us wish that this congress will open a new era in the future development of math."

Today, China enjoys more mathematical and scientific communication with the world than it ever had, perhaps as a result of Chern's efforts.

3.8 Conclusion

Dr. Shiing-Shen Chern lived a long and prosperous life in which he continuously revolutionized the field of differential geometry. Dr. Chern's commitment to the progression of mathematics in China and his drive to uplift others in the field helped inspire many Chinese mathematicians. Dr. Chern will forever be recognized as an individual who has not only advanced the field of mathematics but as an individual who helped progress cooperation between scientific communities in China and the United States.

4 Muhammad Ibn Zakariya al-Razi (c.854-c.925)

Father of Psychology and Psychotherapy

By Peter Bebi, Gabriella Bacchus, Whitney Trinh, Shathani Manako, and Raees Bajwa

4.1 Birth and Early Childhood

During the Islamic medieval period in Persia (650-1500 CE), themes prominent in Islamic teachings and the Quran had a considerable influence on the culture and mindset of the Persian people. The pursuit of knowledge was an emphasis outlined in the Quran and was a theme conveyed by the Holy Prophet of Islam, Muhammad (sa) (Kadi, 2006). Abu Bakr Muhammad ibn Zakariya al-Razi was a visionary and philosopher who embodied this theme throughout his life, he was continually fixated on understanding how and why processes occurred and manipulating known relationships in order to reach a desired conclusion. His zeal in education developed his empirical approach to science rather than strictly philosophical theories.

Abu Bakr Muhammad ibn Zakariya al-Razi was a Persian physician, philosopher and alchemist born on 865 CE in Shahr-e Rey, known as Rey County in the Iranian capital of Tehran (al Biruni, 1936). The city of Rey was located on the banks or the silk road, where trades were facilitated between nations east and west of Persia. The Persian name Razi references his birthplace and translates roughly to "from the city of Rey" (Ansari, 1976). Al-Razi spent his formative years as a singer and lute player, this passion for music eventually led him to compile of an encyclopedia on the topic. Al-Razi eventually traded musical expression for the pursuit of knowledge in alchemy under the supervision of his father, a renowned goldsmith (al Biruni, 1936).

Al-Razi was known in his youth to be a successful alchemist and generated fame with travelers passing through Persia for his ability. He once sold a set of toy birds to visiting travelers, but as time passed, the gold colour of the birds began to fade and eventually these birds were returned. Though al-Razi did not successfully generate gold from copper and silver from mercury, the information he discovered in pursuit of alchemy assisted future generations of visionaries understand relationships between chemical bodies (Ansari, 1976).

Over years of working with the fumes from chemical compounds without personal protective equipment, al-Razi began to develop an eye disease approximately at the age of 30. Through the pursuit of remedies and doctors, al-Razi decided to pivot form the pursuit of knowledge in alchemy to medicine in order to treat his ailment. He relocated to Baghdad and practiced medicine in a local hospital. Al-Razi authored many books on medicine and treatments and became an advocate for experimental medicine. Al-Razi once stated:

"The doctor's aim is to do well, even to our enemies, so much more to our friends, and my profession forbids us to do harm to our kindred, as it is instituted for the benefit and welfare of the human race, and God imposed on physicians the oath not to compose mortiferous remedies."

He was known to be extremely generous and commented on the ethics of the medical field, namely providing service for all humans regardless of context (Ansari, 1976).

4.2 Razi and Alchemy

The term alchemy conjures images of mysticism mainly because the subject is cloaked in symbolism and metaphors. Alchemy was twofold, the exoteric and esoteric alchemy. Esoteric alchemy was primarily concerned with mysticism and religion, while exoteric alchemy was concerned with transmuting base metals such as lead, tin, copper, iron and mercury into precious metals such as gold and silver (Holmyard, 1990). The latter led to the development of modern-day chemistry, and al-Razi is one of the prominent figures that contributed immensely to its development. Professor T. J. De Boer says the art of alchemy in the eyes of al-Razi was an art indispensable to philosophers and which he believed had been practiced by Pythagoras, Democritus, Plato, Aristotle and Galen. It is purported that al-Razi's alchemical work was influenced by Jabir Inbn Hayya, the celebrated Muslim scientist and father of Arabian-alchemy (Ansari, 1976).

Up to al-Razi's time, substances were classified into bodies, souls and spirits. Al-Razi is credited with introducing the classification of animal, vegetable, and mineral. He divided minerals into spirits, bodies, stones, vitriols, boraxes, and salts and distinguished between volatile bodies and non-volatile spirits (Ansari, 1976). Al-Razi documented his experiments and procedures in the *Kitab Al-Sarar* or *The Book of Secrets*, which was later translated into an influential Latin text, the *Summa Perfectionis*.

According to Gail Taylor, the goal of procedures in the Kitab Al-Asrar is to transmute materials into gold and silver. In this manual we get a glimpse of al-Razi's experimental methods and his dedication to laboratory safety and the reproducibility of quality results that are comparable to modern-day laboratory standards. In the manual al-Razi provided a series of procedures that the alchemist must conduct under specified conditions to ensure reproducibility. The conditions included selecting chemicals, combining them in defined proportions, and subjecting them to heat for a specified period to achieve a fixed endpoint. Regarding safety, al-Razi instructed the alchemist on handling chemical substances such as mercury and arsenic sulfide and emphasized proper ventilation when working with toxic fumes (Taylor, 2010).

In addition to the classification of substances and his systematic approach to alchemy, al-Razi introduced mercury as a chemical drug after experimenting with it on monkeys. Furthermore, he introduced white lead granules for application to sore eyes. Al-Razi is also credited with inventing the hydrostatic balance, which he used to investigate specific gravity (Ansari, 1976).

As the laboratory is dependent on funding for its operation al-Razi wrote books and tracts on the art of alchemy to gain financial support. Ibn Khallikan, in his *Wafayat-Al-A'yan* says that al-Razi had written a book on the vindication of the art of alchemy for the governor of Rey for which he paid him a sum of one thousand dinars with the proviso he should demonstrate what he has written. However, al-Razi failed to transmute copper into gold and mercury into silver (Ansari, 1976). Despite the controversies surrounding the story, in the words of Ruska, the credit goes to al-Razi for bringing alchemy to a strictly scientific format for the first time (Taylor, 2010).

4.3 Razi the Physician

In addition to his work in physics and alchemy, al-Razi also made significant contributions in the medical community. His works in the medical field were performed in a time where the primary source of knowledge was rooted in religion, and there was not much evidence backing the medical practices he employed. His findings went on to influence several medical fields including medicine, psychiatry, pharmacology, pediatrics, and psychosomatic medicine, just to name a few (Yilanli, 2018).

One of al-Razi's many notable discoveries is within the field of pathology and surgery, with the introduction of the inhalation of opioids as a method of anesthesia in surgeries. He also contributed to the field of otorhinolaryngology with his technique of using direct sunlight and mirrors to examine the nose and ears of his patients. He was the first to make the distinction between medical conditions such as smallpox and measles, and concussions from other similar neurological conditions. Al-Razi contributed significantly to the foundation of studies in neurology and neuroanatomy by contributing to the classification of several cranial and spinal nerves (Amr and Tbakhi, 2007). He used this knowledge along with his ability to establish a link between the anatomic location of a lesion and the clinical signs, to localize lesions found within the nervous system specifically (Amr and Tbakhi, 2007). His work with this specificity have led to him being considered a pioneer in applied neuroanatomy.

Much of al-Razi's medical practices revolved around nutrition in medical practices. His preferred method of treatment centred on providing his patients with the appropriate food groups for treating them with simple remedies; as he believed complex medicine should only be used as a last resort (Nikaein et al., 2012). Many of his theories around how food affects certain aspects of the body are still used, and have been proven to hold merit in society to this day, such as the use of prunes to relieve constipation.

Outside of his contributions to physical health and anatomy, al-Razi was well known for his contribution to the field of mental health as well. During his time as the director of a hospital in Baghdad, he established a separate unit for the treatment of those who were mentally ill (Yilanli, 2018). In his treatment of these illnesses he conducted in depth clinical observations on the effects of treatments such as diet, occupational therapy, and music therapy, and was one of the firsts to use cognitive therapy for obsessive behaviour (Yilanli, 2018).

Throughout his career, he wrote around 237 papers and books on the medical field alone, however only 36 of them are available today (Yilanli, 2018). In his writings, he used case histories of the various diseases and illnesses he treated to document and educate on his methods. One of his books, the *Kitab al-Tajarib*, is one of the oldest and largest collection of case histories recorded in medieval Islamic medical literature (Amr and Tbakhi, 2007). Al-Razi was also one of the first to write on pediatrics as its own unique field in medicine, which earned him the title “Father of Pediatrics” in the eyes of many scholars.

4.4 Razi the Philosopher

Al-Razi was a multi-faced and versatile genius with a career of a specialization-cum-generalization. He was a controversial philosopher. Like Galen, another philosopher-physician and one of his main sources, he was considered by many an excellent physician but a poor philosopher. Most of al-Razi's philosophical ideas were pieced together based on reports found in other authors, who are often hostile to him due to his views on religion and prophecy to an extent that they called him "the heretic." Al-Razi was a great admirer of natural philosophy of antiquity as propounded by Pythagoras and Thales of Miletus, who preceded Aristotle (Adamson, 2019). He accused Aristotle of corrupting the basic principles of natural philosophy, he went on to introduce five "eternal principles" as opposed to Aristotle's three principles that govern the existence of cosmos.

The five "Eternal Principles" based on old doctrines was one of the major philosophical achievements of al-Razi; at the top of his system stands five co-eternal principles: the creator, the universal soul, the primeval matter, absolute space, and absolute time. Al-Razi argues that God's existence is shown on the basis of the good design of the universe. While the soul is invoked as the source of life in bodies and its major function is to facilitate a distinctive theodicy. He maintained that the presence of suffering in the world, alongside the good design of this universe, could not be a direct creation by God, as God is not unwise. According to him, God, only intervenes to make the world good, however, it is the soul that conceives the desire or passion to be mixed with matter, which initiates the process of the world's creation.

Al-Razi believed that Creatio ex Nihilo was impossible, presence of matter, time, and place was necessary for the universe to be created. Material therefore according to him existed before cosmos existed. On this principle, he argued that matter is eternal, that creation is a manifest, there must be ipso facto a creator and what is created is nothing but formed matter, therefore existence of matter is co-eternal with the existence of the creator. And for space, he says that as matter should occupy space, therefore, space is also eternal as a co-existent, which is infinite and what is infinite is eternal. On the last of the five "eternal principles," al-Razi stated that time is an independent substance that flows; it is eternal. Time according to him existed before the creation of the world and will continue to exist after its dissolution (Ansari, 1977).

On ethics, al-Razi defends a lifestyle of moderation, and distances itself from outright asceticism as mentioned in his philosophical way of life. One of the philosophical problems dealt with by al-Razi is that of ecstasy and pain. Stating that both ecstasy and pain are perceptible; therefore, there is absence of pleasure and pain when one is in the natural state because the natural state is not tangible. His exposition of ecstasy and pain is the same as given by the modern science of psychology. In his *Spiritual Medicine* al-Razi takes a dim view of pleasures, and offers advice for resisting the allure of food, drink, sex, and luxury. According to Lenn E. Goodman, al-Razi was defending epicurean ethic in which pleasure should be maximized (Adamson, 2019).

On religion and prophecy, al-Razi like Avicenna, had no belief in revelation and prophecy. Both did not subscribe to the view that all kinds of miracles are possible because they believed that certain events are 'evidently impossible'. It is in his non-belief in revelation and prophecy that resulted in criticism and hostility towards him from religious scholars.

4.5 Works, Writings, and Later Years

Al-Razi continued down the path of learning throughout his lifetime, displaying the breadth of his knowledge through the many publications that he would write (Amr and Tbakhi, 2007). His principles as a medical practitioner and philosopher drove him to acquire this knowledge and justice, as well as treat his patients with morality and care (Gammal, 1995). He remained teaching to his students in his hospital at Rey, and practiced medicine without charging his patients, instead opting to gain further exposure to various cases along the way (Amr and Tbakhi, 2007).

Al-Razi's generosity and kindness expanded past the hospital as well, even reaching as far as the books he wrote. The book *Man la yahduruh al-Talib* or *Every man is his own doctor* was one of the first medical books written to the general public, and contained a vast amount of medical knowledge and treatments for a variety of problems, along with where to readily access ingredients for medicine (Gammal, 1995). For his students, he provided them with his own book, *Kitab al-Murshid* (*The Guide*), to provide introductory principles for medicine (Amr and Tbakhi, 2007). His most well known work, *Al-Hawi fi al-Tibb* (*The Comprehensive Book on Medicine*), would be completed after his death by an unknown pupil. Unfortunately many of his books, including some volumes of The Comprehensive Book on Medicine, would become lost in the future (Gammal, 1995).

Not all of his books were looked on so favourably by the public. One of his famous and controversial works is the *Al Shakook ala Jalinoos* (*The Doubt on Galen*). Al-Razi was a man who often liked to challenge previous knowledge, even if they were widely accepted, if they disagreed with what he observed (Gammal, 1995). The book in particular criticized Galen and his theory on there being four humors (Amr and Tbakhi, 2007). He also criticized Hippocrates (Gammal, 1995). Statements such as these often gave way to being classified as a "freethinker" over the years, and for some of his statements to be critized in the future.

During his late years, al-Razi would choose to lose his vision over undergoing surgery. While the reasons behind it are unknown, some speculate he refused treatment due to feeling like he had seen enough of the world. Whether this had philosophical implications or not, the definitions he considered to have been the end would later fuel advances in alchemy, medicine, and philosophy within Islamic and European civilizations even after his death on October 27, c.925 (Amr and Tbakhi, 2007).

5 List of Contributions

Amir A. Aliabadi received his bachelor's and master's degrees in Mechanical Engineering, in 2006 and 2008 respectively, from University of Toronto, Toronto, Canada, and his doctoral degree in Mechanical Engineering in 2013 from University of British Columbia, Vancouver, Canada. He is an assistant professor of engineering in the Environmental Engineering program at the University of Guelph, Canada. He is specialized in applications of thermo-fluids in buildings and the environment. Prior to this position he was a visiting research fellow at Air Quality Research Division, Environment and Climate Change Canada from 2013 to 2015 in Toronto, Canada, and a research associate in Department of Architecture at the Massachusetts Institute of Technology (MIT) from 2015 to 2016 in Cambridge, U.S.A.

Reza Aliabadi graduated from University of Tehran, Tehran, Iran, in 1999 with a master's in Architecture, and founded the "Reza Aliabadi Building Workshop". After completing a post-professional master's of Architecture at McGill University, Montreal, Canada, in 2006 and obtaining the OAA license in 2010, the workshop was reestablished in Toronto as atelier Reza Aliabadi "rzlbd". He has established a strong reputation in both national and international architectural communities. Local and global media have published many of rzlbd's projects. He has been invited to install in Toronto Harbourfront Centre, sit at peer assessment committee of Canada Council for the Art, speak at CBC Radio, give lectures at art and architecture schools and colleges, be a guest reviewer at design studios, and mentor a handful of talented interns in the Greater Toronto Area. He also had a teaching position at the School of Fine Arts at the University of Tehran and was a guest lecturer in the doctoral program at the same university. Artifice has recently published Reza's first monograph "rzlbd hopscotch". He maintains an ongoing interest in architectural research in areas such as microarchitecture, housing ideas for the future, and other dimensions of urbanism such as compactness and intensification. Beside his architectural practice, Reza also publishes a periodical zine called rzlbdPOST.

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