BEYOND SCIENTIFIC RESEARCH: TRACING THE CONTRIBUTIONS ERNEST RUTHERFORD MADE TO THE NEXT GENERATION OF SCIENTISTS

A Thesis

by

ANDREW A. ARMSTRONG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Science and Technology Journalism

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Committee Members, Anthony Stranges
Jonathan Coopersmith
Head of Department, Barbara Gastel

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ABSTRACT

Beyond Scientific Research: Tracing the Contributions Ernest Rutherford Made to the Next Generation of Scientists. (May 2006)

Andrew A. Armstrong, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Edward Walraven

Before his death in 1937, Ernest Rutherford discovered the rate of radioactive decay of atoms. In 1911 he proposed the nuclear structure of the atom, and in 1919 he successfully split the nucleus of an atom. Rutherford also achieved success when advising his students to follow his research method in nuclear physics. As a faculty advisor to research students, Rutherford advised courses, research topics, and experimental research. To determine whether Rutherford made an impact on his students, this study focused on the relationship between Rutherford and 24 researchers and students at McGill University, the University of Manchester, and Cambridge University. Rutherford had a significant impact through his advising efforts at each institution and contributed to the success of his students. This study may not include a complete list of students at each institution because of a lack of records at each institution. Instead, this study focused on the students included in the Rutherford biographies.

The study included a content analysis on Rutherford biographies and memoirs from students under Rutherford's direct influence at McGill University, the University of Manchester, and Cambridge University. Historical information from J.L. Heilbron, David Wilson, and J.G. Crowther supplied the timeline at each institution where

Rutherford conducted research. The results show an overwhelming contribution by Rutherford's leadership in the direction of his students. Rutherford made a significant impact in the research direction of all his students examined in this study, including eight research students under Rutherford that were later honored with a Nobel Prize.

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CHAPTER I

INTRODUCTION

Ernest Rutherford (1871-1937) became one of the greatest scientists of the twentieth century with his discoveries in radioactivity beginning in 1898, the nuclear model of the atom in 1911, and splitting of the atomic nucleus in 1919 (Heilbron, 2003). Rutherford's great scientific discoveries and political efforts during World War I, topics well covered in biographies, overshadow his advising efforts in student research. Beyond scientific research, Rutherford's greatest achievement came when guiding the next generation of nuclear physicists as a faculty member and research director. Rutherford had a great impact on the students conducting research under his direction. From tracing Rutherford's advising record, today's professional staff advisors and faculty advisors can learn how to advise today's science research students.

Rutherford transferred from Canterbury College in New Zealand to the Cavendish Laboratory at Cambridge in 1895 (Crowther, 1952). He brought experimental work in radio waves, initially winning him high praise, but soon redirected his research to gas ions under J.J. Thomson. As a student, Rutherford's relationship with teachers and professors produced a mentor-type mentality with a philosophy of open communication between professor and student. At McGill University, in Montreal, Canada, Rutherford took on his first role as a professor, building the reputation of the physics research laboratory. Rutherford worked with R.B. Owens for his first collaborative effort (Wilson, 1983). Others who worked with Rutherford at McGill include Harriet Brooks, R.K.

This thesis follows the style of the *NACADA Journal*.

McClung, Arthur Grier, Samuel Allan, Frederick Soddy, and Otto Hahn. From his work at McGill, Rutherford won the 1908 Nobel Prize in Chemistry for discovering radioactive decay in atoms.

Rutherford continued experimental research at his next position at the University of Manchester in Manchester, England. Rutherford continued working in the laboratory, mentoring and advising his research students, but now a Nobel laureate, he attracted more students as compared to his time at McGill (Wilson, 1983). The students at Manchester include Hans Geiger, Thomas Royds, Ernest Marsden, George de Hevesy, Charles Darwin, James Chadwick, Niels Bohr, Edward Andrade, Henry Moseley, and Harold Robinson. Rutherford's research students helped him discover the nuclear model of the atom and split the atomic nucleus of an atom.

After World War I, Rutherford accepted a new position moving him back to Cambridge in 1919. As the research director of the Cavendish Laboratory there, Rutherford rebuilt British science after the war, directing the path of the famed laboratory. By taking a less active approach in individual research, Rutherford maintained a few personal projects (Heilbron, 2003). Students at the Cavendish who worked under Rutherford include Patrick Blackett, John Cockcroft, Charles Ellis, Ernest Walton, Thomas Allibone, Mark Oliphant, and Paul Harteck.

Research directors in a faculty advisor position guide students by creating an atmosphere for research. Edward Bullard (1965, p. 264), the department head of Geodesy and Geophysics from 1957 to 1974 at the University of Cambridge, described to Rutherford's atmosphere in the laboratory; "Some men, of whom Rutherford was the outstanding example, can make those who work with them not merely appear outstanding but actually produce outstanding results." As research director, Rutherford advised students based on his expert knowledge of nuclear physics and formulated research projects based on student inquiries.

Rutherford's unique educational background as a student, coupled with his own experience in radioactivity enabled him to advise students effectively as a laboratory research director. Rutherford became a great scientist because he knew he had to be a great student first. He understood the disciplined observations needed to formulate a scientific theory. This made students follow him as a faculty advisor because he achieved outstanding results through closer collaborations with his students. To understand the relationship between advisor and advisee, this study examines Rutherford's guidance with his students, and proposes a model for current faculty advisors to follow. This study adheres to the advisor/advisee definition given by the National Academic Advising Association (NACADA), "The purpose of academic advising is to help the student choose a program of study which will serve him in the development of his total potential" (O'Banion, 1994, p. 10)

NACADA outlined the role of faculty advisors in a 1995 monograph *Reaffirming the Role of Faculty in Academic Advising*, and again printed in the 2003 book *Faculty Advising Examined*. Margaret King (Kramer, 2003, p. 125), Associate Dean for Student Development at Schenectady County Community College in New York, and a founding member of NACADA and past president, presented numerous advising models including the "faculty-only" delivery system. In the "faculty-only" model she included two strengths faculty members exhibit when advising students; knowledge of academic discipline within a field and credibility. Other advising delivery systems King included in her study include “supplementary,” which includes a faculty advisor with an advising center for academic information and referrals; “Split,” where students begin their academics as a non-major, then are sent to faculty advisors once certain conditions are met; “Dual,” where both the faculty and staff advisors provide advising information; “Total intake,” where all students are in one major until credit hours are met, but assigned to a faculty member in their academic department; “Satellite,” where all advising offices are within each department and faculty may or may not have responsibilities in advising; and “Self-contained,” where all advising is administered in a central department without faculty input. (King, 1995, pp. 22-23)

King (Kramer, 2003, p. 128) defined the “faculty-only” model as “each student is assigned to a specific faculty member for advising, generally someone in the student’s program of study.” This advising delivery system requires full-time faculty to provide academic assistance as part of their other assigned duties as a faculty member. Rutherford’s advising position parallels this definition of a faculty advisor. Rutherford possessed these strengths with his unparalleled knowledge, including numerous awards and accolades, in nuclear physics.

This study demonstrates the “faculty-only” advising model and meets the NACADA charter “to enhance the educational development of students” by giving a historical representation of a research-based faculty advisor. The textual searches are a result of traditional biographical and science writing designed to "advance science and innovation throughout the world for the benefit of all people,” as stated in the mission of the American Association for the Advancement of Science (AAAS, 2006). Like the

AAAS, this study will “enhance the science and technology workforce and infrastructure” by providing a working “faculty-only” model for research institutions.

The information collected in the study came from Rutherford’s students, early science writers, science institution sociologists, and biographers in primary and secondary sources. By examining Rutherford’s educational background and his guidance of student research, faculty and professional advisors can understand the relationship needed for advising science research students. This study will demonstrate a working model of the “faculty-only” advising model for current professional advisors to follow when advising science research students.

Research Objectives

1. List, from available sources, 24 students and researchers under Rutherford at each institution and their research outcomes.
2. Examine the guidance or advice Rutherford gave so that current faculty advising profession can use for today’s students.

Research Questions

1. What guidance from Rutherford led to a student’s success in completing scientific research?
2. From Rutherford’s model of advising, what can professional or faculty advisors learn for advising today’s student?

CHAPTER II

RESEARCH METHODOLOGY

In order to advance science and innovation, the mission of the AAAS, the organization established a goal to “foster communication among scientists, engineers and the public” (AAAS, 2006). This study will allow a professional advisor to gain a better understanding and appreciation for the research conducted by scientists and engineers. By systematic observation that reviews historical trends in science, science journalists help professional advisors understand research focused students in a research institution where the “faculty-only” model approach to advising exists. Research students rely on faculty advisors to understand their research background, previous courses, and ability to conduct experiments based on educational knowledge.

Data collection came from published biographical information on Rutherford, but did not include journal articles. Once collected, a content analysis determined if advising by Rutherford made an impact on his students’ research results. Rutherford’s efforts in advising students show an impact in their research direction in nuclear physics.

While all of these works provide valuable insight into the researchers under Rutherford, they are limited in supplying a complete list of students at each institution. Compiling a complete list of students at each institution was not the focus of Rutherford’s biographers. Instead they focused on published research. In following the results from Rutherford’s biographies, the results in this study examined a possibly incomplete list of students at each institution. A complete list of students could not be obtained through records at each institution. [1]

This thesis searched for examples of the "faculty-only" advising model. Students under his direct guidance and leadership that produced an outcome of the benefits from advising were used for this study. If communication between Rutherford and student occurred and influence from Rutherford advanced the student's research outcome, it was indicated during the content analysis and included in determining a relationship between professor and student. Each individual had different relationships, but the contact influenced the students' research objective, scientific achievement, and is included with personal remarks made by the students of how Rutherford affected their research. In each of the references made in this study, communication from advisor to advisee determined the direction and outcome of results.

This thesis focused on published biographical material covering Rutherford's lifetime of contributions in science from 1890 to 1937. Although Rutherford passed away 70 years ago, his contributions to science and his leadership abilities in guiding scientific research continue to play a vital role in today's scientific research. Rutherford started his scientific career under J.J. Thompson at Cambridge in 1894, completing a few experiments previously in New Zealand. Rutherford passed away in 1937, leaving behind his many research students to continue efforts in understanding radioactivity.

Arthur S. Eve, a former colleague and friend of Rutherford, published *Rutherford*, in 1939 as the first biography on Rutherford. Eve started with Rutherford's childhood in New Zealand until his death using notes and letters Rutherford had written to family,

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[1] A complete record of students for this study was unattainable through communication with McGill University, University of Manchester, and the University of Cambridge. Further investigation into university records containing student enrollment data would be required in order to comprise a complete list of students that studied under Rutherford at each institution.

colleagues, and students. The book presented Rutherford's thoughts and feelings as he explored new discoveries in radioactivity.

David Wilson, a former Cambridge graduate, although not a student of Rutherford, in 1983 wrote a complete biography of Rutherford's life in *Rutherford: Simple Genius*. Similar to other biographies on Rutherford, Wilson (1983) begins with Rutherford's childhood and ends with the few years following Rutherford's unexpected death. Wilson added details concerning Rutherford's years as the leader in nuclear physics and the relationship between the scientist and his students. From Wilson's work a reader can fully appreciate and understand Rutherford's significance and the contributions he made to helping others.

Wilson included students and research colleagues who worked with Rutherford from McGill to Cambridge, including those with very little contact with Rutherford. Some researchers only spent a semester or two under Rutherford before continuing their research at another institution. Wilson portrayed the major contributors to Rutherford's success and wrote extensively about Frederick Soddy, Hans Geiger, George von Hevesy, Otto Hahn, Niels Bohr, Henry Moseley, Peter Kapitsa, Ernest Marsden, James Chadwick, and John Cockcroft. Others who contributed to Rutherford's research included Thomas Royds, Patrick Blackett, Charles Wilson, Ernest Walton, Mark Oliphant, and Edward da Andrade. Testimonials from these students gave insight into how they felt about their professor and what type of impact faculty advising can have on research students. The completed list used for this study, including each student's time with Rutherford, appears in Appendix A.

The research for this study included viewpoints from different students, authors, and biographers that captured the time spent between their subjects and Rutherford. To present how Rutherford advised students, several resources were used to describe the “faculty-only” relationship and research situation. As Rutherford moved from one position to another he shifted his time from conducting research to advising student research. Rutherford’s directorial efforts at the Cavendish placed more emphasis on directing research goals, no longer the hands-on experiments in the laboratory.

Biographical Work

Students, science writers, and biographers provided the information used for this study. Several former Rutherford students wrote about their life and time spent working with Rutherford in some capacity. Former students provided insight on Rutherford’s advising based on his knowledge of investigative inquiry in research. Science writers, such as J.G. Crowther, contributed to understanding science by providing historical references in a timeline. Unlike magazine and journal articles, biographical books require a greater depth of research and time.

A qualitative content analysis of this work identified details about Rutherford, colleagues, research students, advising statements, and outcomes. The coding of the analysis quickly identified useful sources that added to the research study. Previous biographers include Arthur Eve, 1939; J.G. Crowther, 1952; David Wilson, 1983; and J.L. Heilbron, 2003.

Using John L. Heilbron’s biography on Rutherford, this study focused on Rutherford’s life and contributions to mentoring others in science. The writers and scientists who studied Rutherford, his students, and his efforts in radioactivity for nearly a century provided the advising information from Rutherford. From these works this current study focused on interaction between Rutherford and his students, then the eventual outcome of the advising. Heilbron, a former history professor at University of California, Berkeley, used several books written by Rutherford's students when compiling his notes. For scientific discoveries prior to Rutherford, Heilbron used J.G. Crowther's *The Cavendish Laboratory, 1874-1974*. Heilbron did not include *British Scientists of the Twentieth Century*, *Discoveries and Inventions of the Twentieth Century*, and *A Short History of Science*. These additional resources contained information on Rutherford's many discoveries, research colleagues, and a timeline of discoveries.

Identification of Individuals

Students used in this faculty advisor to student relationship came from the source material listed. All books reviewed for content on Rutherford's students came from Heilbron's *Ernest Rutherford and the Explosion of* Atoms and Wilson's *Rutherford: Simple Genius*. The two authors focused on Rutherford's life and his relationships with researchers and students (Appendix A). Wilson's work produced the most comprehensive list of students and colleagues under Rutherford, along with an extensive bibliography for other references. Wilson's book aided in establishing which student attended where, and where more information could describe the situation between the student and Rutherford.

Wilson covered the beginning with Rutherford's first chair appointment at McGill University to his final position back at Cambridge and the student researchers at each institution. The students discussed by Wilson and Heilbron who worked with Rutherford comprised the list of students to review for this research study. The final group of students used to explain the faculty advisor role in advising students consisted of 24 students.

Data Collection and Analysis

The initial reading of results looked for guidance from Rutherford on student research. The collected results were placed onto a data sheet for further review (Appendix B). Each reviewed passage from Appendix B produced the results of this study. The descriptions were included on a collection sheet identifying the student, the time the student spent with Rutherford, publication, and author. Within this data section a separate question asked if the student gave personal remarks about Rutherford.

All collected and compiled data made a time frame split into the three institutions: McGill, Manchester, and Cambridge. Within each institution the referenced material was placed in sequence as it occurred during Rutherford's life. This study focused on Rutherford's advising ability for students conducted research, and exemplifies the role between faculty advisor and the student researcher.

The students covered in this study were advised by Rutherford in their experimental research. His advising efforts made a significant impression on their research and their future in nuclear physics. This study included some students whom Rutherford directed in their research efforts, but their success was not recorded by those referenced. These parameters defined the total number of students to an acceptable number needed to portray the faculty-to-student advising relationship. By following a large number of students this study will give a representation of the faculty advisor relationship.

Heilbron provided an outline of Rutherford's life, work, and accomplishments, highlighting his work with others: however, he excluded all students and their relationship with Rutherford. Crowther’s research on Rutherford and other science discoveries created the time frame in which to research more information on the students under Rutherford. Crowther’s work portrayed the everlasting impact Rutherford made on his students. Wilson included the most comprehensive details about Rutherford and the students that worked for him throughout his career.

CHAPTER III

STORY REVIEW

Faculty Advising and Research Institutions

Faculty advising evolved with the changing scene at growing universities and colleges in the United States. To confront new problems faced by many institutions, faculty advisors assumed unexpected roles in the evolutionary process. Wes Habley (1995, pp. 11-12), a founding board member of NACADA, stated , “To the role of faculty member as teacher and mentor were added ever-increasing expectations of the faculty member as researcher, writer, grant procurer, and participant in faculty governance, as well as a number of other activities.” Rutherford took on more responsibility at each institution as his role changed from a professorial chair at McGill University to research director at the Cavendish.

In considering the “worthwhileness” of a research laboratory, Bullard examined the contributing factors at laboratories based on financial contributions as compared to application uses in discoveries. Scientists interested in joining a research institution can form an impression of a laboratory by talking to researchers at the institution to determine the quality of its work. Bullard, however, claims this decision can come with very little knowledge of the research topic or other related issues. Bullard (1965, p. 263) argued, “Such judgments are based, I believe, on recognition of an attitude of mind of the staff to the work and to the establishment.” He recommended a research institution must form the right climate for those wanting to do research suggesting, “that the first consideration in the organization of a research establishment is the fostering of the right climate of opinion” (Bullard, 1965, p. 263). He continues, “This consideration is, perhaps, more important even than the intellectual quality of the staff.” (p. 263)

The limited number of research institutions in nuclear physics during this time, including Cambridge University, the Radium Institute in Paris, University of Göttingen in Germany and later the University of California, Berkeley (Segre, 1966), gave little choice for students continuing research beyond undergraduate work. Rutherford, according to Bullard (1965, p. 264), represented an "outstanding" example of how an institution can maintain quality research without an elaborate facility. The atmosphere research directors create, Bullard claimed, was crucial to research production.

Nelson College

In a lecture delivered to the Physical Society in November 1942, Harold Robinson (1942) described Rutherford as a great scientist because of his legacy. In the lecture, Robinson traced Rutherford's life starting at New Zealand. Unlike most of the young European science students in the early 1900s, Rutherford came from New Zealand. Robinson outlined Rutherford's early life in New Zealand before leaving for Cambridge. Robinson claimed New Zealand's culture and educational system contributed to Rutherford's development into a studious pupil. New Zealand attracted settlers interested in developing a strong educational system reasserted by Parliament's Education Act of 1877, allowing a free "secular and compulsory" education (Robinson, 1942, p. 55). Without this unique educational background, Robinson explained, the modern world of physics would not be where it is today.

The significance of Rutherford's education and his rise to an authoritative figure in nuclear physics begin on 30 August, 1871, when James and Martha Rutherford gave birth to Ernest. Born in Brightwater, New Zealand, Rutherford moved during his early years, but his family continually stressed education. Rutherford attended the state primary school and won a scholarship to the more progressive Nelson College in 1886. At Nelson College, Rutherford received academic awards in mathematics, Latin, French, English, literature, history, physics, and chemistry. A strong work ethic led Rutherford to the top of his class at Nelson.

Rutherford's broad educational background in New Zealand covered topics ranging from history and literature to multiple foreign languages, but his true talent came from his voracious appetite for learning. Crowther (Crowther, 1952, p. 50) commented, "His greatness of style was an uncultivated expression of a natural greatness of physical imagination and achievement." Crowther described Rutherford as a "Homeric figure," or a warrior coming from an agrarian society that brought a sense of passion and wholesomeness to science (1952, p. 54). Rutherford's friendly approach with honesty and trustworthiness enabled him to excel along with those around him.

In New Zealand when Rutherford studied at Nelson College, he started exploring the passage of transient currents in conductors leading him to a paper written by Kelvin and Rayleigh titled "An accidental illustration of the shallowness of transient current in an iron bar" (Crowther, 1952, p. 51). Rutherford disagreed with Faraday's time integrals of induced currents passing through very fine or thick wires. His disagreement led him to review research studies to help create in-class practical experiments, a method Rutherford continued to use in his professional career. While trying to disprove Faraday's research, Rutherford showed an ability to replicate laboratory experiments. His efforts failed to disprove Faraday, but his judgment coincided with Sir W. Thomson and Kelvin, two of the greatest scientists at that time.

Rutherford’s first paper, “Magnetization of Iron by High-frequency Discharges” in the *Transaction of the New Zealand Institute*, examined the transient behavior in an iron bar (Crowther, 1952, p. 51). His research started with the experiments of Oliver Lodge, J.A. Fleming, and Hertz. Lodge’s research concluded that iron could not be magnetized by an oscillatory discharge from a Leyden jar. Rutherford found the claims in the relatively old study using steel needles inaccurate. Rutherford’s experiments proved Hertz’s oscillator had a strong iron magnetization. Crowther discussed Rutherford’s attitude as he compared his discovery to that of Thomson and the science behind Rutherford’s discovery. In 1893, just before Rutherford’s New Zealand paper, Thomson conducted experiments on the energy absorption between iron and copper cylinders. Crowther (1952, p. 51) quoted Rutherford as saying “the experimental methods pursued here is entirely different from Professor Thomson, but the final results obtained are the same. The results are also quantitative, while Thomson’s method only admitted of qualitative results.”

An outsider to England’s academic culture, Rutherford’s style by the first paper soon differentiated himself from other student researchers. Crowther (1952, p. 51) described Rutherford’s voice as “authentic,” expressing himself with “magisterial style, which came natural to him.” Crowther questioned Rutherford’s academic survival if born and educated in England. According to Crowther (1952), New Zealand’s educational atmosphere, especially at Canterbury College with Bickerton, influenced Rutherford’s free thinking.

In later years, Rutherford’s roots in New Zealand became more apparent in his dedication towards experimental research and limited laboratory equipment. As a noncapitalist, Crowther (1952) explained, Rutherford could never fit into the mold of European society as capitalists changed the agrarian culture made of farmers and craftsmen. New Zealanders worked together as equals striving to contribute to the community for the benefit of the entire group. Crowther made the analogy of Rutherford working hard for science through his research efforts. Students benefited from the positive atmosphere in Rutherford's laboratories as he welcomed new and fresh ideas.

Canterbury College

Rutherford continued his education at Canterbury College in 1890, on a Junior University Scholarship. Robinson (Robinson, 1942, p. 56) described the teaching style of A.W. Bickerton, one of Rutherford's teachers at Canterbury, as having "lively and unbounded enthusiasm for experimental science in all its manifestations." Robinson recognized the role Bickerton played inspiring Rutherford's curiosity stating, "It is doubtful whether Rutherford's scientific curiosity ever needed sharpening from without, but it is certain that if he had needed a stimulus he would have found it in Bickerton's laboratory" (1942, pp. 56-57).

Bickerton introduced Rutherford to chemistry and physics. According to Crowther (1952, p. 50), Bickerton inspired Rutherford, helping him to develop his boldness and imagination, a characteristic Rutherford used when advising his own students later in life.

Bickerton died in 1929, and at his funeral Rutherford spoke affectionately of his former professor, saying his "enthusiasm and encouragement of original investigations helped promote science in New Zealand" (Robinson, 1942, p. 57). Rutherford biographers, like Crowther, contend Bickerton's research in novae collisions gave Rutherford an image for formulating his planetary theory.

Rutherford's research at Canterbury College consisted of Hertzian waves, described by Robinson as remarkable for such a young researcher, especially considering the poor working conditions and crude laboratory equipment (Robinson, 1942). Meager laboratory conditions plagued Rutherford throughout his career as laboratories fell short in funding scientific experiments.

Rutherford joined Canterbury's unofficial college science society to study physics. The society openly discussed Bickerton's teaching style and the philosophical evolution of the elements. Rutherford, described as an outsider, formed an understanding of the world of physics, but lacked the research experience. Rutherford started his research during his last two years at Canterbury on secondary circuits and the passage of transient currents in conductors. This sparked Rutherford's interest in papers written by Kelvin and others on transient currents.

Mark Oliphant (1901-2000), a biographer and former research student under Rutherford at Cambridge, focused on Rutherford's scientific studies while at Canterbury College. According to Oliphant (1972, p. 5), Rutherford experimented with electromagnetic magnetizing waves discovered by Hertz. His research results showed only the outer metal layer, the Hertzian oscillator, received magnetization and detected wireless waves that could travel through brick walls. Rutherford replicated high voltage experiments first conducted by Tesla. By using his own resonant transformer, Rutherford measured intervals down to ten microseconds. His experiments led to lectures in the Science Society and two published papers in *Transactions of the New Zealand Institute*.

From Canterbury College Rutherford received his B.A. degree in English, French, Mathematics, Mechanics, and Physical Science. Rutherford also received his M.A. as Canterbury's first double major in mathematics and physical science.

During Rutherford's senior year at Canterbury College, J.S. MacLaurin of Auckland won the 1851 Exhibition Science Scholarship, a scholarship that allowed students to transfer to a university in England to continue their studies. MacLaurin eventually turned down the scholarship, citing family reasons, giving second place winner Rutherford the opportunity. Rutherford traveled to Cambridge in 1895 to study at the Cavendish under Thomson.

Cambridge University

Thomson (1937) later wrote about the policies that allowed Rutherford and other transfer students full admission to Cambridge. Rutherford arrived in 1895, after the university changed admission requirements to admit graduate research students from other universities. The policy allowed transfer students to submit a research thesis to a committee to earn a M.A. degree, later replaced with a Ph.D. Others students who took advantage of the admission standards included J.S.E. Townsend from Trinity College and J.A. McClelland from Queen's College.

Heilbron (2003) described the atmosphere surrounding Cambridge as tension mounted between the traditionally admitted students, who worked their way to become Cavendish junior members, and the new transfer students. Rutherford and other transfer students won academic prizes and scholarships, gaining professorships as research students. The transfer students were faced with overwhelming adversity in their new educational surroundings. Heilbron (2003, p. 17) said of Rutherford, "He needed the support Thomson gave, especially during his first few months, when the native demonstrators (teaching assistants) sneered at the barbaric newcomers without Cambridge degrees."

At Cambridge, Rutherford continued his research in radio waves using a magnetic detector. Crowther (1952, p. 56-57) stated the first scientific achievement that separated Rutherford from his peers at Cambridge when at the request of Thomson, Rutherford demonstrated his detector to the Physical Society gaining him much honor and praise. At one point the detector gained the long distance record of over half a mile. Townsend and others took note of Rutherford's work and spoke enthusiastically about his experiments. Rutherford's radio detector opened research opportunities including the dinner invitation by Sir Robert Ball, the Lowndean Professor of Astronomy, at King's College. Three months after his arrival at Cambridge, Rutherford made a name for himself in the laboratory with his radio detector and on the social ladder with Ball.

Not all writers viewed Rutherford's ability to pick up and drop scientific research as beneficial. According to Crowther (1952, p. 57), Rutherford once said scientists should know when to start and when to stop research. Furthermore, a great researcher should know an exhausted subject, the readiness of a subject for further scientific inquiry, or when the researcher's skills do not suit the subject. In other instances students should become aware of the bias demonstrated by their school. As an example, Crowther (1952, p. 57) referred to the German school that favored wave-theories over particles, which kept Goldstein and Hertz from determining cathode rays as the latter. Rutherford could determine his own limitations and abilities as a researcher enabling him to stop research whenever he thought necessary. After a short-term thought of selling his invention for profit, Rutherford dropped the magnetic detector to work with Thomson on the gases produced by x-rays.

Crowther (1952, p. 57) described Rutherford's change in research as having "profound significance." Although Rutherford succeeded in demonstrating his own invention from New Zealand with the added benefit of possibly making a fortune from his efforts, he changed direction; instead of leading, Rutherford followed the leadership of another. Crowther (1952, p. 57) explained this incident as the "fundamental humility and social discipline" of Rutherford. Crowther believed this quality of Rutherford separated him from other students.

The New Zealand native traveled nearly halfway around the world to study at the Cavendish under Thomson. This determination, as Crowther (1952, p. 57) indicates, dictated Rutherford's passing up of financial gain in order to continue his studies and research. Rutherford's quick acceptance by his Cambridge professors allowed him to achieve acceptance from the Cavendish junior members. Rutherford embarked with Thomson on a new study, which no one at that time knew anything about, including the junior members.

In the late nineteenth century, scientists observed radioactivity, the emission of α, β, and/or γ rays (particles), in certain elements, creating the field of nuclear physics. Only financially established European institutions contributed to the new research field until the early 1930s. Prior to this discovery, physicists studied radio waves and electromagnetic waves. In 1895, Wilhelm Roentgen (1845-1923), at the University of Munich produced the first x-ray (Nobel Prize Foundation, 1967b). A year later Henri Becquerel (1852-1908), a professor at the Paris Museum, discovered the fluorescing of crystals in uranium (Nobel Prize Foundation, 1967a). Becquerel's discovery inspired new experiments using Roentgen rays.

Rutherford experimented, according to Crowther (1952, p. 58-59), in wireless telegraphy with a magnetic detector at Cambridge until he started research on gas ions with Joseph John (J.J.) Thomson (1856-1940). Roentgen's tube aided Thomson and Rutherford with their discovery method of ionizing gases, and then Rutherford turned to examining ions produced by Becquerel rays. Becquerel's discovery of radioactivity in 1896 prompted Rutherford, already an accomplished student under Thomson, to change his research focus from electrical properties of gases to the new physics field. Rutherford concentrated his research efforts in radioactivity for his remaining time at the Cavendish and continued at McGill University. Discoveries from Pierre and Marie Curie escalated the curiosity in radioactivity with their radium observations. Radium, an element more radioactive than uranium, made research studies easier to conduct in laboratory experiments.

In *Discoveries and Inventions of the 20th Century*, Crowther (1966) focused on the growth in radioactivity research as physics mixed electrical conductivity in gases and electron physics. From this point x-rays included "classical electricity and magnetism," a scientific study dating back to research conclusions in the early nineteenth century (Crowther, 1966, p. 395). Using radium, Rutherford found and identified three distinct radiations named α, β, and γ rays. The α-particles carried a positive charge that was twice the charge of an electron, and was four times as heavy as a hydrogen atom. Rutherford had discovered ionized helium atoms.

Crowther (1966, p. 395) described Rutherford's diverse educational background and boldness in the laboratory by writing, "He was in a perfect position to look at new phenomena in a new way." The view of radioactivity changed as Rutherford studied the newly discovered α-particles as they passed through atoms. Rutherford's views of the α-particles drastically differed from Thomson's, and the differences were seen as both physicists described their own α-particle structure. Thomson described the atoms, in which α-particles pass through, as having a "positive sphere of electrification in which electrons were embedded." (Crowther, 1966, p. 395) If applied to testing the α-particles in Thomson's atom, they would only deflect slightly. Rutherford identified the α-particle using his imaginative thinking and his knowledge as he surpassed his own mentor's knowledge in the field.

X-rays caught Rutherford's attention for their unknown physical nature and ability to produce a skeleton image of living people on a screen. Crowther (1966) argued that during this period physics needed a new direction from that of classical physics. Previous theories became increasingly harder to explain new discoveries. Studying a new field of physics, such as x-rays, gave researchers a new field of study, a sign of the end for classical physics.

Others experimented with the new x-rays, but Thomson soon discovered that x-rays made gases electrically conductive. This discovery helped further his previous research interest in the electrical conductivity of gases. By February 1896, Thomson invited Rutherford to help with his newest investigation into how x-rays affect gases during the x-ray process. The x-rays, Thomson found, made gases conductors of electricity because they split the molecules of gases into electrified particles. At this point, unregretful, Rutherford dropped all his research in magnetic detectors to work solely with Thomson on x-rays. (Crowther, 1966)

Thomson and Rutherford presented their results on x-rays to the Liverpool Meeting of the British Association in 1896. The following year Rutherford's demonstration of his magnetic detector was published in the *Philosophical Transactions of the Royal Society*. Rutherford continued working on the x-ray gases by applying voltages, enabling him to measure the velocities of the positive and negative-charged ions. These experiments produced quantitative formulas based on exact measurements, which later enabled Thomson, in 1897, to prove the existence of the electron in and later calculate its mass. Although Thomson's discovery would bring new areas of research for physicists, Rutherford decided to focus his efforts in a different direction away from Thomson's discovery.

In 1897 Rutherford was awarded a B.A. Research Degree and the Coutts-Trotter Studentship of Trinity College. The following year Rutherford ended his work with Thomson by accepting his first professorship. Rutherford continued his quantitative research in the electrical effects produced by uranium radiations and his research to identify α- and β-rays.

McGill University (1898-1907)

In 1898, Rutherford accepted the MacDonald Research Professorship of Physics at McGill University in Montreal, Canada. Whether politics at Cambridge pressured Rutherford or pressure from his fiancée Mary Newton to marry, he took the appointment and continued researching the disintegration of atoms in radioactivity (Robinson, 1942, p. 63). Rutherford's accomplishments grew at each institution throughout his career, but at

McGill he lacked a developed research laboratory with research students to help carry out experiments. Rutherford continued his research by studying thorium radiations with R.B. Owens, who held the title of Professor of Electrical Engineering at McGill.

Owens found thorium radiations very unsteady and easily affected by air drafts and varying results in the penetration ability of thorium as compared to uranium radiations. Owens' work with thorium puzzled Rutherford. The work of Owens, guided by Rutherford, started the research on examining thorium radiations (Wilson, 1983). Owens and Rutherford published their thorium experiments and outcomes in the *Transactions of the Royal Society of Canada* in May 1899. Over the summer Rutherford coined the term "emanation" to describe the process in which radioactive particles change properties (Wilson, 1983, pp. 136-137).

Owens did not stay long at McGill University, departing for Cambridge and leaving Rutherford to continue research. After a multitude of experiments, Rutherford found radioactive particles emitted from the thorium compounds. The particles kept their radioactive power for several minutes, and were capable of ionizing the gas around the particles (Wilson, 1983, p. 137). The radioactive particles could pass through thick paper and thin metal layers.

Further experiments found the gas absorption rates of α- and β-rays to be proportional to their density. Rutherford found a connection between the fixed quantity of gases and the ions they produced after absorption. His experiments led to the discovery of thorium emanation. Rutherford published the results in "Uranium Radiation and the Electrical Conduction Produced by It" in January 1899 (Wilson, 1983). Besides thorium emanations, the paper focused on uranium radiations, including the 19 different aspects of uranium, another discovery from the experiments.

Rutherford moved his attention from β-rays to α-rays when he found a smaller quantity of β-rays compared to α-rays. During this time Marie (1867-1934) and Pierre (1859-1906) Curie published their work on radiation found in pitchblende. Rutherford concluded the radiation came from the division of a substance instead of a new powerful radiating substance. The Curies later identified the radiation as polonium and radium, not a division of elements as Rutherford predicted. Crowther (1952, p. 62) labeled Rutherford's mistake as "probably the biggest scientific misjudgment that he ever made." Crowther (1952) explained how this difference came from the different research ideologies from each school. In France, research excelled in qualitative discoveries, whereas in British schools research excelled in quantitative.

"Excited radioactivity," coined by Rutherford, described what happened when radioactive particles come in contact with other substances creating radioactivity (Crowther, 1952, p. 64). Rutherford hoped for artificial radioactivity, but instead it became the starting point for identifying the differences between thorium and an emanated thorium compound. Emanation particles, Rutherford found, were not electrically charged when they were moving in an electric field. Instead, emanation particles acted similar to atoms of an ordinary gas.

There were many views as to how the atomic properties of a substance could change when subjected to radioactivity. Marie Curie concluded radioactivity is an atomic property based on the ability of radioactive atoms coming into contact with other atoms. No one predicted the atom could undergo a fundamental change when subjected to radioactivity. When Rutherford discovered emanation, he found a new way for creating radioactivity by adding radioactive substances to taking away atomic particles through disintegration (Crowther, 1952).

Hugh L. Callendar (1863-1930), a former student under Thomson at Cambridge, started his career at McGill prior to Rutherford's appointment. Like Rutherford, Callendar showed great success at an early age receiving a position at McGill five years earlier. Callendar received praise for his improvements to the Siemens thermometer and was elected fellow to the Royal Society in 1894. Rutherford viewed Callendar as an engineer tinkering with equipment rather than a devoted physicist using laboratory apparatus for scientific discoveries (Crowther, 1952). In describing Rutherford's view of scientific research, Crowther (1952, p. 63) wrote, "The kernel of his genius was imaginative, to see the possible explanation of phenomena, and in simple terms which could be tested." Rutherford never spent time improving laboratory apparatus. Instead he concentrated his time and energy on producing results from experimentations (Crowther, 1952).

Rutherford first used his honors physics students and fellow McGill researchers, including Harriet Brooks (1876-1933), R.K. McClung**,** Samuel Allan, A.G. Grier and H.T. Barnes, to help with research (Wilson, 1983). Brooks, a physics honors student, and Barnes, part of the McGill faculty, measured emanation rates from thorium. Barnes worked later with Rutherford in 1904 on radium heating effects. Rutherford published a research paper with McClung on measuring heat and heating effects. Rutherford's first paper at McGill was significant, according to Wilson (1983, p. 131), because it was "Rutherford's first jointly-authored paper with himself as senior partner." Rutherford believed the emanation process came from a chemical change, requiring Rutherford to find a chemist to join his research team in order to test his theory (Wilson, 1983, p. 152).

Rutherford's life changed in the summer of 1900, when he sailed for New Zealand to marry his fiancé of five years, Mary Newton. When he returned to McGill, a young chemist from Oxford, Frederick Soddy (1877-1956), joined the staff in the McGill Chemistry Department. With the lines between chemistry and physics blurring, Rutherford used Soddy's knowledge in chemistry to help him understand the chemical changes in atoms. Soddy devoted all his time at McGill to working with Rutherford to understand the properties occurring during emanation and radiation.

Rutherford and Soddy worked together insisting their discoveries resulted from collaborative efforts, yet Rutherford, Merricks (1996, p. 32) claimed, received the majority of the credits and awards for the discoveries. This is understandable considering the two collaborated in Rutherford's laboratory, their experiments were inspired by Rutherford, and Rutherford held senior partnership in the group. Differences between the two grew after Rutherford received the 1908 Nobel Prize in chemistry. Rutherford never considered himself a chemist, which was the very reason he needed Soddy for the experiments at McGill.

Merricks tried to make sense of these complicated issues that made the two scientists separate, describing Rutherford as a "pragmatic experimentalist, while Soddy, although a brilliant practical chemist, was also a philosopher" (Merricks, 1996, p. 33). After the experiments, Soddy wanted to look at the historical and social significance of their discoveries as they related to the world of alchemy. Rutherford had other ideas for the use of their discoveries, which did not include chemistry. Soon afterward Soddy went back to England to study under Sir William Ramsay.

Crowther (1952. p.43) argued that Rutherford's profound imagination made up for his lack of math knowledge needed for theorizing complex experiments. Rutherford used little philosophical or mathematical theories when conducting experiments, unlike Galileo Galilei (1564-1642), Isaac Newton (1642-1727), Clerk Maxwell (1831-1879) and Gustav Hertz (1887-1975). And unlike the pure theorists Albert Einstein (1879-1955), who used thought experiments, and Max Planck (1858-1947), who used mathematics, to establish new ideas, Rutherford directed his efforts towards spending long hours in the laboratory with experiments (Crowther, 1952). Peers and students of Rutherford saw his imagination, energy and focus in the laboratory.

Rutherford and Soddy first examined thorium alone with a small concentrate chemically separated from the original element. As the radioactivity in the concentrate decayed, the thorium recovered to a non-radioactive state. Radium's discovery made by the Curies explained how neighboring objects became excited by radioactivity. Becquerel, duplicated Rutherford and Soddy's experiments with thorium, found a way to chemically separate uranium, and the separated sources decayed equally. Unlike uranium, thorium could create radioactive properties from within itself as long as the radioactivity was not removed. Rutherford and Soddy published the "Spontaneous Transformation Theory of Radioactivity" in the 1902 *Cause and Nature of Radioactivity*. They connected the rate of decay to the proportional amount of radioactive material. Radioactivity, they concluded, came from a chemical change within the atom transforming the radioactive element (Crowther, 1952).

Once again after a major scientific accomplishment in radioactivity, Rutherford turned his attention to another topic. Crowther (1952, p. 66) remarked that "Rutherford's imagination began to turn from the study of radioactivity itself to the use of it to discover the secrets of the interior of the atom." From results in previous studies Rutherford knew α-rays contained a positive charge, could be deflected by electric and magnetic fields, and had a greater mass than hydrogen. Rutherford concluded the α-rays were in fact "atomic fragments" projected out of the atom during experiments (Crowther, 1952, p. 66). The β-rays, known as electrons, discovered by Thomson in 1897, were not the prominent component in radioactive matter like α-rays. Crowther (1952, p. 66) quoted Rutherford describing the importance of α-rays as playing "the most prominent part in the changes occurring in radioactive matter."

Rutherford secured a liquid-air machine for his research with Soddy in order to liquefy the emanations. Thorium emanation liquefied at -120°C, and radium emanation at -150°C. Their results included the argon gas group and their theory of Radioactive Change, which they published in 1903 (Crowther, 1952). Their paper included their calculations for α-particles and the magnitude of atomic energy in atoms. The rate of energy output allowed them to calculate the half-life of radioactive elements.

Their published work from 1902-1903 made a great contribution to the study of radioactivity; as Crowther (1952, p. 67) described it, "the ideas and the experiments were easily understood, and their novel implications were thrilling." Soddy played a big role in contributing to the success of the research. Crowther described the balance of the two-man team stating Soddy "was strong enough in talent to influence Rutherford and, besides chemical skill, he contributed a speculative quality, which lightened Rutherford's exceedingly power imagination, relentlessly bent to the demands of experimental procedure" (1952, p. 67). Rutherford constantly worried about counterparts in France, Becquerel and the Curies, publishing their discoveries before him since his publications took a month to travel from McGill to London (Crowther, 1952).

Rutherford's first book, *Radioactivity*, was published in 1904, along with various lectures from the Silliman Lectures at Yale University published under the title *Radioactive Transformations* in 1906. In 1905 Rutherford received the Rumford Medal, including a £1000 gift, from the Royal Society "in recognition of an outstanding important recent discovery in the field of thermal or optical properties" (The Royal Society, 2005).

In 1905, Otto Hahn (1879-1968) joined Rutherford's research team at McGill University. Hoffmann (Hoffmann and Cole, 1993), a biographer of Hahn, expressed the important relationship between student and mentor. Hoffmann (1993, p. 39) described the relationship between Hahn and his mentor Rutherford as open and helpful. In describing the atmosphere of Rutherford's laboratory, Hoffmann stated, "Rutherford's institute was unconventional and friendly. The liberal deep discussions about only factual arguments Hahn felt stimulating." To explain Rutherford's personal influence on Hahn, Hoffmann (1993, p.40) said, "Rutherford's bubbling enthusiasm for scientific research and his joy at work were proverbial, and awoke in Otto Hahn the love of science and a restless spirit of research." Hahn continued his research at the Chemistry Institute of Berlin University less than a year later.

Rutherford introduced Hahn to radioactive thorium during a speech given to welcome newcomers to the McGill physics research department. During this time

Rutherford focused on α-particles emitted from radioactive thorium. Rutherford and his research students counted the number of α-particles that collided with a fluorescent screen, known as the scintillation method. Hahn published their radioactive thorium scintillation results, titled "On Some Characteristics of the Alpha Rays of Radio-Thorium," in the *Philosophical Magazine* of June/July 1906 (Hoffmann, 1993, p. 38).

Rutherford introduced Hahn to his next scientific problem: to find the charge to mass ratio of α-particles. They found similar particle masses, regardless of the radioactive element. Their results were published in the October 1906 issue of the *Philosophical Magazine*.

At McGill University, Rutherford researched thorium radiations with Owens then α- and β-rays experiments discovering thorium emanation. His work and leadership role with Owens demonstrated his collaborative efforts, a characteristic Rutherford exercised throughout the rest of his career. Rutherford's research with Soddy, beginning in 1900, garnered attention from the scientific community for his work on α-rays. Rutherford worked with Hahn during his last few years at McGill, but combined with his work with Soddy, Rutherford demonstrated leadership in the laboratory guiding the two research students in radioactivity research.

Universities, including several schools in the United States, offered department research chairs to Rutherford, but Rutherford denied all offers until 1906, when offered the chair at Manchester. Rutherford moved back to England the following year.

Before Rutherford took his new position at Manchester, he traveled throughout the United States to give several lectures, including a short stay in San Francisco, California. In Jacques Loeb's laboratory at Berkeley, Rutherford reconstructed a famous experiment on parthenogenesis, or reproduction without sexual union, of sea urchins. Demonstrating his mastery of the biology laboratory, Rutherford added chemicals to unfertilized sea urchin eggs, and then watched the sea urchin grow in maturity (Wilson, 1983, p. 205). At this point Rutherford's reputation at McGill for his research in radioactivity inspired students to study nuclear physics as he spoke at universities across the United States.

Manchester (1907-1918)

Rutherford continued his experimental research at the University of Manchester in Manchester, England. Now a Nobel laureate, Rutherford attracted research students to help with his experiments. Rutherford's discoveries at McGill established his reputation, but his Manchester position established his legacy in advising students. Rutherford's open-mindedness to physical inquiry inspired students including Niels Bohr, a student under Rutherford at Manchester. In a letter commemorating Rutherford's achievements, Bohr (1942, p.44) said, "Equally those of us who have benefited from Rutherford's unique gifts as a leader of scientific cooperation have had much occasion to remember his beliefs and hopes regarding the opportunities which science offers for promoting understanding and confidence between individuals from different nations."

Rutherford's reputation in the science community grew with his work at McGill University, but his ability to lead research students, like Soddy and Hahn, solidified his reputation as a research director. This characteristic would flourish at Manchester. Like Bickerton, his former teacher at Nelson, Rutherford made an impact on his students' learning and research. From previous research conducted under Thomson, along with his close associations with teachers back in New Zealand, Rutherford committed himself to advising students in the laboratory.

At Manchester, Rutherford and others in 1908 directed α-particles towards thin pieces of gold foil to measure the deflection of α-particles. Rutherford found Thomson's theory to only work capriciously as the experiments found "an accumulation of slight deflections through impingements on successive atoms" (Crowther, 1966, p.395). Rutherford continued experimenting with α-particles until he found a larger deflection with bigger angles than expected, especially for the atom theorized by Thomson. The team found the α-particles bouncing back when directed towards thin sheets of gold foil. Crowther (1966, p.395) described the situation as bullets being fired at a sheet of paper only to bounce off.

Thomas Royds (1884-1955) worked exclusively with Rutherford at Manchester in 1908-1909. Their collaborative work produced the "first correct spectrum of radium emanation," published in a 1908 issue of *Nature* (Wilson, 1983, p.286). Their work produced conclusive evidence that α-particles were helium atoms. Their results, titled "The Nature of the Alpha-Particle," were published in the February 1909 *Philosophical Magazine*, delayed a year due to Rutherford winning the Nobel.

From these studies Rutherford deduced that the atom's main mass contained a "high positive electric charge" that allowed it to strongly repel the positive α-particle charge. (Crowther, 1966, p.395) In 1911 Rutherford based his nuclear theory of an atom on this study. His theory claimed that electrons circulated around the nucleus, which had a relatively heavy positive charge. In an atom's normal condition, the positive charges in the nucleus balanced the negative charges of the circulating electrons (Crowther, 1966).

When Rutherford arrived at Manchester he inherited a working laboratory and staff, unlike the situation when he arrived at McGill. William Kay helped with laboratory set-ups, diagram preparations, and the handling of radioactive substances (Andrade, 1962, p.30-31). Kay and a young laboratory assistant from Germany, Hans Geiger (1882-1945), remained at Manchester for Rutherford. Geiger worked with Rutherford in the laboratory researching the α-particle. Manchester purchased three hundred milligrams of radium in 1908, allowing Rutherford to continue research in radioactivity (Andrade, 1964, p.103). Rutherford worked with Geiger creating the Geiger counter in 1913.

Rutherford and Geiger's α-particle research produced underlying knowledge for further research studies. They increased measurement accuracies in the particle charges released by radioactive elements such as radium. This allowed them to find the electronic charge of the element in its natural state. The two-man team measured the electronic charge, *e*, more accurately than anyone before them. Later in 1908, the two developed a method for counting single alpha particles. This method, called the scintillation method, required the researcher's eyes to adjust to complete darkness (Crowther, 1952, p.71). The researcher sat in complete darkness at least half an hour before starting the experiments in order to see the small flashes of light.

Rutherford completed this research within his first year at Manchester. The small monetary prize Rutherford received in early 1908 from the Academy of Sciences of Turin did not compare to the nearly £11,000, or $20,000, award for the Nobel Prize in Chemistry in November. In typical Rutherford humor, his speech focused on his research as it dealt with transformations on an atomic level. He then equated it to his own sudden transformation from physicist to chemist (Andrade, 1964, p.108).

After receiving his Nobel Prize at Stockholm, he continued his α-particle research. In 1908, Geiger applied the scintillation method to measuring the scattering of α-particles using photographic plates Rutherford devised back at McGill. A new research student, Ernest Marsden (1889-1970), aided Geiger in the laboratory. Fleming (1971, p.464), author of a biographical memoir of Marsden, wrote "Rutherford immediately suggested that Marsden, under Geiger's direction, should examine whether any α-particles were scattered through large angles from a metal surface." Geiger and Marsden demonstrated how α-particles were capable of traveling backwards. Rutherford saw this discovery as one of the greatest achievements in his life. From one of Rutherford's last lectures, Andrade (1964, p.111) quoted his professor as once saying, "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you."

Geiger and Marsden's complex research results, completed in 1909, took Rutherford two years to process in order to formulate a theory. Rutherford responded to Geiger that he could imagine the structure of an atom. He put Geiger back to work in order to test his theory.

Rutherford's nuclear structure of the atom shaped the modern study of nuclear physics. To explain both the chemical properties of matter and the radioactivity of atoms required the knowledge of chemistry and physics. In explaining the difference between the two studies, Crowther (1966, p.395) noted, "the chemical properties of matter depended on the electrons outside the nucleus, while radioactivity, which was independent of the chemical properties of atoms, depended on the nucleus." The ability to explain the processes going on in the laboratory grew more difficult requiring collaboration between physicist and chemists, similar to the work completed by Rutherford and Soddy.

By 1911, Rutherford's image of the atom required laboratory research to garner scientific credibility. To complete the laboratory work, Rutherford appointed Geiger, Marsden and Charles Darwin (1887-1962). Darwin worked on the mathematical evidence to back their experiments, and later helped Rutherford with a mathematical problem developing Rutherford's theory on the hydrogen atom.

At the request of Rutherford, Marsden came back to Manchester, leaving his position at Queen Mary College in London. Marsden projected α-rays at hydrogen causing some hydrogen atoms to move, an incident later called playing marbles (Eve, 1939, p.232). Marsden discovered how larger atoms passed momentum to smaller atoms. According to Eve (1939, p.232), Marsden's work might have helped Rutherford adding, "Perhaps this effect simmered in the mind of Rutherford and helped towards the nuclear theory, and to the greater transmutation work of 1919." Marsden and Geiger published their results in the 1913 *Philosophical Magazine* giving credit to Rutherford's theory and leadership (Wilson, 1983, p.305).

Not all of Rutherford's theories were as successful as his work with Geiger and Marsden. Working with Edward Andrade (1887-1971) and Harold Robinson (1889-1955) in 1913-1914, Rutherford used β- and γ-radiations to look for atomic structures to complement research conducted on α-particles. Andrade succeeded Moseley at Manchester and led experiments modifying the Bragg method of x-ray crystal reflections.

Less significant than α-ray, their research on β-rays produced several published papers for the young researchers under Rutherford (Wilson, 1983). In 1914, Andrade left Manchester and his work with Rutherford when he received a military commission as an artillery officer during World War I. Rutherford's lasting influence on Andrade became evident when the student decided to write a book about his time spent with his professor, for "the inspiration which he felt from his contact with Rutherford led him to write a book, *The Structure of the Atom*, a standard work on the subject" (Cottrell, 1972, p.3).

James Chadwick (1891-1974) was another student Rutherford made a long-lasting impact on. Chadwick started his education at Manchester at 16 as a prospective mathematics or physics student. In a memoir of Chadwick, biographers Massey and Feather (1976) described Chadwick's education. During his second year at Manchester he took an electromagnetism course taught by Rutherford. The third year course required the execution of a physics research project. Rutherford gave Chadwick "the task of developing a method for assaying radium" (Massey & Feather, p.12). Chadwick graduated with a Master of Science in 1913. Like Rutherford, he won the Exhibition of 1851 Senior Research Studentship award, requiring the winner to continue his research at another institution. Chadwick attended the Reichsanstalt in Berlin to continue his research efforts with Geiger.

German universities, unlike the British research schools, offered students a chance to earn a Ph.D., drawing many of Rutherford's students after completing their experimental research at Manchester. By 1918, the British schools adopted the notion of offering a Ph.D. in order to compete with other nations, and to meet growing demands from students (Ashby, 1963, p.22).

Wilson addressed Rutherford’s ability to attract the greatest students in radioactivity: Niels Bohr (1885-1962) and Henry Moseley (1887-1915). Wilson (1983, p.307) said, “if the director of a modern research laboratory had recruited two such men in a life-time of work he would be regarded as a genius for that alone.” Moseley had previously worked with Darwin passing x-rays through crystals to demonstrate the work done by the father and son team of William Henry Bragg (1862-1942) and William Lawrence Bragg (1890-1972) at Cambridge, to prove that x-rays were actually waves.

After returning to Manchester from the first Solvay Conference at Brussels, sponsored by Ernest Solvay, in which Rutherford met Einstein and Max Planck, Rutherford met a young physicist Niels Bohr. Bohr, from Denmark, showed interest in studying radioactivity at Cambridge and met with Rutherford to discuss radioactivity’s future. Moore (1966) wrote that Rutherford’s ability to recruit Bohr away from Cambridge for his own institution demonstrates Rutherford’s ability to assess research talent.

Bohr, under Rutherford’s advice, enrolled in a class on experimental methods of radioactive research taught by Geiger, Marsden, and Walter Makower (1879-1945) (Moore, 1966, p.39). The course discussed the structure of the atom and the experimental methods behind them. To help gain experience in the laboratory, Rutherford would gather all the research students each afternoon for tea as they conversed about physics and life. As an empiricist, Rutherford taught in his laboratory that all knowledge came from experience, including ideas. Rutherford allowed everyone to add their own opinion, even the new research student Bohr. Bohr discussed the implications

Rutherford's atom could make when arranging elements in the periodic table based on the element's properties, such as dividing them into solids and gases.

Bohr suggested many radical ideas, but his greatest idea came out of a problem another young researcher faced separating some radioactive materials (Moore, 1966, p. 40). Rutherford assigned George von Hevesy (1885-1966), who followed Rutherford from McGill to Manchester, to separate the materials, but Hevesy found the separation of the material impossible. Hevesy decided to devise a way to understand why the material would not separate by comparing the radioactive material to the materials non-radioactive counterparts. Bohr, hearing of Hevesy's problem, combined Rutherford's atom theory with the problem (Moore, 1966). Bohr believed the materials only differed in the nucleus holding the same number of circling electrons. From this he concluded that the elements became inseparable because an element's chemical property gives it the number of electrons, but if they contain the same number of electrons they are chemically identical. This meant the elements were inseparable. Lacking any physical evidence, Rutherford did not accept Bohr's theory, citing his distrust in theorizing without experimenting.

Rutherford used an inductive method of science when understanding nature. This characteristic of Rutherford is predominately visible when Bohr announced a theory to Rutherford, yet lacked any physical evidence to support it. Rutherford performed scientific experiments and proposed his ideas based on results.

Bohr's theory would soon find physical evidence after an independent discovery from Soddy, Kasimir Fajans, and A.S. Russell (Moore, 1966). Their discovery found that elements could transform chemical properties to the next element on the period table when they emit a β-particle. The loss of one negative charge produced a gain in one positive charge. The same principle applied to α-particles meant the loss of two in atomic number of that element. Bohr's theory finally had physical evidence. While Soddy received the attention and praise from the scientific community for the discovery, Bohr continued to study under Rutherford at Manchester.

Bohr studied the new discovery to identify how the atom's nucleus could be at the center of radioactivity. Bohr considered electrons circling the nucleus and that the electrons would determine the structure of the element along with its properties. Contrary to the popular notions discussed in the laboratory, Bohr used thermal radiation and light theories, called "quanta" first proposed by Planck and Einstein (Moore, 1966, p.43). Bohr used quantum theory to show the placement of electrons circling an atom's nucleus, but in a fixed orbit, unlike Rutherford's original model.

Like Rutherford, Bohr used every aspect of his education when trying to formulate theories. Bohr sought Rutherford's approval for a paper demonstrating the connectivity between Rutherford's atom and quantum physics. Bohr determined that electrons circle an atom's nucleus without losing energy, this time arming his theory with mathematical calculations. Bohr's proposal, accepted by Rutherford, questioned the differences between one element and the next element (Moore, 1966).

Bohr left Manchester, but his work with Rutherford created profound effects in nuclear physics. Bohr applied Rutherford's atom to theories first used by Planck and Einstein, different from Newtonian physics. Electric charges of the nucleus govern how electrons configure around the center, enabling Bohr's discovery to explain the facts in Mendeleev's Periodic Table of the Elements. For researchers, spectroscopy made a little more sense as Bohr's theory aided in the study of observing and measuring spectral lines.

Hevesy was a student intellectually comparable to Bohr, and started at Manchester about the same time. Hevesy started his academic career at Manchester in January 1911, by measuring radioactivity. Hilde Levi (1985), author of *George de Hevesy: Life and Work*, referred to the first encounter between Hevesy and Rutherford. As proposed by Rutherford, Hevesy determined the solubility of actinium emanation in water, his first task at Manchester. According to Levi (1985, p.23), this was very difficult for anyone to accomplish since actinium had a half-life of four seconds. Hevesy's second task, again given by Rutherford, separated radium-D from pitchblende. Hevesy often referred to his second task as a humorous story for young researchers dealing with complicated tasks (Levi, 1985, p.23). The results from his second task started his career in radioactivity. Hevesy, unable to separate chemically identical elements, eventually traced elements using radioactive isotopes. Rutherford's discovery of the atomic nucleus aided Hevesy's understanding of chemically identical elements with different atomic weights. Levi (1985, p.24) described Hevesy's time under Rutherford:

> Aside from the immense influence of Rutherford and his school on the scientific career of the young Hevesy, one can hardly overestimate the imprint they made on Hevesy's personal development. Rutherford's personality and his approach to scientific as well as to personal and political questions put his stamp on his co-workers, many of whom were – or grew to become – outstanding scientists and very special characters.

Moseley studied under Rutherford's after graduating from Oxford in 1910. He studied under Rutherford's guidance for two years before finding his passion in radioactive research. His final research calculations started with relating the atomic weight of the lower elements in the periodic table. In 1912, Moseley started using x-rays to relate the elements from calcium to zinc. Using Z, the number of positive charges in the nucleus as the placement order of elements, Moseley used Rutherford's atom to build the periodic table. Moseley showed that periodic arrangement of the elements depends on the atomic number of an element (Z). He arranged the elements according to their increasing atomic numbers (Heilbron, 2003, pp. 75-77). Unfortunately for science, Moseley was killed in 1915 in action at Gallipoli during World War I.

At Manchester, Rutherford established his legacy in science by using his Nobel fame to attract students and his talents in advising research. Working with Royds, Rutherford starting researching the structure of the atom beginning with the atom's mass. Geiger and Rutherford fired the α-particle at thin gold sheets, and with Marsden found the particles bouncing back. Two years later, in 1911, Rutherford formed his theory on the structure of the atom on these results. Finishing research on β- and γ-radiations, Rutherford published research conducted with Andrade and Robinson. Bohr came to Manchester in 1912, and in 1913 produced his theory of electrons circling the atom in a fixed orbit based on quantum mathematics. Hevesy conducted several research experiments proposed by Rutherford. From one of his experiments Hevesy separated chemically identical elements using radioactive isotopes. Moseley, after studying under Rutherford's research guidance for two years, embarked on his own research establishing the order of elements in the periodic table based on the atomic number of each element. Rutherford's success at Manchester proved his ability to produce scientific research and his ability to lead students.

The Cavendish Laboratory (1919-1937)

In 1919, after World War I, Thomson retired from the Cavendish, giving Rutherford the coveted position (Heilbron, 2003). Rutherford became the fourth Cavendish Professor of Experimental Physics at the University of Cambridge, in charge of all teaching and research. Rutherford made the post-war Cavendish Laboratory functional for scientific research by creating research initiatives in radioactivity. He directed a campaign to start recruiting faculty and staff needed for the laboratory.

The newly formed Department of Scientific and Industrial Research (DSIR) gave some financial resources. Rutherford's other task of recruiting credible researchers seemed more problematic as Rutherford looked for help from his former students. Bohr remained in Copenhagen, but Chadwick, who left prior to the war, returned from Germany, becoming the Cavendish's Assistant Director for Research from 1919 until he left for a professorship at the University of Liverpool in 1935 (Heilbron, 2003).

Heilbron (2003) claimed that Rutherford's new position in science made more progress securing the future for nuclear physics than towards physical research. Many of his students gained fellowships, grants, and professorships to continue research. Three of the students attending the Cavendish under Rutherford's direction earned a Nobel Prize, making Cambridge the center of physics in the world. Female enrollment at the Cavendish improved, especially after the war, under Rutherford's direction (Heilbron, 2003).

Rutherford continued researching α-particles using the radium obtained from Vienna. With Chadwick, the two worked on experiments colliding α-particles with radioactive nuclei. After careful consideration of the many possibilities from the experiment results, Rutherford found the emitted particles before disintegration in the nucleus started. This agreed with the nuclear structure of an atom he first proposed in 1911. Rutherford looked for the neutral charge in the atom, but in the wrong place thinking it was gamma radiation. In 1932, Irene Curie (1897-1956) and Frederic Joliot

(1900-1958) discovered the neutral particle in their Paris laboratory, but did not realize what they had in their results (Heilbron, 2003, pp.109-110). Chadwick quickly replicated their experiment at the Cavendish. The 1932 experiment resulted in neutrons ejected from the nucleus, proving Rutherford's atomic model that the nucleus contained neutrons.

Patrick Blackett (1897-1974), a recent Cavendish graduate, stayed to work with Rutherford as a researcher until 1933. Rutherford worked briefly with Blackett as they researched the interaction between hydrogen gas and α-particles (Heilbron, 2003). Rutherford continued the research with Charles D. Ellis (1895-1980) (Wilson, 1983, p. 448). Ellis came to the Cavendish as a junior research officer in 1922, working with Blackett and Chadwick. Rutherford's book, originally titled *Radioactive Transformations* (1911), was revised with assistance from Chadwick and Ellis. With their contributions added, Rutherford renamed the book *Radiations from Radioactive Substances* (1930) (Mackintosh, 1995, pp. 227-228). Rutherford played a role in Ellis's success in founding nuclear spectroscopy. In a 1995 speech to the Royal Society, Mackintosh (p. 290) stated "Like many of Rutherford's students, Ellis was fortunate in being given a research project with the potential of leading to a major advance in physics." Ellis contributed his research success, the method of using nuclear spectroscopy, and direction to Rutherford.

During a speech about his time at Cambridge, Blackett (1962, p.107) described Rutherford as possessing "great physical energy and power of work and concentration – without these even his experimental genius could not have borne such fruit." To help guide his students' research, Rutherford reviewed their completed laboratory results.

Blackett (1962, p.110) recalled the years at the Cavendish when Rutherford, already pressed with other duties, would "give the new student a fertile problem, leave him to it for a year or two, ignore all the years of travail, but welcome the eventual results with enthusiasm."

Mark Oliphant (1972), a former student of Rutherford, recalled his first research work with John Cockcroft (1897-1967) in *Rutherford: Recollections of the Cambridge Days*. Cockcroft joined the Cavendish as a research student in 1925, working on vacuum glass equipment, a similar field in which Oliphant researched. Cockcroft shared laboratory space with another newcomer to the Cavendish, Ernest Walton (1903-1995). Rutherford persuaded Cockcroft to work with Peter Kapitsa, a Russian researcher at the Cavendish, in discovering magnetic fields, which found a use in engineering applications (Oliphant & Penney, 1968).

Rutherford suggested to Walton, along with Thomas Allibone (1904-2003), to research electron accelerations in a glass tube, but each attempt failed. Guy Hartcup and Allibone (1984), authors of *Cockcroft and the Atom*, viewed Walton's contribution to the Cavendish as an important step in the new age of nuclear physics. In 1928, Walton proposed to Rutherford the method of linear acceleration using cesium ions (Hartcup & Allibone, 1984, p.39). The method accelerated positively charged particles in a chamber, and through the next four years Walton added other mechanisms to the accelerator including a small magnetic energy booster. Physicists later called this apparatus a cyclotron.

In 1929, Cockcroft studied the wave-mechanical theory of Russian theoretical physicist George Gamow (1904-1968), realizing that bombarding light atoms with artificially accelerated protons would produce nuclear disintegration. Rutherford gave the green light on Cockcroft's proposal to produce millions of disintegrations using the wave-mechanics theory. Walton worked with Cockcroft in assembling the needed pieces for the experiment, including an accelerator tube developed by Allibone (Heilbron, 2003).

The two continued manipulating the accelerating tubes until finally an impatient Rutherford wanted results. In April 1932, their experiments produced α-particle scintillations, first witnessed by Walton then later by Cockcroft. Rutherford confirmed their discovery and they immediately began writing a letter for publication. Walton and Cockcroft started the new age in nuclear physics involving a cyclotron (Heilbron, 2003, p. 114-115, 118).

From this point, nuclear physics and the instruments used to study radioactivity changed forever. Rutherford's era in simplistic nuclear physics modeling was over. In order to study nuclear physics, researchers required complex instruments and machines. The apparatus Rutherford used for research grew in size, complexity, and power. The Cavendish kept pace in research efforts with world-wide research institutions by acquiring larger particle accelerators that pushed protons to 710,000 electron volts, the same energy as turning on nearly 24 cathode-ray tube color televisions at the same time. Tired of waiting on new equipment, an impatient Rutherford directed Cockcroft and Walton to begin experimentations. Their discovery in 1932 demonstrated the split of an atomic nucleus; the Cavendish, as Heilbron (2003, p.115) described it, was now the center of the world's attention.

Rutherford’s impatience paid off for Cockcroft and Walton. At Berkeley, California, the physics department, led by Ernest Orlando Lawrence (1901-1958), could push protons faster than Cockcroft and Walton, but because they never attempted an experiment with their cyclotron, they failed at discovering first how to split an atomic nucleus. The Berkeley laboratory offered to help the Cavendish build a cyclotron, but Rutherford and Cockcroft elected to keep their method of proton acceleration. The next year, after Chadwick left, Rutherford authorized the building of a cyclotron, but it was already too late for the Cavendish. Heilbron (2003, p.119) estimated, “The delay put the Cavendish two generations of accelerators behind Berkeley at the end of World War II.”

Oliphant, a research student from Australia, had the privilege of working with Rutherford during his last few years of life (Eve, 1939, p. 370). Oliphant originally considered joining other research groups, but after meeting Rutherford he decided to focus on experimental research at the Cavendish instead of the theoretical school in Göttingen, Germany. Their work, with the aid of another research student Paul Harteck (1902-1985), included the transmutation of atoms along with the search for hydrogen and helium isotopes. Before Rutherford’s untimely death in 1937, their results concluded with the discovery tritium.

As director of the Cavendish Laboratory at Cambridge, Rutherford moved from directing individual research to setting long-term goals for a research institution. Unlike his previous positions at McGill and Manchester, Rutherford’s first task was to recruit faculty, staff, and students following World War I. Chadwick rejoined his professor from Manchester to help lead the laboratory. Rutherford worked with Blackett researching hydrogen gas and α-particles, continuing the research with Ellis. Rutherford’s era in basic experiments changed with the introduction of particle accelerators. Cockcroft, Walton, and Allibone bombarded atoms in a artificial accelerator producing nuclear disintegration in 1932. Competing against Lawrence at Berkeley, Rutherford's Cavendish Laboratory split an atomic nucleus first.

Conclusions

Rutherford brought experimental work in radio waves, initially winning him high praise, but soon redirected his research to gas ions under J.J. Thomson. As a student, Rutherford's relationship with teachers and professors produced a mentor-type mentality with a philosophy of open communication between professor and student. At McGill University, Rutherford took on his first role as a professor building the reputation of the physics research laboratory. Rutherford worked with Owens for his first collaborative effort. Others that worked with Rutherford at McGill include Brooks, McClung, Grier, Allan, Soddy, and Hahn. From these students at McGill Soddy and Hahn would win a Nobel Prize. In his 1921 Nobel Prize speech Soddy mentioned his work conducted with Rutherford at McGill (Soddy, 1922, p. 371). Hahn, winning the Nobel in Chemistry in 1944, never recognized Rutherford as a contributor to his success in research; but he did recognize Rutherford's scientific achievements. Rutherford's success in the artificial transmutation of atoms in 1919 started the research direction in which Hahn studied in order to produce a transmutation of uranium in 1939.

He continued experimental research as he moved to his next position at the University of Manchester in Manchester, England. Rutherford continued working in the laboratory, mentoring and advising his research students, but now a Nobel laureate, he attracted more students as compared to his time at McGill. The students at Manchester include Geiger, Royds, Marsden, Hevesy, Darwin, Chadwick, Bohr, Andrade, Moseley, and Robinson. Rutherford's research students helped him discover the nuclear model of the atom and split the atomic nucleus of an atom.

From these students Hevesy, Chadwick, and Bohr won Nobel Prizes in their respected fields. Hevesy won the 1943 Nobel Prize in Chemistry for his application of isotopic indicators. In his Nobel Lecture, Hevesy (1964, p. 9) acknowledged Rutherford's inspiration and leadership in isotope research, while a student at Manchester

Chadwick won the 1935 Nobel Prize in Physics for discovering the neutron and its properties in 1932. In his lecture speech Chadwick (1935, p. 339) credited his discovery to Rutherford's 1920 suggestion of a neutral particle within the atom.

Bohr won the 1922 Nobel Prize in Physics for his theory of the structure of the atom he published while a student under Rutherford at Manchester in 1913. Bohr (1922, p. 7) gave credit to Rutherford in his Nobel lecture stating "The present state of our knowledge of the elements of atomic structure was reached, however, by the discovery of the atomic nucleus, which we owe to Rutherford, whose work on the radioactive substances discovered towards the close of the last century has much enriched physical and chemical science."

After World War I, Rutherford accepted a new position moving him back to his Cambridge in 1919. As the research director of the Cavendish, Rutherford rebuilt British science after the war directing the path of the famed laboratory. By taking a less active approach in individual research, Rutherford maintained a few personal projects. Students at the Cavendish under Rutherford include Blackett, Cockcroft, Ellis, Walton, Allibone, Oliphant, and Harteck.

From the researchers under Rutherford's guidance at Cambridge, three received a Nobel Prize. Blackett received the 1948 Nobel Prize in Physics for his research on cloud chambers. In his prize lecture, Blackett (1948, p. 97) described the first experiments using the cloud chamber. Blackett acknowledged his research started when Rutherford turned from using the scintillation method to using Wilson's cloud method to collide alpha particles with a nitrogen nucleus.

Cockcroft shared the 1951 Nobel Prize in Physics with Walton. Cockcroft received the prize for his experiments at the Cavendish where, along with Rutherford and Walton, he produced transmutations. Cockcroft expanded his research in artificial radioactivity by building the first cyclotron at the Cavendish Laboratory.

Walton, while working with Cockcroft at Cambridge, received the prize for accelerating particles. Walton (1951, p.187), in his Nobel Prize lecture speech, credited the first transmutation of atoms to Rutherford's experiments conducted in 1919.

Starting as a research student under Thomson and then gaining world-wide fame in the scientific community helped Rutherford become the most predominant scientific figure in nuclear physics research. His leadership roles at each institution created the next generation of nuclear physicists. The listed examples of Rutherford's advising given at each institution demonstrate the impact Rutherford made when advising student researchers.

CHAPTER IV

SUMMARY

The content analysis performed using published biographical data on Rutherford and his students provide overwhelming evidence of Rutherford's advising impact on the students under his direction at each institution. At each institution Rutherford followed the advising guidelines defined by NACADA by advising students when choosing a program to develop their potential. Professional and faculty advisors can follow Rutherford's example when advising today's science research student.

An empiricist, Rutherford gained from his experiences with Bickerton at Nelson and his time under Thomson while a student at Cambridge. At the beginning of his career, Rutherford collaborated with other faculty members, undergraduate research students, and graduate students as a professor at McGill University. Rutherford made an impact by leading and conducting the research efforts with each individual. The 1921 Nobel Laureate Soddy and the 1944 Nobel Laureate Hahn started their award winning research under Rutherford's guidance at McGill.

At the University of Manchester, Rutherford expanded his role as an advisor as he attracted students to his lab. Rutherford made an impact on all his students listed, especially for those that received a Nobel Prize. As found in the content analysis, Rutherford impacted the research of Geiger, Royds, Marsden, Darwin, Andrade, Moseley, and Robinson. For Nobel Laureates Hevesy, Chadwick, and Bohr, Rutherford started them in research that ended in the highest level of scientific accomplishment.

Returning to Cambridge University after World War I, Rutherford impacted the future of nuclear physics by advising new areas in research and rebuilding a post-war laboratory with faculty, staff, and students. The content analysis proved Rutherford impacted the research of Ellis, Allibone, Oliphant, and Harteck. The remaining students at Cambridge impacted by Rutherford, Blackett, Cockcroft, and Walton, received the Nobel Prize in their respective fields. In each case the Nobel Laureates based their success as a direct result of Rutherford's impact on their research. Rutherford guided his students based on his expert knowledge in nuclear physics and projected himself as a model for his research students to follow as an example.

Rutherford's advising at McGill, Manchester, and Cambridge is a working model of NACADA's "faculty-only" model. Rutherford demonstrated the two strengths outlined by King in the "faculty-only" model of advising students. Rutherford's education background from Nelson, to Canterbury, and finally at Cambridge, plus his knowledge in radioactivity earning him a Nobel Prize in Chemistry, gave him credibility within the science community.

Conclusions

This study identified the significant achievements made by Rutherford and the advising efforts he gave to students. His advising gave students a directed path in science research based on their abilities and interest in nuclear physics. The "faculty-only" model outlined in this study provides a historical model for current day faculty advisors to follow and a working relationship that professional advisors need to understand when advising research-oriented students. Rutherford's students gave credit to their professor for their success, a perfect example of how a faculty member directs the research efforts of students. By understanding the research field, Rutherford guided his students in directions that developed more understanding of nuclear physics.

Rutherford’s attitude and guidance shaped the research atmosphere at all three institutions. This attitude came directly from his days with Bickerton in New Zealand and Thomson in Cambridge. Rutherford concentrated on experimental research in nuclear physics, laying the foundation for discovering the atom and radioactivity. From these discoveries he gained international fame, giving him a reputation for admitting the best research students throughout European.

Rutherford became more than a physics professor and creator of nuclear physics; he became an amazing advisor to the next generation of nuclear physicists. Because of Rutherford, many students from around the world studied in his laboratories and made significant impacts in science. Lord Rutherford of Nelson inspired and motivated the scientific community by pushing experimental research in radioactivity. His legacy played a role for the next generation of scientific discoveries; including the role of researcher’s in World War I and World War II. Rutherford’s educational background led him to success in an unknown area, inspiring scientists to continue researching atomic physics for the next century.

In a 1954 lecture delivered to the Imperial College Physics Department, Blackett recalled a comparison of Rutherford’s teaching style to that of the French General Napoleon, who once said “There are no bad soldiers, only bad generals” (Blackett, 110). Blackett believed Rutherford never saw bad students, just bad professors unable to inspire their students in research.

Professional advisors and NACADA should consider using historical studies similar to this when explaining the significant impact made by faculty advisors. The dedicated faculty advisors in each department should provide adequate advising based on their research knowledge in the field and their knowledge from working with the individual students.

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APPENDIX A

RUTHERFORD TIMELINE WITH STUDENTS AT EACH INSTITUTION

Educational
Career

1887 Entered Nelson Collegiate School
1893 Earned M.A. at Canterbury College
1894 Earned B.Sc., entered Trinity College, Cambridge
1897 Earned B.A. Research Degree

⇩

1898 McGill University
Macdonald Chair

1899 - R.B. Owens
1899 - 1900 Harriet Brooks, R.K. McClung, Arthur Grier, Samuel Allan
1900 - 1902 Frederick Soddy
1905 - 1906 Otto Hahn

⇩

1907 University of Manchester
Langworthy Professor of Physics

1907 - Hans Geiger
1908 - 1909 Thomas Royds
1908 - 1909 Ernest Marsden
1910 - George de Hevesy
1910 - 1911 Charles Darwin
1909 - 1913, 1919 James Chadwick
1912 - 1913 Niels Bohr
1913 - 1914 Edward Andrade
1913 - Henry Moseley
1913 - 1914 Harold Robinson

⇩

1919 Cambridge University
Cavendish Professor of Physics

1919, 1922 - Patrick Blackett
1924 – John Cockcroft
1922 - Charles Ellis
1925 - 1928 Ernest Walton
1929 - Thomas Allibone
1933 - 1937 Mark Oliphant, Paul Harteck

APPENDIX B

DATA COLLECTION AND ANALYSIS

QUESTION 1

Student: ____________________

Time Period: ________________

QUESTION 2

Author: ____

Title: ____

Chapter: ______________ **Pages:** ________________________

QUESTION 3

Previously Referenced?
☐ Yes ☐ No

Location: ____________________

QUESTION 4

Type of Book:
- ☐ Biography
- ☐ Autobiography
- ☐ General
- ☐ Other

QUESTION 5

Book Topic:
- ☐ Student
- ☐ Rutherford
- ☐ General Science

QUESTION 6

Theme:
- ☐ Direct
- ☐ Indirect
- ☐ Direct Advances
- ☐ Indirect Advances
- ☐ Other

QUESTION 7

Time period with Rutherford:
- ☐ McGill University
- ☐ Manchester University
- ☐ Cambridge University

QUESTION 8

Influence from Rutherford:
☐ Yes ☐ No

Significant scientific achievements:
☐ Yes ☐ No

Personal Remarks made by student:
☐ Yes ☐ No

QUESTION 9

Received Nobel Prize in Science:
☐ Yes ☐ No

Rutherford mentioned in Nobel acceptance:
☐ Yes ☐ No

DATA SET

	Q 1	Q 2	
Student	**Time Period**	**Author**	**Title**
OTTO HAHN	1905-1906	KLAUS HOFFMANN	OTTO HAHN: ACHIEVEMENT AND RESPONSIBILITY
FREDERICK SODDY	1900-1902	LINDA MERRICKS	THE WORLD MADE NEW: FREDERICK SODDY
HARRIET BROOKS	1899-1900	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
R.K. MCCLUNG	1899-1900	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
ARTHUR GRIER	1899-1900	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
SAMUEL ALLAN	1899-1900	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
R.B. OWENS	1899-1900	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
WILLIAM KAY		E.N. DA C. ANDRADE	RUTHERFORD AT MANCHESTER
		E.N. DA C. ANDRADE	RUTHERFORD AND THE NATURE OF THE ATOM
THOMAS ROYDS	1908-1909	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
HARRY MOSELEY	1913	J.L. HEILBRON	RUTHERFORD AND THE EXPLOSION OF ATOMS
	1913	J.L. HEILBRON	H.G.J. MOSELEY: THE LIFE AND LETTERS 1887-1915
GEORG DE HEVESY	1910	H. LEVI	GEORGE DE HEVESY: LIFE AND WORK
ERNEST MARSDEN	1908-1909	RUTH MOORE	NIELS BOHR: THE MAN, HIS SCIENCE
	1908-1909	FLEMING	ERNEST MARSDEN, 1889-1970
	1908-1909	E.N. DA C. ANDRADE	RUTHERFORD AND THE NATURE OF THE ATOM
	1908-1909	ERNEST MARSDEN	RUTHERFORD AT MANCHESTER
	1908-1909	EVE	RUTHERFORD
HANS GEIGER	1907	RUTH MOORE	NIELS BOHR: THE MAN, HIS SCIENCE
	1907	E.N. DA C. ANDRADE	RUTHERFORD AND THE NATURE OF THE ATOM
NIELS BOHR	1912-1913	RUTH MOORE	NIELS BOHR: THE MAN, HIS SCIENCE
	1912-1913	NIELS BOHR	RUTHERFORD OF MANCHESTER
HAROLD ROBINSON	1913-1914	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
	1913-1914	H.R. ROBINSON	RUTHERFORD: LIFE AND WORK TO THE YEAR 1919
E.N. DA C. ANDRADE	1913-1914	COTTRELL	EDWARD NEVILE DA COSTA ANDRADE. 1887-1971
	1913-1914	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
CHARLES DARWIN	1910-1911	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
	1896-1936	EVE	RUTHERFORD
JOHN COCKCROFT	1925	OLIPHANT & PENNEY	JOHN DOUGLAS COCKCROFT, 1897-1967
	1925	MARK OLIPHANT	RUTHERFORD: RECOLLECTIONS OF THE CAMBRIDGE DAYS
	1925	J.L. HEILBRON	RUTHERFORD AND THE EXPLOSION OF ATOMS

	Q 1	**Q 2**	
Student	**Time Period**	**Author**	**Title**
PETER KAPITZA	1925	MARK OLIPHANT	RUTHERFORD: RECOLLECTIONS OF THE CAMBRIDGE DAYS
	1921-1934	LAWRENCE BADASH	KAPITZA, RUTHERFORD AND THE KREMLIN
	1921-1934	ALBERT PARRY	PETER KAPITSA ON LIFE AND SCIENCE
ROBERT OPPENHEIMER	1925	DAVID CASSIDY	J. ROBERT OPPENHEIMER & THE AMERICAN CENTURY
MARK OLIPHANT	1933-1937	EVE	RUTHERFORD
PAUL HARTECK	1933-1937	EVE	RUTHERFORD
PATRICK BLACKETT	1919	J.L. HEILBRON	RUTHERFORD AND THE EXPLOSION OF ATOMS
	1919	PATRICK BLACKETT	RUTHERFORD AT MANCHESTER
	1919	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
JAMES CHADWICK	1919	J.L. HEILBRON	RUTHERFORD AND THE EXPLOSION OF ATOMS
	1919	MARK OLIPHANT	RUTHERFORD: RECOLLECTIONS OF THE CAMBRIDGE DAYS
	1909-1913	MASSEY & FEATHER	JAMES CHADWICK. 20 OCTOBER 1891-1924
CHARLES ELLIS	1922	DAVID WILSON	RUTHERFORD: SIMPLE GENIUS
	1922	MACKINTOSH	THE THIRD MAN: CHARLES DRUMMOND ELLIS
ERNEST. WALTON	1925-1928	HARTCUP & ALLIBONE	COCKCROFT & THE ATOM
	1925-1928	MARK OLIPHANT	RUTHERFORD: RECOLLECTIONS OF THE CAMBRIDGE DAYS
THOMAS ALLIBONE	1929	J.L. HEILBRON	RUTHERFORD AND THE EXPLOSION OF ATOMS

Q 1	
Student	**Time Period**
OTTO HAHN	1905-1906
FREDERICK SODDY	1900-1902
HARRIET BROOKS	1899-1900
R.K. MCCLUNG	1899-1900
ARTHUR GRIER	1899-1900
SAMUEL ALLAN	1899-1900
R.B. OWENS	1899-1900
WILLIAM KAY	
THOMAS ROYDS	1908-1909
HARRY MOSELEY	1913
	1913
GEORG DE HEVESY	1910
ERNEST MARSDEN	1908-1909
	1908-1909
	1908-1909
	1908-1909
	1908-1909
HANS GEIGER	1907
	1907
NIELS BOHR	1912-1913
	1912-1913
HAROLD ROBINSON	1913-1914
	1913-1914
E.N. DA C. ANDRADE	1913-1914
	1913-1914
CHARLES DARWIN	1910-1911
	1896-1936
JOHN COCKCROFT	1925
	1925
	1925

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	180-181
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Student	**Time Period**
PETER KAPITZA	1925
	1921-1934
	1921-1934
ROBERT OPPENHEIMER	1925
MARK OLIPHANT	1933-1937
PAUL HARTECK	1933-1937
PATRICK BLACKETT	1919
	1919
	1919
JAMES CHADWICK	1919
	1919
	1909-1913
CHARLES ELLIS	1922
	1922
ERNEST. WALTON	1925-1928
	1925-1928
THOMAS ALLIBONE	1929

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6, 7, 8	
	122-139, 91-121
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	107-110,
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	109-110, 119
	69-70, 74-77
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	227-228, 290
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	79-81, 85-88
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Q 1		Q3	Q4	Q 5	Q 6	Q 7
Student	**Time Period**	**Previously Ref.**	**Type of Book**	**Book Topic**	**Theme**	**Time Period**
OTTO HAHN	1905-1906	N	B	S	D	MCGILL
FREDERICK SODDY	1900-1902	N	B	S	D	MCGILL
HARRIET BROOKS	1899-1900	N	B	R	D	MCGILL
R.K. MCCLUNG	1899-1900	N	B	R	D	MCGILL
ARTHUR GRIER	1899-1900	N	B	R	D	MCGILL
SAMUEL ALLAN	1899-1900	N	B	R	D	MCGILL
R.B. OWENS	1899-1900	N	B	R	D, I	MCGILL
WILLIAM KAY		Y	B	R	D	MANCHESTER
		Y	B	R	D	MANCHESTER
THOMAS ROYDS	1908-1909	N	B	R	D	MANCHESTER
HARRY MOSELEY	1913	Y	B	R	D	MANCHESTER
	1913	Y	B	S	D	MANCHESTER
GEORG DE HEVESY	1910	N	B	S	D	MANCHESTER
ERNEST MARSDEN	1908-1909	Y	B	S	D	MANCHESTER
	1908-1909	Y	B	S	D	MANCHESTER
	1908-1909	Y	B	R	D	MANCHESTER
	1908-1909	Y	B	R	D	MANCHESTER
	1908-1909	Y	B	R	D	MANCHESTER
HANS GEIGER	1907	Y	B	S	D	MANCHESTER
	1907	Y	B	R	D	MANCHESTER
NIELS BOHR	1912-1913	Y	B	S	D	MANCHESTER
	1912-1913	Y	B	R	D	MANCHESTER
HAROLD ROBINSON	1913-1914	Y	B	R	D	MANCHESTER
	1913-1914	Y	B	R	D	MANCHESTER
E.N. DA C. ANDRADE	1913-1914	Y	B	S	D	MANCHESTER
	1913-1914	N	B	R	D	MANCHESTER
CHARLES DARWIN	1910-1911	N	B	R	D	MANCHESTER
	1896-1936	N	B	R	I	CAMBRIDGE
JOHN COCKCROFT	1925	Y	B	S	D	CAMBRIDGE
	1925	Y	B	R	D	CAMBRIDGE
	1925	Y	B	R	D	CAMBRIDGE
						CAMBRIDGE

Q 1	
Student	**Time Period**
PETER KAPITZA	1925
	1921-1934
	1921-1934
ROBERT OPPENHEIMER	1925
MARK OLIPHANT	1933-1937
PAUL HARTECK	1933-1937
PATRICK BLACKETT	1919
	1919
	1919
JAMES CHADWICK	1919
	1919
	1909-1913
CHARLES ELLIS	1922
	1922
ERNEST. WALTON	1925-1928
	1925-1928
THOMAS ALLIBONE	1929

Q3	Q4	Q 5	Q 6	Q 7
Previously Ref.	**Type of Book**	**Book Topic**	**Theme**	**Time Period**
Y	B	R	D	CAMBRIDGE
Y	B	S, R	I	CAMBRIDGE
Y	A	S	I	CAMBRIDGE
N	B	S	IA	CAMBRIDGE
N	B	R	D	CAMBRIDGE
N	B	R	D	CAMBRIDGE
Y	B	R	D	CAMBRIDGE
Y	B	R	D	MANCHESTER
Y	B	R	D	CAMBRIDGE
Y	B	R	D	CAMBRIDGE
Y	B	R	D	CAMBRIDGE
Y	B	S	D	CAMBRIDGE
Y	B	R	D	CAMBRIDGE
Y	B	S	D	CAMBRIDGE
Y	B	S	D	CAMBRIDGE
Y	B	R	D	CAMBRIDGE
N	B	R	D	CAMBRIDGE

Q 1		Q 8			Q 9	
Student	**Time Period**	**R Influence**	**Sig. Achieve?**	**Remarks?**	**Nobel?**	**Mentioned?**
PETER KAPITZA	1925	Y	Y	Y	Y	N
	1921-1934	Y	Y	Y	Y	N
	1921-1934	Y	Y	Y	Y	N
ROBERT OPPENHEIMER	1925	N	Y	N	Y	N
MARK OLIPHANT	1933-1937	Y	Y	Y	N	N
PAUL HARTECK	1933-1937	Y	N	N	N	N
PATRICK BLACKETT	1919	Y	Y	N	Y	Y
	1919	Y	Y	Y	Y	Y
	1919	Y	N	N	Y	Y
JAMES CHADWICK	1919	Y	Y	N	Y	Y
	1919	Y	Y	Y	Y	Y
	1909-1913	Y	Y	N	Y	Y
CHARLES ELLIS	1922	Y	Y	N	N	N
	1922	Y	Y	N	N	N
ERNEST. WALTON	1925-1928	Y	Y	Y	Y	Y
	1925-1928	N	Y	Y	Y	Y
THOMAS ALLIBONE	1929	Y	Y	N	N	N

Q 1		Q 8			Q 9	
Student	**Time Period**	**R Influence**	**Sig. Achieve?**	**Remarks?**	**Nobel?**	**Mentioned?**
OTTO HAHN	1905-1906	Y	Y	Y	Y	N
FREDERICK SODDY	1900-1902	Y	Y	N	Y	Y
HARRIET BROOKS	1899-1900	Y	N	N	N	N
R.K. MCCLUNG	1899-1900	Y	N	N	N	N
ARTHUR GRIER	1899-1900	Y	N	N	N	N
SAMUEL ALLAN	1899-1900	Y	N	N	N	N
R.B. OWENS	1899-1900	Y	Y	N	N	N
WILLIAM KAY		Y	N	N	N	N
		Y	N	N	N	N
THOMAS ROYDS	1908-1909	Y	Y	N	N	N
HARRY MOSELEY	1913	Y	N	N	N	N
	1913	Y	N	N	N	N
GEORG DE HEVESY	1910	Y	Y	Y	Y	N
ERNEST MARSDEN	1908-1909	Y	N	N	N	N
	1908-1909	Y	N	N	N	N
	1908-1909	Y	Y	N	N	N
	1908-1909	Y	Y	Y	N	N
	1908-1909	Y	Y	N	N	N
HANS GEIGER	1907	Y	Y	Y	N	N
	1907	Y	Y	N	N	N
NIELS BOHR	1912-1913	Y	Y	Y	Y	Y
	1912-1913	Y	Y	Y	Y	Y
HAROLD ROBINSON	1913-1914	Y	N	Y	N	N
	1913-1914	Y	N	Y	N	N
E.N. DA C. ANDRADE	1913-1914	Y	N	Y	N	N
	1913-1914	Y	N	Y	N	N
CHARLES DARWIN	1910-1911	Y	Y	Y	N	N
	1896-1936	N	Y	N	Y	N
JOHN COCKCROFT	1925	Y	Y	Y	Y	Y
	1925	Y	Y	Y	Y	Y
	1925	Y	Y	Y	Y	Y

VITA

Andrew A. Armstrong was born to Danny and Lindi Armstrong in 1978 in Coleman, Texas. After graduating from Coleman High School, he attended Texas A&M University in College Station, Texas, from 1997-2001. He received a Bachelor of Science degree in Journalism and a minor in Earth Sciences.

Armstrong married Jennifer Spurlock in January 2002 and moved back to College Station where he began employment with Texas A&M as an academic advisor for General Academic Programs. He started graduate school in the fall of 2003 to pursue a Master's in Science and Technology Journalism from Texas A&M University under the guidance of Dr. Susanna Priest. After the closing of the Journalism Department at Texas A&M, Armstrong began working with Dr. Ed Walraven and others in order to finish his courses and thesis. He currently works in the General Academic Programs, Texas A&M University, College Station, Texas 77843-4247.