The Role of Inquiry-based Learning in Entrepreneurship Education

By:

Dr. Luke Pittaway,
William A Freeman Distinguished Chair in Free Enterprise
College of Business Administration
Georgia Southern University
P.O. Box 8154
Statesboro
GA, 30460
912-478-5321 (Direct)
lukepittaway@georgiasouthern.edu

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Abstract
This paper introduces a course design that used history and inquiry-based learning to develop science students understanding of invention, innovation and commercialisation processes. First, it explains inquiry-based learning and next it introduces a sample course design explaining the rationale, structure and process. Following on from the introduction a student case study on the development of Taxol is used to show how inquiry-based learning can enhance science students understanding of entrepreneurial processes. The case study provides an illustration of the forms of knowledge gained through the use of inquiry-based learning. Finally, the paper concludes by highlighting the benefits and challenges of this type of course for the students and explains how such a course may provide a different approach for entrepreneurship education targeted at science and engineering students.

Keywords
Entrepreneurship Education; History; Inquiry-Based Learning; Taxol; Invention; Ideas; Commercialisation; Science Students.

Introduction
The purpose of this paper is to provide an explanation of how historical analysis via inquiry-based learning can be used in entrepreneurship education. The paper will explore a rationale for this approach; it will explain the value of history and introduce
inquiry-based learning. The paper will proceed to provide an illustrative case study of a course that used inquiry-based learning. During the case study samples will be used of student output to explain the nature of the learning that can take place and how it can expand science students understanding of entrepreneurial processes. Finally, the paper will conclude by discussing the potential of this approach more generally within entrepreneurship education.

The role of pedagogy has been widely discussed in the literature. These discussions include arguments for and against different teaching methods (Pittaway and Cope, 2007a). Despite these wide-reaching conversations little consensus has emerged on the methods that are most appropriate and in which context they should be applied. This is not surprising and variation in teaching methods should be both welcomed and expected (Pittaway et al., 2009). It is somewhat inevitable that consensus on teaching methods cannot be reached when most educators cannot agree on what ‘entrepreneurship’ is and ‘how best to learn it’ (Gartner and Vesper, 1994). For example, assumptions about ‘entrepreneurship’ made by educators continue to vary widely. Some prefer to apply broad definitions focused on generic ‘enterprise skills’ while others prefer narrower definitions focused on particular aspects of entrepreneurial processes. This variation in conceptualisation permeates programs where significant differences can be observed. Despite the variation many educators accept diversity and introduce courses and programs targeted at different aspects and forms of entrepreneurship (Gorman, Hanlon and King, 1997).

Like definitional issues an educator’s views about ‘how best to learn it’, which are often guided by philosophical assumptions about education (Hannon, 2005), will impact on their preference for particular pedagogies. In terms of learning there are four identified modes of educational design described as ‘about’; ‘for’; ‘through’; and ‘embedded’ which impact on the educators’ views about ‘how best to learn it’ (Gibb, 2002; Pittaway and Cope, 2007b; Handscombe, Kothari, Rodriguez-Falcon and Patterso, 2007). As highlighted elsewhere ‘about’ approaches tend toward traditional didactic methods which are knowledge and content driven (Handscombe et al. 2007; Pittaway and Hannon, 2008). ‘For’ approaches engage in methods (for example simulations) that allow students to acquire essential ‘entrepreneurial’ skills. ‘Through’ approaches engage students in the practice of entrepreneurship and typically use experiential and action learning (Gibb, 2002). ‘Embedded’ approaches look at ways to insert entrepreneurial concepts and forms of learning into existing disciplines so that students can learn alongside their main subject of interest (Handscombe et al. 2007).

As different definitions and views about entrepreneurship education have varied so to have the teaching methods. Most studies explore the role of particular pedagogies and their potential value without reference to wider debates about the nature of ‘entrepreneurship’ and discussions about ‘how best to learn it’ (Pittaway et al., 2009). With this weakness of previous studies in mind this paper will outline next how inquiry-based learning with a historical focus can be used effectively within the ‘embedded’ form of entrepreneurship education. It will do so where the entrepreneurial phenomenon being focused on is the invention and commercialisation process of new technologies.

Inquiry-Based Learning in Embedded Entrepreneurship Education

Science education has seen a general demand for more inquiry-based learning. This increased attention has been driven by the view that science is a question driven open-ended process and the students can gain from such experiential learning (Edelson, Gordin and Pea, 1999). In the entrepreneurship domain it also evident that science students’ main interest tends to be basic science and they are not often interested in the commercialisation process following scientific discovery. Using history as a means to connect students to previous scientific discoveries, and to how they were developed, can be an effective way to enhance both scientific and entrepreneurial understanding. Scientific understanding is enhanced because history can show both what can occur and how it occurs within the discovery process. Entrepreneurial understanding is enhanced because students become
interested in processes when they are linked to their core scientific discipline and are embedded in their ‘way of learning’.

Inquiry-based learning using a historical method can, therefore, be important in the context of entrepreneurship education for science students because it embeds educational practice in a pedagogy that is familiar and appropriate to developing an historical understanding of a subject. Inquiry is viewed as the pursuit of ‘open questions’; questions that cannot be simply answered, that required detailed research. Such inquiry-based learning should be ‘authentic’ to practice and should mirror how learning in practice occurs (Dewey, 1964). The concept of authentic learning usually implies that learners become motivated to acquire new knowledge through their engagement in the subject of study (Edelson et al. 1999). Inquiry-based learning, therefore, describes an approach to learning that is formulated as a process of self-directed learning or research (Brew, 2001). Students conduct inquiries that encourage them to engage with a problem or issue relevant to their particular discipline. The approach used is typically problem-based and often collaborative and designed to offer open-ended problems requiring many responses or solutions (Khan and O’Rourke, 2005). This form of learning tends to be both student-centred and active; requiring autonomous learning, information literacy and critical thinking (Jenkins et al., 2003), and thereby helping the acquisition of general inquiry abilities. For example, students must define and redefine the question, plan and manage the investigation, conduct analyses and report results (Blumenfeld et al. 1991).

Embedding inquiry into a student’s core discipline through historical analysis can thus be seen as an effective way to encourage entrepreneurship education that is meaningful to that discipline. It can enhance entrepreneurship education in a number of ways:

i) Students may benefit from heightened engagement with the subject if the discovery is scientifically meaningful to them.

ii) Inquiry-based course designs can be more attuned to the way students learn in science and engineering subjects and, therefore, are more in line with their expectations about learning.

iii) Inquiry-based learning forces students to learn key concepts about discovery, invention, innovation and commercialisation through the process of inquiry. Students can begin to learn more about these subjects in a less daunting and more emergent way. This is beneficial if they are ‘put off’ by business education or are not particularly interested in these subjects at the beginning.

In the next part of the paper the application of inquiry-based learning in the particular case study is outlined in more detail.

**Inquiry-Based Learning Course Design**

The course design was guided by two factors. Firstly, it was targeted at students on a Science Enterprise Programme coming from Biomedical Science; Physics; and Chemistry. Secondly, the number of students engaged in the course was always likely to be very low making traditional didactic methods impractical. As it turned out only two students selected the course, which was consequently discontinued after its first year. Due to the nature of the circumstances a learning design was needed that enabled the students to learn independently via tutorial support in a subject area (ideas, invention and innovation) where they had little prior knowledge and which was outside of their main educational experience. The solution was to develop a historical inquiry-based learning design using the principles outlined in the previous section of this paper.

In this course design inquiry-based learning was adopted with a historical component. The students were introduced to a local chemical research company who chose a chemical structure and supporting chemical formula (see Figure 1).
The students were asked first to identify what the chemical was and were then asked to undertake a historical analysis of the molecule presenting a detailed explanation of how it was found, developed and ultimately commercialised. The learning objectives for the course were, therefore, for the students to understand:

1) the nature of ideas, innovations and new technologies as critical resources for an enterprise
2) the concept of the marketing mix in the context of technological products
3) the importance of protecting intellectual property rights in new product development

And be able to:
4) evaluate the activities appropriate for the promotion and sale of technological products/services
5) identify the means of protecting intellectual property for technological enterprises

The course design revolved around four important elements: the students working together to solve the problem; academic tutorials focusing on specific research papers about various aspects of ideas, innovation and commercialisation; practical tutorials on research methods and the progress of the inquiry; and, the engagement of the company via mentoring and the reporting of the final conclusions. Consequently, there were four key learning methods used; active experimentation (AE); abstract conceptualisation (AC); questioning insight (QI), and reflective observation (RO) (Kolb, 1984; Revans, 1982).
Figure 2

Inquiry-based Learning Course Structure

WEEK 1
Tutorial 1: Course Introduction
Tutorial 2: The innovation process in science and technology enterprises (AC)

WEEK 2
Visit to the client company
Client sets the research problem (RO)

WEEK 3
Tutorial 1: What is the compound? Who discovered it? (QI)
Tutorial 2: Scientific Invention (AC)

WEEK 4
Tutorial 1: Networks of scientists? Collaborative or individual discovery (QI)
Tutorial 2: The role of networks in scientific innovation (AC)

WEEK 5
Tutorial 1: The role of prior discoveries? (QI)
Tutorial 2: Analysis of infrastructure and institutions in innovation (AC)

WEEK 6
Tutorial 1: How was the discovery accepted? How was it distributed or disseminated? (QI)
Tutorial 2: The role of intellectual property (AC)

Independent work to identify the molecule (AE)
Independent work to researching individual scientists (AE)
Independent work to researching the role of prior technologies (AE)
Independent work to researching the role
The interaction of these aspects can be seen in Figure 2 which highlights the progress of the course according to the tutorial structure and the form of learning encountered. The tutorials involved meetings two hours a week over a ten week period, with two visits to the sponsoring company, one at the beginning and one at the end of the course. The assessment was developed to capture the forms of learning encountered (AE; AC; QI; RO) and to test the learning outcomes. It involved: a group report on the historical analysis of the commercialisation process; a formal presentation to the company as a client at their offices; and, an essay based on the academic literature of the student’s chosen subject.

The course was somewhat innovative in its combination of inquiry-based learning and historical research but it is through the students’ engagement with the problem and the subsequent output from their work which best demonstrates the learning that took place. The next section of the paper proceeds to demonstrate this learning through an abridged case study. The purpose of the case study is to provide an illustration of the learning that took place. The final section of the paper will explore the linkage between the intended learning outcomes, the learning processes applied and the student output as presented.

A Case Study of Inquiry-based Learning: Taxol

Selecting the Focus of Inquiry

The students took about a week to identify the chemical structure set by the sponsoring company’s chemists. It required them to engage in some investigative work and discussions with their chemistry professors to identify the chemical structure and formula as Taxol. The students reported that this early discipline-based challenge was an important motivating factor. It pushed them academically in their core discipline while attracting their interest in their inquiries into the history of the drug and its development. The company’s chemists who were carefully briefed on the selection process chose well. They were given two basic criteria to guide their choice: make it challenging for a fourth-year chemistry student to identify but also ensure the product is relatively well known. The first aspect was
to ensure that it was a professional challenge for the students. The second aspect was to ensure that there was sufficient historical information available for the students to undertake a meaningful investigation. The molecule Paclitaxel (Taxol) was a good choice because there had been three decades of well documented commercial development and there had been a number of challenges during its history. Likewise the length of Taxol’s development, its implications for the development of natural products and its efficacy as a chemotherapeutic agent, make it a significant discovery worthy of study.

This first step in the inquiry process seems important for educators wishing to use this approach. The focus of inquiry must be carefully selected to attract the interest and attention of students in a particular discipline, and therefore, the science behind the discovery needs to originate from the student’s core area of interest. Likewise it must not be too new so that there is insufficient historical information or too obscure making information difficult to find. For non-experts in the core science discipline it may be necessary to ask the students to select the focus of inquiry themselves or ask a discipline expert (in this case the sponsoring company’s chemists) to set the challenge drawing on their discipline-based knowledge.

The Historical Context Influencing Taxol’s Development

The first step that the students take following the initial identification of the subject of inquiry is to explore the initial discovery processes and importantly the historical context of the discovery process. The following extract from the student’s work illustrates this aspect:

To appreciate Taxol’s development it is necessary to be aware of the scientific understanding of cancer. The general consensus is that modern cancer chemotherapy emerged from research in gas warfare during World War II (Goodman and Walsh, 2001). Work on nitrogen mustards led to interest in chemical agents in the treatment of cancer and wartime programmes convinced people that diseases could be eradicated by chemical means.

In the case of Taxol the students learnt the important preconditions for the development of a new technology. Certain conditions were important, for example, chemical approaches to treating disease were considered to offer potential and had been proven through early successes with penicillin and anti-malarial drugs. Other important preconditions necessary for discovery were highlighted during the inquiry as the institutional environment, funding for basic research, political considerations and an ‘important people’. These are highlighted in the following extract:

Until the 1950s there was only limited institutional infrastructure for researching chemotherapy with the exceptions being a small number of private biological research institutes. With the end of the war, cancer chemotherapy research became more widespread. One of the most influential people in implementing this change was Cornelius Rhoads. At the end of the war Rhoads was employed as a Director of the Sloan-Kettering Institute, which was set up in 1945. In his role Rhoads led the institute’s focus on chemotherapy research. The Sloan-Kettering Institute rapidly became the largest private cancer research institute in the US. The existence of the institute is one of the reasons for the change in emphasis, as it helped to raise the standing of experimental cancer chemotherapy research. The general public were also influential in this change as they began to push for something to be done and groups such as the American Cancer Society increased their lobbying of the US government. As a consequence, the US government invested more money into cancer research and the budget of the National Cancer Institute (NCI) increased exponentially from its founding in 1937 and by 1948 cancer had become America’s best funded area of disease research.

The historical context shows some important aspects which the students learnt through their inquiry. For example they learnt that contextual factors needed to be in place...
first for a discovery to occur (Germunden, Heydebreck and Herden, 1992; Hendry, Brown and Defillippi, 2000; Fritsch, 2001). They learnt that institutional structures for collaboration are sometimes necessary for the innovation process to begin (Ragatz, Handfield and Scannell, 1997). They also saw from the historical record that the contextual conditions required the ‘entrepreneurial behaviour’ and scientific expertise of an individual (Cornelius Rhoads), which helped shift the emphasis of technology towards experimental chemotherapy cancer research. Finally, they were able to observe that part of the preconditions included public lobbying and increases in public investment.

**The Development of the Idea**

When the students started to look at the initial idea development process they were able to see the relationships between the historical conditions and the discovery. For example, the increasing budget of the NCI allowed employees such as Jonathan Hartwell, who becomes important in the discovery story, to research their personal areas of interest within chemotherapy (Birkinshaw, 2000; Chesbrough, 2002). The students emerging appreciation of the idea discovery process in this case becomes evident as their research progressed; for example:

An agreement between the NCI and the United States Department of Agriculture (USDA) was signed in July 1960 for the large-scale screening of natural products for potential chemotherapeutic activity. The main instigator of this agreement was Dr. Jonathan Hartwell. As a research fellow for the NCI he worked on the first two natural compounds that were thought to have anti-tumour activity. This sparked his interest in plant folklore which he began to research. Following a research paper he received many letters regarding natural resources with anti-cancer properties. He took these seriously keeping detailed records and to discover the real nomenclature for vague descriptions of plants included in the letters, he turned to the USDA for help.

In this extract it is evident that the students have become aware of the role of strategic relationships, have appreciated the role of an individual’s drive and personal enthusiasm in a subject and have seen how this can drive discovery. They are also starting to observe some of the scientific preconditions for the key discovery (the role of plant extracts) as identified next.

The principal scientist on the cortisone programme was Dr. Monroe Wall, who Hartwell visited in 1957. After much persuasion from Hartwell, over a thousand extracts from the cortisone programme were handed over to the NCI to be screened for anti-tumour activity. After a year of testing, seventeen of these extracts were found to be active. Hartwell then approached the USDA to ask for further help and a formal relationship between the National Cancer Institute and the USDA was established. Hartwell had been so impressed with Wall’s work on the cortisone project, that he out-sourced much of the fractionation and isolation of the extracts taken in the NCI/USDA programme to the newly formed Research Triangle Institute, where Monroe Wall had recently moved to head the fractionation and isolation laboratory. Time would prove that the programme had a poor success rate; the only victory of the screening was extracted two years after the programme began. In 1962 paclitaxel was collected the molecule originated from the Pacific yew tree (*Taxus brevifolia*).

Their knowledge of this process is further enhanced when they began to explore the networks that led to the initial discovery. They identified ongoing personal relationships between Hartwell and members of the USDA as being important (Birley, 1985). In particular they focused on the relationship between Hartwell and Monroe Wall and the expansion of this personal relationship into two formal alliances between the NCI and USDA
and between the NCI and the Research Triangle Institute (Conway, 1995; Bee, 2003; Pittaway et al., 2004).

The Invention Process

Once much of the ground work had been set there was still further scientific work required for the real invention of Taxol to occur and the students discovered this during their inquiry. For example, it is possible to break down the scientific process from their research:

**Step 1: Identification**

In August 1962 the botanist, Arthur Barclay, collected, what was to become, two of the most important samples of the programme. These samples were: stems and fruit, and bark, of the Pacific yew. The stem bark of the tree was found to be cytotoxic on 22nd May 1964 (Goodman and Walsh, 2001).

**Step 2: Isolation of the molecule**

With the identification of the Pacific yew as a source of a potential chemotherapeutic agent, isolation of the active molecule was next. The first samples of *Taxus brevifolia* to be studied arrived at the RTI in 1964. By 1966, at least one year before Taxol was isolated, doctors Wall and Wani wrote to Jonathon Hartwell requesting extracts of *Taxus brevifolia* that they had sent to ‘receive a special priority with the biological screeners’ (Wall, 1998, p.299). This recommendation sparked the RTI into placing a huge amount of research effort into *Taxus brevifolia*. The isolation of paclitaxel proved difficult and it took over two years but was completed in June 1967.

**Step 3: Working out the molecule’s structure**

Now that paclitaxel could be isolated the next stage was to determine the molecule’s structure. The complexity of paclitaxel’s structure is highlighted by the fact that it took a team of skilled scientists many years. At the time of isolation, methods for x-ray crystallography and UV, infra red and mass spectrometries were at an advanced level. NMR spectroscopy, however, was relatively primitive. The lack of advanced NMR techniques caused great difficulty. Dr. Wani’s expertise in recrystallisation finally paid off, when he prepared a sample suitable for x-ray crystallography. To aid him in interpreting the crystallographic data, Dr. Wani enlisted the help of Dr. Andrew McPhail, an expert in x-ray crystallography. The two scientists worked tirelessly until the structure of paclitaxel was finally determined in 1971.

The inquiry for the students, up until this point, shows a traditional scientific discovery process that would be familiar to chemistry students. They also demonstrate here that discovery sometimes requires the existence of previous technological advancement (in the example of NMR spectroscopy). While they have the opportunity to see the role of multiple experts, scientific networks and public funding the progress of discovery is not particularly unique. What happens next begins to display some of the serendipity and chance that can play a role in entrepreneurial processes:

From 1971 to 1974 Wall and Wani made repeated attempts to interest the NCI in obtaining larger quantities of paclitaxel. The NCI, however, were involved with the procurement of new anti tumour agents and the response was that it would be too expensive to extract. Frustratingly for Wall and Wani paclitaxel remained ‘on the shelf’. There it would remain until the unique nature of its mechanism was uncovered.

**Step 4: The mechanism of action**

Its saviour was a young molecular pharmacologist who had taken an interest in paclitaxel. If it had not been for this keen interest, paclitaxel may have sat on a shelf indefinitely. Dr. Wall received a letter from John Douros\(^1\) in August 1978 that
read: ‘Dear Monroe: Can you help this poor girl?’ He found attached a letter from Susan Horwitz asking for some radiolabeled paclitaxel to conduct experiments on. In common with many researchers, Horwitz, a molecular pharmacologist had been hearing reports about paclitaxel. She had managed to obtain only a few milligrams of the substance, which she used to kill cancer cells growing in a culture. Determined to find out how it worked, Horwitz pressured the NCI to obtain more. Eventually Dr. Horwitz was able to secure enough paclitaxel to run tests that revealed its secret, which turned out to be a mechanism completely new to scientists.

The students discover in this part of their inquiry that chance can play a role in discovery. Without the introduction of John Douros and the interest of Susan Horwitz the discovery of Taxol may have died at this point. They then show that the identification of its mechanism of action and its success in causing regression in certain forms of cancer, Taxol became seen as a potential ‘miracle drug’. But then there was yet another scientific set-back. How could paclitaxel be administered intravenously? The students learnt here that the scientific discovery process is not a linear one but an uncertain one driven by chance and unforeseen events. Eventually after a year of searching the NCI manage to dissolve it in a form of castor oil and another two years pass before the Food and Drug Administration (FDA) approve clinical trials in humans. During this point in the inquiry the students are learning some of the key aspects of drug regulation. That you have to conduct trials and that you need to gain approval to do so. They also get to see, as outlined next, how events can impact on the development process:

In October 1981 the Board of Scientific Counsellors of the Division of Cancer Treatment brought to an end the NCI-USDA plant screening programme. The USDA would no longer be involved in plant procurement. The termination of the agreement would cause the NCI problems during the clinical trials, as they had no experience in the procurement of natural products. Clinical trials are usually split into 3 phases: phase I tests for safety, phase II for effectiveness, and phase III is a comparison against standard therapies. The three phases usually follow each other in quick succession; however the clinical trials for Taxol were plagued with supply issues of the active molecule, which caused severe delays. The problems caused by the shortage of paclitaxel prompted the formation of the Taxol Working Group. The first meeting of the Taxol Working Group took place on the 23rd June 1988. The conclusions of the Group led to the formation of a Cooperative Research and Development Agreement (CRADA).

In this part of the inquiry the students begin to learn several important aspects about the development process. They are learning about what is involved in the different stages of clinical trials. In addition, the failure of the joint venture has unforeseen circumstances for the development of Taxol and has consequences later in the commercialisation process.

**The Innovation and Commercialisation Process**

The students learn through their inquiry that the first step in the commercialisation process was the publication of a notice in the U.S. Federal Register for a pharmaceutical partner in the Cooperative Research and Development Agreement (CRADA). They are thus learning the formal steps taken by public agencies in the US when seeking commercialisation partners. The NCI received applications from long-established pharmaceutical companies including Bristol-Meyers Squibb (BMS). The establishment of a commercialisation relationship and the companies involved is highlighted in the next extract from the student’s work:

By the deadline only four companies had submitted a proposal. BMS's proposal included participation by Hauser Chemical, who would be responsible for the bulk supply of Taxol. The agreement was made official on January 19th 1991. BMS
agreed to provide NIH with 17 kilos of Taxol and use its 'best efforts' to commercialise the drug. The NCI and Bristol-Myers Squibb would collaborate on the ongoing and future clinical studies and the NCI would make available the data and results of all Taxol studies. BMS now had all the government funded data related to Taxol. Only one further issue remained the supply of the Pacific yew. On June 19th 1991, Edward Madigan, Secretary of Agriculture, signed a CRADA between USDA Forest Service and Bristol-Myers Squibb, giving BMS exclusive rights to harvest Pacific yew tree from Forest Service lands. The Department of the Interior awarded a similar CRADA to BMS for Pacific yew trees on Bureau Land Management lands.

Interestingly at this point the students are beginning to learn the complexity of commercial relationships and the implications of contracts. Not only did the CRADAs involve the NCI and BMS they also required input from a sub-contractor (Hauser Chemical) and other public agencies (USDA and the Department of the Interior). There were, however, still problems to be overcome in the commercialisation process which the students learnt about. BMS acquired the CRADAs during phase I and II clinical trials but the supply of the raw materials continued to present challenges:

Due to the low concentration of paclitaxel in the bark of the Pacific yew tree a large number of trees were required to yield sufficient amounts of the molecule. Consequently, there was a supply crisis during phase I and II clinical trials and secondly concerns over the mortality of the Pacific yew tree. These concerns led to a petition, as well as, the formation of a group whose sole interest was the fate of the Pacific yew. In addition, at a very early stage in the development of Taxol, the tree’s bark became locked in as the source of Taxol. This had three implications. First, alternative solutions were dismissed as an area of research. Secondly, using bark for the supply of paclitaxel locked bark into the approval procedure. This meant that if all of the clinical trials used bark alone, then new clinical trials would have to be carried out if new methods were developed. Finally, stripping of the bark kills the whole tree. The slow growing nature of the tree means that increased demand for paclitaxel inevitably equates to an increased mortality. The solution was eventually found for the supply and mortality problems and in January 1993 Bristol-Myers Squibb announced the end of Taxus brevifolia’s use in the production of Taxol. To the delight of conservationists a semi-synthetic route to the molecule had been developed.

As the students inquire further into the commercialisation process they discovered both managerial problems and scientific problems. The supply of the Pacific yew caused serious managerial problems and strained relationships between BMS and its sub-contractor, as well as, significant public relations problems for BMS. Further scientific problems and challenges continued to emerge (semi-synthesis and full-synthesis of the molecule) well into the commercialisation and testing processes and these were driven principally by non-scientific needs.

Trade Marking and Patenting

The students learnt that Bristol-Myers Squibb successfully trademarked the name ‘Taxol’ on 20th December 1990 and that they needed to do this with the Trademark Office of the Department of Commerce. This aspect of the study the students found particularly interesting and they gained considerable insights into how companies can use litigation to protect their commercial value. Firstly, the students discovered controversy when the trademark was first secured:

Wall named the compound before its exact structure was known. He used the name drawing on the species of tree Taxus and the knowledge that it contained some alcohol groups. Trade marking of the name, of course, did not go unnoticed,
although the extent of the public criticism did not escalate. A publication in the journal *Nature* urged BMS to surrender the protection granted by the trademark stating that the name 'Taxol' had been in use for over two decades. Bristol-Myers Squibb lawyers swiftly responded to this stating that the name had been used in past had *‘no bearing on whether Taxol is a recognised trademark among oncologists’*.

Here the students begin to pick-up understanding about the role of trademarks and patenting. This awareness was further enhanced via the history of Taxol when they dug more deeply into some of the issues that emerged between competitors in this marketplace. For example, in 1994 there was a dispute between BMS and a Canadian firm Biolyse. The BMS claim was that Biolyse had used the names ‘Taxol’ and ‘paclitaxel’ interchangeably passing off their products as those of BMS. A court judgement in favour of BMS followed and this led to Taxol being trademarked worldwide by BMS. Further disputes and tactics were highlighted during the students’ inquiry. BMS for example tried to delay entrance of generic paclitaxel products entering the market by filing patents on the methods of administering the drug. They sort Orphan Drug status for a version using paclitaxel to treat Kaposi’s sarcoma blocking a competitor’s entrance into the market. The students learnt how BMS filed patents worldwide, filed suits rigorously if they felt a patent was being infringed and used the law to the full extent to protect their market. Further disputes were uncovered between BMS and Biolyse over a cheaper version of ‘paclitaxel’ that Biolyse tried to bring to the Canadian market. This part of the students’ inquiry showed that they could learn significant technical details about patents, trademarks and their effective protection through undertaking an historical analysis despite the fact they were moving increasingly away from their disciplinary base. The next part of the paper will discuss more deeply the learning benefits that science and engineering students gain when they engage in this form of learning design.

**Discussion and Conclusions**

The case study presented shows a comprehensive analysis undertaken by the students about invention, innovation and commercialisation processes within their scientific field (chemistry). The concluding part of the paper, therefore, will draw together a review of this output while reflecting on the earlier pedagogic discussions. It will focus on: the benefits and challenges of this approach, linking together the intended learning outcomes and learning processes, with the students’ learning (as illustrated by their output); and, finally it will discuss the value of inquiry-based learning and historical analysis in entrepreneurship education.

**The Value of Inquiry-based Learning**

Having experienced an inquiry-based design, having observed student engagement with it and having marked student output from it, leads me to a belief in the value of this approach for educating science and engineering students in entrepreneurship. Unpickin objectively why this is so, however, is more challenging. Firstly, the use of self-directed learning and research (Brew, 2001) to explore a problem, in this case the development of a drug, in the students’ discipline provides a level of disciplinary embeddedness and engagement that is greater than many other approaches (particularly didactic). In this case disciplinary embeddedness is derived from researching the commercialisation process of a molecule and learning through this research the steps through which drug development flows (e.g. the different stages of medical trials illustrated in the case study). Engagement is achieved by exploring something for which the student has scientific understanding and can appreciate at a scientific level. Relevance to the discipline would, therefore, seem an important prerequisite when seeking student engagement. A challenge that this can create is the tutor’s knowledge of the discipline. The benefit of inquiry-based learning here is that
the tutor becomes a research coach and mentor and consequently does not need disciplinary specific knowledge.

Secondly, the collaborative and open-ended nature of inquiry-based learning (Khan and O’Rourke, 2005) seems important at a number of levels. Collaborative research endeavour engaging two students in the process ensures ‘research methods’ and ‘information seeking’ skills are not only transferred between the tutor as mentor and the students but also between the students through peer-to-peer learning and from the company mentor to the students. The input of the company as a collaborator in the context of this course design also raised the credibility of the course in the students’ minds. It provided evidence that the knowledge gained on the course was valued and useful within a commercial pharmaceutical research context and motivated the students to impress the client. The open-endedness of the research, which is illustrated by the potential for ever increasing depth in the historical analysis of the particular case, required the student’s to define the problem, the research process and the information requirement. So student-centred learning made the students’ take responsibility for their own learning moving the learning process from a passive to an active design.

Thirdly, as this learning was student-centred and active requiring autonomous learning, information literacy and critical thinking (Jenkins et al., 2003) it enabled the students to gain other ‘skills’ not directly relevant but useful for their general personal and academic development. In this case, for example, the students developed additional research methods and information literacy skills as a consequence of their research efforts. In terms of the learning objectives identified by the course both ‘content’ and ‘skill’ elements of the original objectives were consequently met and the interaction of the learning methods (active experimentation; abstract conceptualisation; questioning insight; and, reflective observation) were important in achieving mutually reinforcing but different learning approaches.

**Inquiry-based Learning in Entrepreneurship Education**

Using a historical inquiry-based design does have some useful educational benefits within the context of science enterprise education. But the question remains what form of enterprise education is it and does it improve on existing approaches (Gibb, 2002)? As the approach used focuses on ‘understanding’; ‘knowledge’; and, ‘awareness’ of commercialisation processes it can be categorised in the ‘about’ form of enterprise education but is also essentially ‘embedded’ as it is fully within the students’ core discipline. A course designed in this way does not principally seek to develop ‘enterprising skills’ or to enable entrepreneurial learning through direct engagement in practice (Gibb, 2002). As a method of engaging in knowledge about enterprise and embedded in a discipline, inquiry-based learning leads to a deeper form of learning when compared to other alternatives. Deeper learning is achieved because students are not only engaged in abstract conceptualisation of innovation and commercialisation processes but because they must understand and appreciate these processes in a particular industrial context. This deeper learning is, therefore, achieved through:

i) reflective observation where students reflect on the history of a particular case;

ii) active experimentation because students must also develop strategies for gaining and organising this knowledge;

iii) and, questioning insight, because the students must question the basis of this knowledge and the assumptions they make during their inquiries.

There are also some limitations to inquiry-based learning. For example, it tends to be more student-centred and can be more costly in lecturer’s time and effort. It may also be argued that it is more difficult to scale and may not be appropriate where educators have to manage large student numbers. Finally, it does depend on the willingness of the students’ themselves to shift ‘mind-sets’ from more passive modes of learning to more active modes. In conclusion, and despite some of these challenges, the experience of inquiry-based
learning outlined in this paper does show that it has many qualities that make it a valuable addition for entrepreneurship education particularly for science and engineering students.

References


Notes

1 Who succeeded Hartwell, on his retirement, as the Head of the Natural Products Section of the Division of Cancer Treatment of the NCI.