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CONTENTS

Graphene and the 2010 Physics Nobel Prize

The 2010 Nobel Prize for Physics has been awarded to professors Andre Geim (51) and Konstantin Novoselov (36). Both were born in Russia and completed their graduate training there, subsequently Andre supervised Konstantin's PhD in Holland and since 2001 both have worked at Manchester University (UK). By their own admission they have a passion for physics and their 'energy and joy' for the subject is recognised in the Nobel citation.

Almost every school-leaver in the world must be familiar with the hexagonal pattern of sheets of carbon atoms that, when stacked on top of one another form the crystal structure of graphite. They will probably also know that these sheets are not strongly bonded together since the ease with which they can slide over each other explains the slippery nature of graphite and its use as a lubricant. However, even though the *idea* of single sheets of carbon atoms (graphene) had been studied theoretically since 1947 it had proved impossible to make the material and many believed that such a preparation could not be carried out because if formed such sheets would spontaneously curl up to form tubes. Almost unbelievably in 2004, Andre Geim and Konstantin Novoselov succeded in separating single sheets of graphene from graphite crystals using a strip of 'Scotch Tape' and were able to transfer these to a silicon surface.

Publication of this breakthrough began an explosive growth in interest in the making and properties of graphene and it is currently being studied intensively. Graphene is the first two dimensional crystal to be prepared and, although Geim and Novoselov did not anticipate widespread applications it is now predicted that its unique properties will probably lead to a multibillion dollar industry over the next five years. Graphene has interesting electrical properties, it is transparent to light but totally impervious to gases, it is the thinnest known material and is hundreds of times stronger than the strongest steel (of equivalent thickness) and is very flexible. Recently it has become possible to fabricate large sheets of graphene. Using near-industrial methods, sheets with a width of 70 cm have been produced. Since graphene is a transparent conductor it can be used in applications such as touch screens, light panels and solar cells, where it can replace the rather fragile and expensive Indium-Tin-Oxide films currently in use.

Figure 1. The model of graphene (dos Santos, 2009).

The New Scientist recently reported a world record for rotating a small chip of graphene trapped in a vacuum chamber and levitated by an oscillating electric field. This was made to spin using a circularly polarised light beam. Rotation speeds of one million revolutions per second were achieved – without graphene's amazing strength the flakes would have disintegrated at this speed.

It has been suggested that since Geim and Novoselov achieved so much using a strip of Scotch Tape and graphite (from a pencil?) that with an improved research budget (using pens, paperclips and super-glue) there may be many other valuable discoveries from their 'blue-skies' research, more applications and possible even more Nobel Prizes.

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A review of research on the history and philosophy of the periodic table

Una revisión de investigaciones sobre la historia y la filosofía de la tabla periódica

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Abstract

The article summarizes the present state of research into the conceptual foundations of the periodic table. We give a brief historical account of the development of the periodic table and periodic system, including the impact of modern physics due to the discoveries of Moseley, Bohr, modern quantum mechanics etc. The role of the periodic table in the debate over the reduction of chemistry is discussed, including the attempts to derive the Madelung rule from first principles. Other current debates concern the concept of an "element" and its dual role as simple substance and elementary substance and the question of whether elements and groups of elements constitute natural kinds. The second of these issues bears on the question of further debates concerning the placement of certain elements like H, He, La and Ac in the periodic table.

Key words: *periodic table, history, philosophy, Mendeleev.*

Resumen

El artículo muestra el estado actual de la investigación sobre las bases conceptuales de la tabla periódica. Damos una breve reseña histórica del desarrollo de la tabla periódica y el sistema periódico, en particular el impacto de la física moderna, debido a los descubrimientos de Moseley, Bohr, la mecánica cuántica moderna, etc. El papel de la tabla periódica en el debate sobre la reducción de la química se discute, incluso los intentos de derivar la regla de Madelung a partir de primeros principios. Otras discusiones refieren los debates actuales del concepto de un "elemento" y su doble función como sustancia simple y sustancia elemental y la cuestión de si los elementos y grupos de elementos constituyen tipos naturales. El segundo de estos asuntos tiene que ver con la cuestión de los debates sobre la posición de ciertos elementos como H, He, La y Ac en la tabla periódica.

Palabras clave*: tabla periódica, historia, filosofía, Mendeleev.*

INTRODUCTION

The periodic table of the elements is perhaps the most natural system of classification in the whole of science. Whereas biological classification is continually debated, the classification of the chemical elements is far more clear-cut as a result of the periodic table, although some disagreements still persist.

The periodic table is a physical representation of two more abstract notions, namely the periodic law and the periodic system, both of which are more fundamental that the familiar periodic table. Nevertheless, the terms periodic table and periodic system will be used somewhat interchangeably in what follows.

Unlike other sciences only chemistry possesses a single chart, the periodic table, which embodies the whole of the discipline both explicitly and implicitly given that new analogies and relationships continue to emerge from it. The periodic law, which underlies the periodic table, represents one of the big ideas in chemistry, along with the idea of chemical bonding, with which it is intimately connected. Not surprisingly, considerable attention has been devoted to the periodic table, and its fundamental aspects, in the philosophy of chemistry.

Before surveying the recent work that has been carried out it is necessary to briefly consider the historical evolution of this icon of chemistry as well as the forms in which it is commonly presented (SCERRI, 2007a). The idea of chemical periodicity is deceptively simple. If the elements are arranged in order of increasing atomic weight, as they were initially, approximate chemical similarities occur after various regular intervals. From this simple idea many far-reaching discoveries have followed concerning the structure of the atom, such as the manner in which electrons are arranged in shells around the nucleus. When discussing the putative reduction of the periodic table to modern physical theories, it is worth recalling that historically speaking it is the periodic table that led directly to many developments in modern physics. In a purely analytical approach to the philosophy of chemistry this fact may be less significant than in the historically informed approach that some authors adopt.

It has long been recognized that the periodic system does not fit into the traditional categories which philosophers of science are accustomed to discussing. It is neither a theory, nor a model nor perhaps even a law of nature in the traditional sense. Yet the periodic system is capable of rationalizing vast amounts of information, and capable of making successful predictions. The philosopher DUDLEY SHAPERE has provided an original analysis of the periodic system in which he concludes that it is rather an 'ordered domain' (SHAPERE, 1977).

Not surprisingly, before the recent advent of philosophy of chemistry, philosophers of science devoted little attention to the periodic system, just as they neglected the whole of chemistry. There are some interesting exceptions, however. As long ago as 1958 KULTGEN produced a philosophical analysis of Mendeleev's ideas and the way in which he established his version of the periodic system (KULTGEN, 1958).

A BRIEF HISTORY

From the early days when chemistry was just a qualitative science, chemists began to group together elements that were similar such as copper, silver and gold, the coinage metals. The beginnings of quantitative chemistry are not easily pin-pointed but they include the stoichiometric studies of LAVOISIER and RICHTER, followed by the establishment of laws of chemical combination and the Gay-Lussac law of combining gas volumes. Dalton's introduction of atomic weights provided a direct means of quantitatively comparing the various elements. For example, Döbereiner discovered the existence of various triads, that is groups of three elements such as lithium, sodium and potassium in which one element is intermediate in terms of chemical reactivity and also in its atomic weight. This finding pointed to an underlying numerical relationship that connects different elements to each other.

In 1860 an international congress held in Karlsruhe served to rationalize chemists' views on the meaning of 'atom' and 'molecule' and also led to a consistent set of atomic weights, the latter being due to CANNIZZARO. With this information in place, the stage was set for the independent discovery of the periodic system by six individuals, culminating in the work of LOTHAR MEYER and DIMITRI MENDELEEV in Germany and Russia respectively.

MENDELEEV receives most of the credit for not only producing the most mature and comprehensive periodic table but for also making predictions on the properties of elements that had not yet been discovered, three of which were amply verified over the following fifteen years. However, recent work in the history and philosophy of chemistry, and general philosophy of science, has reconsidered the extent to which successful predictions contributed to the acceptance of the periodic table by scientists of the time (BRUSH, 1996; SCERRI, WORRALL, 2001).

Several discoveries in physics of the early twentieth century had important consequences for the periodic table, although they have not changed it in any fundamental way. These discoveries include X-rays, radioactivity, the splitting of the atom, elemental transmutation, isotopy, atomic number as well as quantum mechanics and relativity. The discovery of atomic number by van den Broek and Moseley provided a more natural ordering principle that atomic weight which the pioneers had used. The new ordering principle resolved a number of 'pair reversals' such as in the case of tellurium and iodine which occur in the wrong order, in chemical terms, if one follows an order of increasing atomic weight.

Successive developments in atomic structure provided increasingly successful explanations of the periodic table in terms of electronic structure, although in many cases the periodic table led the way to discoveries in atomic structure rather than vice versa. Among these developments Bohr's model of the atom, one of the first applications of quantum theory to atomic structure, deserves special mention. In arriving at electronic configurations of atoms, which are then used to explain why certain elements are grouped together in the periodic table, Bohr approached the problem in a semi-empirical manner by appeal to chemical behavior and spectral data. The Exclusion Principle which has far-reaching implications in all of science was motivated by Pauli's desire to explain the problem of the closing of electron-shells after their occupation by certain numbers of electrons. Although Pauli's approach of introducing a fourth quantum numbers, coupled with the previous work on the relationship between three quantum numbers, provided a fully deductive explanation for this phenomenon this was not the case for the more chemically important fact of the closing of periods. While the explanation of the closing of electron shells is frequently presented in science textbooks as the definitive explanation for the periodic system, the lack of a rigorous derivation of the point at which periods close stands in the way of a full reduction of the periodic system to quantum mechanics, as contemporary philosophers of chemistry have pointed out (Scerri, 2007a).

The advent of a rigorous quantum mechanics in the period 1925-26 provided a more deductive approach to electronic configurations at least in principle. But not until methods of approximation had been devised by the likes of Hartree and Fock did it become possible to solve the Schrödinger equation for any particular atom to a reliable level of accuracy. From this time onwards the electronic configurations of atoms could be deduced in an ab initio manner, a claim that has been disputed by some philosophers of chemistry (Scerri, 2004) but defended by some theoretical chemists and physicists (Schwarz, 2007, 2009; Ostrovsky, 2001; Freidrich, 2004).

FORMS OF THE PERIODIC TABLE

The original pioneer periodic tables generally consisted of eight columns to reflect the periodicity of the elements. These short form tables (figure 1) survived until well into the twentieth century. If elements are arranged in order of increasing atomic weight the approximate repetition in the properties of the elements occurs after eight elements until the element iron (atomic weight 55) is reached. To cope with this apparent break in periodicity Mendeleev was forced to remove sets of three elements such as iron, cobalt and nickel from each subsequent period and to place them into an anomalous group which he called the transition elements and labeled as group VIII.

Mendeléeff's Table I.—1871.

Series.	Group I. R_2O.	Group II. RO.	Group III. R_2O_3.	Group IV. RH_4. RO_2.	Group V. RH_3. R_2O_5.	Group VI. RH_2. RO_3.	Group VII. RH. R_2O_7.	Group VIII. RO_4.
1	H=1							
2	Li=7	Be=9.4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27.3	Si=28	P=31	S=32	Cl=35.5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Ce=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	? Y=88	Zr=90	Nb=94	Mo=96	—=100	Ru=194, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	I=127	
8	Cs=133	Ba=137	? Di=138	? Ce=140	....	....	....	....
9	....	....	....	....	....	....	....	....
10	....	....	? Er=178	? La=180	Ta=182	W=184	....	Os=195, In=197 Pt=198, Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	....	....	
12	....	....	....	Th=231	....	U=240	....	....

Figure 1. Short-form periodic table.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

Figure 2. Medium-long form periodic table.

The next major change in the form of the periodic table occurred when sets of ten elements, rather than merely three, were removed from the main body of the eight column table, thus producing a block of thirty transition elements to which a further ten have been added more recently. The meaning of the term transition element also changed to denote an element whose atoms are in the process of filling inner, rather than outer, electron shells. The placement of these elements is typically made between the so-called s and p blocks or what constitutes the main-body of the former short-form table, and not on the right-hand side as Mendeleev had placed his transition elements. The reason for this placement is to preserve the order of increasing atomic weight, and later atomic number, in what is termed the medium-long form periodic table (figure 2).

Although not predicted, a new group belonging in the modern p-block of elements was discovered at the end of the nineteenth century. These elements are the noble gases helium, neon, argon, krypton, xenon and radon. The net result of this discovery is that although Mendeleev's group VIII became incorporated into the main body of the medium-long form table, a new group VIII emerged to take its place as far as the main-block elements are concerned. This means that the rule of eight of Mendeleev, Abegg, Kossell and the octet rule of Lewis and Langmuir have persisted and continue to provide a simplified explanation for the occurrence of chemical bonding. Although there are many exceptions, there are also many cases in which elements form compounds in order to obey the rule of eight or, in modern terms, in order to achieve a full outer-shell of eight electrons (Palmer, 1965).

Even more recently, especially since new artificial elements were first synthesized in the 1940s, there has been a further change to the overall form of the periodic table. This change is somewhat analogous to the change from the short to the medium-long form in that the inner transition elements, formerly called the rare earths, have been removed to form the f-block, which is inserted between the s and d-blocks, once again to preserve the order of increasing atomic number (figure 3) or often displayed as a footnote. The recent synthesis of elements up to and including element -118, with the exception of element 117, has led to speculation that the periodic table is due to undergo a further expansion to accommodate the g-block

H																														He
Li	Be																								B	C	N	O	F	Ne
Na	Mg																								Al	Si	P	S	Cl	Ar
K	Ca														Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr														Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

Figure 3. Long-form periodic table.

elements which will begin, at least formally, at element -121 (Scerri, 2009b).

Several chemists, metallurgists and geologists have proposed less elegant periodic systems but ones that may better reflect the similarities between elements (Rayner-Canham, 2003). In this context it is also possible to consider a continuum of periodic systems ranging from the chemically more accurate, but less symmetrical formats, at one extreme to the more symmetrical, and more abstract systems such as the left-step table, at the other extreme. Not altogether surprisingly, the currently popular medium-long form seems to strike a compromise between displaying too many chemical similarities while at the same time maintaining much overall regularity, although not going so far as to place the element helium in the alkaline earth group.

DEVELOPMENTS IN PHILOSOPHY OF CHEMISTRY

The very concept of 'elements' that populate the periodic table is the subject on an on-going discussion dating back to the ancient Greek philosophers and their notions about the nature of matter. Is an element to be regarded as a fundamental abstract entity or a physically realized substance or perhaps as both? Mendeleev, the discoverer of the periodic system had much to say on this question and held that the periodic table was primarily a classification of the abstract sense of the elements. There has also been a long-standing debate about how elements persist, if indeed they do, when present in compounds. Contemporary discussions in the philosophy of chemistry are largely based on a much cited paper by the radiochemist F.A. Paneth, who also suggested the current definition of a chemical element that was adopted by IUPAC in 1923 (Paneth, 2003). Paneth's classic paper on the nature of elements was translated by his son, Heinz Paneth, who later changed his last name to Post. The terminology used by Post was 'element as basic substance' for Paneth's Grundstoff and 'element as simple substance' for Paneth's Einfacherstoff. This terminology and it's interpretation has been the source of disagreement among contemporary authors (Earley, 2005; Hendry, 2005; Needham, 2005; Ruthenberg, 2009; Scerri, 2009a; Sharlow, 2006).

Given the interest in the question of the reduction of chemistry in contemporary philosophy of chemistry, the periodic table is playing at least two related roles in such studies. First it provides a more restricted domain upon which to focus the reduction question than 'the whole of chemistry'. Secondly, some authors have claimed that the periodic table does not completely reduce to quantum mechanics (Scerri, 2004), Others dispute these anti-reductionist claims and emphasize that physics provides an approximate explanation of the periodic table (Ostrovsky, 2005; Schwarz, 2007; Friedrich, 2004).

For example, the structure of the modern periodic table is such that the length of successive periods repeat, with the exception of the very first short period of two elements. Some authors have claimed that this feature which is summarized in the Madelung, or $n + \ell$ rule of electron filling has not yet been deduced from quantum mechanics (Löwdin, 1969; Scerri, 2004). More recently Schwarz has claimed that the Madelung rule is somewhat irrelevant since it refers to the ground state configuration of atoms in their unbound gas phase and not to atoms that have undergone chemical bonding (Schwarz, 2007). This brings us back to the question of how to interpret the term 'element' since Schwarz has also claimed that bonded atoms are equivalent to elements as basic substances, a view that has recently been challenged (Scerri, 2009a). Quantum mechanics is by no means the only approach taken in trying to explain the periodic system from first principles. For example, Kais and Herschbach have tried to develop global approaches which promise to 'solve' the periodic table at one stroke instead of needing to solve the Schrödinger equation for each atom separately (Kais et al., 1994).

The periodic system has served as the arena in which one of the most detailed attempts to reduce chemistry to atomic physics has been conducted. In 1985 the Dutch philosophers of science, Hettema and Kuipers, developed what they termed a 'formalization' of the periodic system, and used this as a basis to discuss the reduction of chemistry to atomic physics (Hettema, Kuipers, 1988; Scerri, 1997). Le Poidevin has referred extensively to the periodic table in a study claiming that chemistry does not even reduce to physics ontologically (Le Poidevin, 2005). Two independent criticisms of this article have appeared in the literature (Hendry, Needham, 2007; Scerri, 2007b). On the question of the law-like status of the periodic law, Christie has authored an article on the different ways in which chemists and philosophers regard the laws of nature (Christie, 1994).

A good deal of work exists on mathematical approaches to the periodic system using similarity studies (Sneath, 2000; Restrepo, Pachón, 2007), group theory (Ostrovsky, Novarro, 1973), and information theory (Bonchev, 2006). Some authors have begun to examine the philosophical significance of this work but much remains to be done (Wang, Schwarz, 2009; Scerri, 2009c).

The perennial debate between realism and anti-realism (instrumentalism) has also been discussed in the context of the periodic system. For example some realists regard the elements as natural kinds and even that the elements in any particular group of the table might constitute a natural kind (Hendry, 2009; Scerri, 2005). It has also been argued that to be a realist about periodic system implies that such classification is an objective matter of fact and not a matter of convention, as some chemists often seem to claim (Scerri, 2007a). This question bears strongly on the question of whether there exists an optimal form of the periodic table, even if such a table may not yet have come to light. As a matter of historical fact, over one thousand periodic tables have been published in print media alone and many more via the electronic media. What presumably motivates these variations is the intuition that an optimal form might indeed exist, a, pursuit that is derided by some professional chemists. The latter response seems to reflect the belief that the periodic table rests on only its utilitarian value rather than its representing any form of 'truth' about the elements.

Of course there are many alternative tables that merely use a different shape, or a third dimension, to display the elements. Nevertheless, some variant tables do actually place traditionally troublesome elements like H, He, Al, Ac, La, Lu, Lr in different groups. Such debates among chemists and chemical educators have recently been enriched by more philosophical considerations on the representation of periodicity.

Among other more serious proposals for alternative forms of the periodic table are the pyramidal tables, which highlight so-called secondary periodicities, that were embodied in the original short-form tables. In addition the left-step table (fig. 4) as first proposed by Charles Janet in 1929, has been the subject of much discussion since it is said to reflect the quantum mechanical understanding of the periodic table to a greater extent that the conventional medium-long form table (Bent, Weinhold, 2007; Scerri 2009a). A parallel discussion concerns the precise membership of group 3, an issue that raises many notions that lie at the heart of the modern periodic table such as the nature of electron configurations (Lavelle, 2008, 2009; Jensen, 2009, Scerri, 2009d).

																														H	He
																														Li	Be
																								B	C	N	O	F	Ne	Na	Mg
																								Al	Si	P	S	Cl	Ar	K	Ca
														Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr
														Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg									

Figure 4. Left-step Periodic Table.

Finally, the synthesis of super heavy elements over the past 60 years or so, and in particular the synthesis of elements with atomic numbers beyond 103 has raised some new philosophical questions regarding the status of the periodic law. In these heavy elements relativistic effects contribute significantly to the extent that the periodic law may cease to hold. For example, chemical experiments on minute quantities of rutherfordium (104) and dubnium (105) indicate considerable differences in properties from those expected on the basis of the groups of the periodic table in which they occur. However, similar chemical experiments with seaborgium (106) and bohrium (107) have shown that the periodic law becomes valid again in that these elements show the behavior that is expected on the basis of the periodic table.

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Consensus among experts on the state of the art of science education research

Consenso entre expertos sobre el estado de arte de la investigación en la didáctica de las ciencias

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Abstract

The review of two of the most relevant research topics in the field of science education: conceptual change and alternative conceptions, shows a series of methodological and theoretical weaknesses which concord with the ones indicated by expert-led seminars. The weaknesses suggest that there are other less rational commitments which explain the heavy production of writings in the field. Our research examines these phenomena and concludes by giving suggestions for progress. We also present a proposal which may contribute to overcoming the deficiencies identified.

Key words: *conceptual change, alternative conceptions, research topics (lines of research) in science teaching.*

Resumen

Revisión de dos de las líneas de investigación más relevantes en el ámbito de la didáctica de las ciencias: cambio conceptual y concepciones alternativas, muestra una serie de debilidades metodológicas y teóricas que son las mismas que se señalan en seminarios de expertos. Las debilidades sugieren que existen otros compromisos menos racionales que explican la fuerte producción de trabajos en el ámbito. Nuestra investigación examina estos fenómenos y finaliza dando sugerencias para el progreso. También presentamos una propuesta que pueda contribuir a la superación de las deficiencias identificadas.

Palabras clave: *cambio conceptual, concepciones alternativas, líneas de investigación en enseñanza de las ciencias.*

INTRODUCTION

In some recent forums and expert-led seminars, the current situation of science education (SE) as a field of knowledge has been evaluated. We focus our interest on two reports that have been published:

- Cachapuz, et al. (2004). These authors are the organizers of the International Seminar on the Present State of Research in Science Education, which was carried out on the 15th and 16th of October, 2004 at the *Universidad de Aveiro* (Portugal), where important experts from all over the world participated, among whom it is worthy of mentioning, among others, in alphabetical order: Duschl, R.; Gil-Pérez, D.; Izquierdo, M.; Jenkins, E. W.; Matthews, M. R.; Osborne, J.; Sequeira, M. C.; White, R., etc.
- Moreira (2005). This work brings together the conclusions and recommendations of experts who met in the *Encuentros Iberoamericanos sobre Investigación en Educación Básica* [Iberoamerican Meetings on Basic Education Research] (Burgos, Spain), in 2002 and 2004. The main senior research in this seminar was Antonio Moreira as well as a group of Iberoamerican researchers.

The writing styles of the seminar reports are quite different. While in the Aveiro report suggestions and directions for improving weaknesses are given, the Burgos report has a more explicit and direct style, exposing the multiple weaknesses in the SE field. Yet, in spite of the difference in styles, both reports present notable coinciding observations on three important aspects of SE field. We will enumerate below, first, the opinion of the Aveiro seminar and, secondly, that of Burgos, on each topic.

1. The body of knowledge

- As of now a theory or cohesive consensual framework in the field of Science Education does not exist, and it seems to be quite improbable that it would come to be formulated soon. However, it's important to move towards the search for a global accord, for which science educators shall have to develop a specific and coherent body of knowledge.
- The majority of research lacks a coherent and consistent theoretical framework. That is, theoretical references, when they are presented, are not articulated either with empirical data or with the analysis of such data. Theoretical references are imported, sometimes in a non-critical manner, that is to say, without reconstruction or adjustments made for suitability in the SE field.

2. Research

- We shall have to establish priorities for SE research, according to relevance for solving real problems and contribution to the construction of a more coherent body of knowledge. The area, which is in rapid growth, should consider more the topic of quality. With that end in mind, researchers will have to maintain a spirit of critical review.
- Few lines of research are progressive and many are planned just for the short term. Lots of hurried and low-quality production exists, which are more of an application than a production of knowledge. The methodological instability is high in qualitative as much as it is in quantitative focuses. The research still does not have a real impact on educational practice. The area researchers do not accept critiques well, nor do they do them themselves. There is a lack of a tradition for critique in SE research.

3. The SE community

- The community should be organized in multidisciplinary research networks, national as well as international, with the goal of improving the relevance, the quality and the visibility of the research. These networks should work at increasing communication among professors and researchers by means of additional means, and not simply publications.
- The community shows significant weaknesses, given that few groups and societies exist. The journals do not have clear criteria or objectives in peer review. There are few strong programs for training. Instead, a light incorporation of researchers from other areas exists, and these do not have sufficient training in SE field. Furthermore, there is a lack of visibility because of the influence of other areas of research and those organizations responsible for educational politics. Finally, little dialogue and interaction is apparent among SE communities.

An interesting exercise is to compare some of the coinciding observations which were stated in the expert forums on the state of the art of SE with some academic reports published in the last 2 decades. The purpose of this article is to contribute some additional elements to those set forth in the expert forums. Ours are intended to help readers to understand the magnitude of the present academic difficulties in SE research.

FOCUSING ANALYSIS IN TWO OF THE MOST INFLUENTIAL RESEARCH LINES IN SE

The literature reveals a significant group of reviews related with two of the most influential research focuses in the SE field, namely: conceptual change (CC) and alternative conceptions (AC). Both research lines contain a sample of empirical works which make use of quantitative and qualitative methodologies and both represent a quarter of the publications in the field of SE (Tsai & Wen, 2005).

In terms of the samples of articles employed, this study carries out a partial analysis of other reviews, 6 done by the authors and 1 by Guzzetti (Guzzetti, et al. 1993). Directly and indirectly, eliminating repetition, a sample of more than 200 papers has been analyzed. The studies, from each of the two areas of research, are:

- Reviews on CC: Guzzetti, et al. (1993); Soto, Otero and Sanjosé (2005) and Marín (1999). These writings bring together international research production from the 80s and 90s. They focus on experimental group research reports and the composition of the SE international community. They deal with topics related to the theoretical and methodological focuses of the CC research area.

- Reviews on AC: Marín and Jiménez-Gómez (1992); Jiménez-Gómez, Solano and Marín (1997); Marín, Solano and Jiménez-Gómez (2001); Marín, Jiménez-Gómez and Benarroch (2004). These projects were carried out in the last 15 years and review more than 100 works on AC, on distinctly scientific issues.

THE MOST RELEVANT CONCLUSIONS OBTAINED IN THE RESEARCH CITED ON CC

The three review research papers on CC coincide in highlighting the following four critical points:

1. The majority of the writings lacks a model or reference theory to give a basis to the research. In the identification of the main foundations which guide CC research, it is found that 2/3 of the works do not follow any theoretical model. Furthermore, it is proven that a similar fraction declare that they follow a model or a theory while making no real commitment is found in the decision making of the different phases of the research (Soto, Otero and Sanjosé, 2005).
2. There is excessive individual production which is both atomized and fragmented. The bibliometrical study of cross references shows that the connections among writings is very weak, in fact, it is not common for authors to quote previous studies which have dealt with the same topic (Soto, Otero and Sanjosé, 2005). With that, in the majority of publications, evidence has not been found to show that authors depend on the results and conclusions of previous research (also see Moreira, 2005). These data are even more significant if one keeps in mind that a good part of the sample was taken out of the most influential journals of the SE field.
3. There are also decisions in what we could call "excessive quotations". In effect, it is common to see that a quotation does not proceed with the logical commitment with the quoted work. Writers tend to quote prestigious works and authors more, in order to "get on board" or to align themselves with a research framework rather than to make a real contribution to the field (Duschl, 1994).
4. An analysis of the *internal validity* for quantitative writings and *credibility* for qualitative works, shows that only 30.7% of the quantitative works and 39.4% of the qualitative ones possess good methodological standards (Soto, Otero and Sanjosé, 2005). This outcome is similar to the one obtained by Guzzetti, et al. (1993), where only 25% of the quantitative works presented a high methodological quality. In that regard, Janiuk (1999) suggests that the European research in chemical education does not have quality standards, while Jenkins (2000) calls upon the SE community of researchers to review the procedures for quality control.

THE MOST RELEVANT CONCLUSIONS OBTAINED BY THE RESEARCH PROJECTS QUOTED ON AC

The AC line of research is the one which more publications have listed in the past 2 decades (Marín, Solano and Jiménez-Gómez, 2001). Many papers have been published with a very similar structure: First, delimiting the conceptions of the student on the content of science which is the object of the teaching, and, secondly, from the information, proposing some pedagogical implications. This way of proceeding is called "the movement of alternative conceptions", by authors who are involved (Gilbert and Swift, 1985). Although afterwards the name passed through various changes (Marín, Solano and Jiménez-Gómez, 1999), it seems to us that the original name is the one which best sums up its essence.

What follows is an orderly synthesis of the main AC research conclusions:

1. The academic content which attempts to know the conceptions of the student is the main reference point for seeking and interpreting data. This is the main characteristic which determines, in a great measure, the rest of the critical commentaries. However, other theoretical contexts (taken, for example, from psychology) are not used (Marín, 2003b).
2. A significant division exists between real supporting documents and the bibliographical supporting documents cited. In the analysis of bibliographical quotes, articles whose supporting documents formulated expectations which, in one way or another, modulated the course after the research were scarce, at 10% (Marín, Solano and Jiménez-Gómez, 2001). The typical situation is that the quotes used for giving bases to the research mean little or nothing for the latter development of the project (questionnaire design, the classification of data, the interpretation of the outcomes, etc.).
3. To analyze the validity or the viability of the information obtained by students is not common. Only the third part of the sample analyzed uses techniques for partially analyzing the degree of validity and viability of the data (Marín, Solano and Jiménez-Gómez, 2001). The controls for analyzing the quality of the data should be consistent in all empirical research which presents itself as having a degree of scientific character.
4. The information (taken from the student) related to the content which is the object of the teaching is biased and limited.

POINTS OF AGREEMENT FROM THE REVIEWS AND REFLECTIONS ON THE STATE OF SE

The notable agreements among the reviews of both lines of research and the corresponding agreement of reviews with the ones obtained in the expert seminars of Aveiro and Burgos should not be ignored (Cachapuz, et al. 2004; Moreira, 2005).

Three general agreements are shown below, followed by others which are incomplete. In the first three, the affirmations of the seminars are shown, accompanied by the agreements in the review of the research:

1. The majority of the projects are developed without a theoretical framework and they demonstrate a deficient coordination among supporting documents and the empirical phase of the research. The data which support the reviews confirm that this is true: 68% of the works which lack a theoretical model to give a basis for the CC research; 80% of the works on AC do not use appropriate theoretical contexts. Academic content is the main reference for seeking and interpreting data. A lack of commitment exists with a firm center of research, even in the CC papers which explicitly declare that they follow such a firm center (34%).
2. A good number of works demonstrate methodological weakness, which is why a greater sense of critique and responsibility should be demanded of researchers. The CC manuscripts demonstrate mediocre methodological quality in 70% of the quantitative research writings and in close to 60% of the quantitative research writings. In AC articles, there are 67% which do not analyze the validity and reliability of the information obtained by students.
3. In the SE field, there is a manifest lack of dialogue among experts, with production being hurried, pointed and poorly coordinated with works on the same topic. In conclusion, while significant gaps between the supporting AC research texts and the ones cited in bibliographies are perceived, in the bibliometrical CC analysis, it becomes evident that an excessively individualized, atomized and fragmented production exists.

There are other agreements, but not as general as the ones which were previously expounded. For example:

1. In the Burgos seminar, as well as in the reviews previously carried out, the use of a deficient psychological vision of the learner is critiqued. It is perceived that the learning proposal which is sustained from CC is very limited, even impossible from a psychological perspective, and that the information which is taken from the student on the content to be taught is biased and limited in AC.
2. In the Burgos seminar and in the review on AC, accusations were raised that the research lines only demonstrate progression and that the majority of the research papers consist of application. They are not production of knowledge. On this particular point, the experts who met in the Aveiro seminar suggested that more contributions towards the creation of an SE theoretical framework of knowledge should be made.
3. In the Aveiro and Burgos seminars, it is affirmed that notable deficiencies exist in the formation of SE experts. This is also perceived in the review of the two lines of research which establishes that the theoretical commitment of the works evaluated is low.

SUGGESTIONS AND PROGRESS DIRECTIONS

The directions of progress should be focused on rectifying the weaknesses found, thereby taking advantage of the elements which are already established in the SE field. These directions align themselves with the ones outlined in the AVEIRO and BURGOS seminars (CACHAPUZ, et al., 2004; MOREIRA, 2005), but they contain details, taken from the reviews of the lines of research (which have been the object of this article), which clarify matters even more:

- An intentional search for a theoretical framework for the SE field is necessary. The current theoretical elements which are the most utilized in the SE field: constructivism and the history and philosophy of science (HPS), cannot be the only candidates for fulfilling the role of a theoretical framework, for the following reasons:

  - With reference to constructivism, it has a high degree of consensus, but in its present condition, it cannot play the role of the theoretical center due to the fact that it is developed in a wide array of levels. The most agreed upon of these levels is the theoretical center called *trivial constructivism* (VON GLASERSFELD, 1991; MATTHEWS, 1994; MARÍN, SOLANO and JIMÉNEZ-GÓMEZ, 1999), whose theoretical commitment does not go beyond the affirmation that knowledge is not received passively, but it is actively constructed by the subject who knows.

  - In the case of the HPS, even supposing that a consensus were reached, it does not offer a strong enough theoretical context for giving an adequate response to the wide array of problems in SE field such as the cognitive phenomenology associated with the learner.

- Improve communication among SE experts. Work must be done in two of the directions where weaknesses have been noted:

  - Intracommunication. Currently, the interchange of contributions of experts is mainly done through journal articles or with projects presented at meetings or conferences. This system of interchange is extremely slow. More than fomenting critique, debate and learning, it serves instead to defend personal positions. Furthermore, it does not improve communication, given that data show that little is being read. Methods which are more interactive such as a seminars or workshops carried out in a conference or in a university interchange context would be helpful.

  - Intercommunication. The SE field urgently requires the scientific formation of future SE experts (GUTIÉRREZ, 1987; GIL, 1991; CAÑAL, 1995). In view of the absence of a firm center, it is no surprise that training tends to be divergent.

- Foment the spirit of friendly critique in the SE field. Although they are not common, some critical articles have appeared which contain serious proposals or which refute certain SE field content. What is the reaction or the attitude of the community in view of such a refutation? In the two research lines analyzed, the typical response is to ignore critiques or to reject them (SOLOMON, 1994; DUSCHL, 1994).

The authors argue that the key to fomenting communication and critical activity in SE is in the existence of a theoretical framework or center. Deciding upon one would have numerous positive effects:

- It would avoid turning publications in directions which, in the passing of time, demonstrate their weaknesses. Such deviance would be avoided, in part, if some of the knowledge available in other similar fields is considered (JIMÉNEZ-GÓMEZ, BENARROCH and MARÍN, 2006).
- It would give an answer to a weakness in the SE field: the unequal training of those who make up the SE field. Currently, a specific plan for training does not exist. The initial university training of the majority of SE researchers is basically in particular science subjects (DUSCHL, 1994). Consequently, the demands of the professional context obligate one to obtain additional training as an expert, generally using the material published in the field of SE. The current divergence in this material and the absence of a common theoretical center explain the unequal development of experts who are orientated by the research group in which they are registered.
- It would permit an answer to the questions surrounding the dispersion of criteria for establishing the contents of disciplines which properly belong to SE.
- It would provide an answer to the lack of identity, or, as MOREIRA (2005) says, the "lack of visibility" of the SE field.

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QBIC, an interdisciplinary and quantitative biological sciences curriculum: concept to implementation

QBIC, un currículo interdisciplinario y cuantitativo de las ciencias biológicas: concepto a la implementación

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Abstract

QBIC (Quantifying Biology in the Classroom) is a reformed four-year (freshman-senior) program within the Biological Sciences Department at Florida International University. QBIC was implemented with a cohort of 23 freshmen fall 2007, a second cohort of freshmen fall 2008, and two cohorts (3rd and 4th) entered the program fall 2009. The blueprint for QBIC was developed beginning 2004 over a 2-year period by 12 faculty members in biological sciences, mathematics, statistics, chemistry, physics, computer science and biomedical engineering. We are working towards better preparing 21st century biology students with tools to think more quantitatively, by offering them a more rigorous interdisciplinary and quantitative curriculum.

Key words: *interdisciplinary, quantitative, undergraduate, biology, curriculum.*

Resumen

QBIC (Quantifying Biology in the Classroom: Biología cuantificada en las aulas) un programa universitario reformado de 4 años (novato - superior) dentro del Departamento de Ciencias Biológicas de la Universidad Internacional de La Florida. QBIC fue implementado en el otoño de 2007 con una cohorte de 23 novatos, una segunda cohorte en el otoño de 2008 y dos cohortes más (3ra y 4to) entraron en el otoño de 2009. La guía maestra que QBIC fue desarrollada en un periodo de 2 años, empezando en el año 2004, por 12 miembros de la Facultad de Ciencias Biológicas, matemáticas, estadística, química, física, informática e ingeniería biomédica. Estamos trabajando para preparar mejor a los estudiantes de biología del siglo XXI con instrumentos para que puedan pensar más cuantitativamente, ofreciéndoles un currículo más riguroso interdisciplinario y cuantitativo.

Palabras clave: interdisciplinario, cuantitativo, estudiante universitario, biología, currículo.

DEVELOPMENT OF A CONCEPT

In 2004, faculty from the Biological Sciences (BS) and Computer Sciences departments at Florida International University (FIU) initially met to brainstorm about perceived and real problems that our undergraduate students bring to the Biology program, as well as real and perceived problems associated with integrating quantitative sciences into the BS curriculum. Subsequent discussions included faculty members from Biomedical Engineering, Statistics, Mathematics, Physics and Chemistry. With increasing amounts of available data, and new tools to analyze data, faculty in the biological sciences, statistics and mathematics, had been thinking of incorporating a more quantitative approach to the biological sciences that would provide our students with valuable tools to better understand and study biological processes. Presently, the biology curriculum includes a very limited exposure to quantitative sciences. Much of the material in our natural sciences, physical sciences, statistics and mathematics courses is presented in isolation of one another. We sought a funded, structured mechanism, and opportunity to proactively correct this shortcoming. These discussions gained momentum with a 2004 request for planning proposals (RFA) for BS Curriculum Improvement from the National Institutes of Health (NIH)/National Institute of General Medicine (NIGMS)/Minority Opportunities in Research (MORE)/Minority Access to Research Careers (MARC). The RFA was largely a response to the report, *"BIO 2010-Transforming Undergraduate Education for Future Research Biologists"*. This report was published in 2003 by the Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, National Research Council of the National Academies. The report's primary recommendation is that an interdisciplinary approach that incorporates a strong basis in mathematics and physical sciences should be used in biology education. A more recent report, *Scientific Foundations for Future Physicians* (www.aamc.org/scientificfoundations), also recommends that physicians have a solid foundation in the biomedical sciences so that they better understand BS relation to the physical sciences and mathematics (Long and Alpern, 2009). Our planning proposal was funded and we subsequently developed an implementation proposal for a *test case curriculum* that we call **QBIC (Quantifying Biology in the Classroom)** *(see Figure 1)*. FIU's Provost recognized the value and promise of the QBIC implementation proposal and provided pilot funding (2007-2011), which was followed by extramural support from NIH/NIGMS/MARC in 2008.

THE QBIC PROGRAM...*integrating knowledge, understanding science*

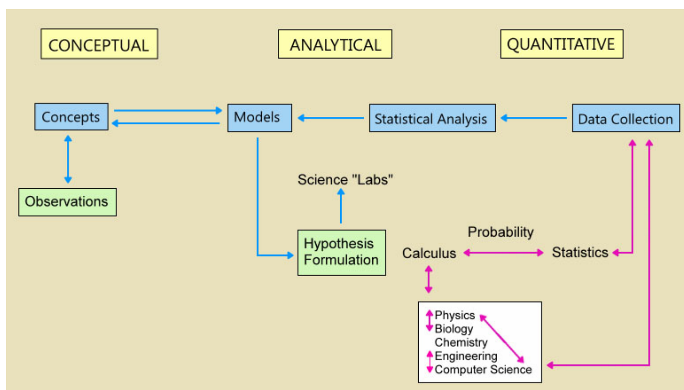

Figure 1. *QBIC Goal Map* generated by QBIC Program founding architects as a guiding tool: Students finishing the QBIC program will have skills needed to move fluidly among *conceptual*, *analytical* and *quantitative* approaches to solving biological problems.

Planning and timeline to develop implementation objectives. The QBIC program *planning* and *implementation* proposals were developed over a 2-year period. We evaluated and identified problems faced by FIU regarding science students' academic preparedness and academic performance; we evaluated and identified problems and programs that promote curriculum improvement and enhance students' performance, as well as curricula effectiveness. We brainstormed for six months, penned implementation components for the *test case* QBIC Program over a four-week period, worked out logistics and fine-tuned the plan for an additional six months. FIU is a >70% minority institution with 59% Hispanic students and 13% African American students; Asian students make up 4% of the enrollment.

BRIEF DESCRIPTION OF THE QBIC PROGRAM

QBIC is a block program with a lock-step curriculum. Each block consists of a cohort of 24 scholars because evidence from another program at FIU, *Freshman Interest Groups (FIGS)*, showed that smaller classes and/or mechanisms that provide for smaller groups of students, results in greater support and bonding/cohesion among students and, students are challenged more effectively; all lead to greater success in college (http://www.fiu.edu/~figs). We also know from experience and from the literature that students learn better when connected to each other and to the subject *(Smith et al., 2004; Tinto, 1998; The Boyer Commission, 1998; Outline Summary of Boyer Report Recommendations, 2001)*. Currently, *QBIC is offered as a Quantitative Biological Sciences track within BS with a long term goal of influencing the format of FIU's BS curriculum, especially for students who are interested in pursuing graduate studies in the biomedical sciences*. As a pilot program, QBIC targets graduate school and medical school bound students. A summer capstone modeling and simulation workshop, a journal club course and a calculus lab are signature courses for QBIC. Currently, entering QBIC scholars have average SAT scores of ~ 1700, with Math scores of ~600), and a high school GPA > 3.3. One third of these students receive merit-based scholarships from a grant awarded to QBIC by the *National Science Foundation*.

QBIC's two-part integrated lock-step cohort format has courses in a block (for a sample QBIC curriculum see http://qbic.fiu.edu). Part 1, covering the freshman through sophomore years, is tightly scheduled and provides the greatest interdisciplinary emphasis. Part 2, covering the junior and senior years is more flexible and offers some tailored upper-division courses. Students in the upper division are encouraged to engage in independent research within funded research programs. A few of the students begin this immersion in research during their freshmen year.

Table 1a. Part/Block I

FRESHMEN: Fall	**Area/Themes**	**FRESHMEN: Spring**	**Area/Themes**
Biological Sciences: ***Biology 1/L***	***Evolution, Ecology, Biodiversity:*** Journey through the history of life ***Biomolecules:*** Biomolecules, osmosis, diffusion ***Introduction to cell biology and genetics:*** cellular organization & division, Mendelian genetics, & gene expression	**Biological Sciences:** ***Biology 2/L***	***Energy Metabolism:*** ATP production, biochemistry ***Organ systems & sensory perception:*** Structure, function, ion channels, neuro-transmitters ***Plants:*** Structure, function, metabolism
General Chemistry 1/L	Content, principles and methods of chemistry-molecules, polarity, biochemical reactions; appreciating the relevance of chemistry in daily life	**General Chemistry 2/L**	Solutions, solid state, thermodynamics, electrochemistry, kinetics, nuclear chemistry, equilibrium; problem solving skills; draw links to biological discoveries and processes
Quantitative Sciences 1: ***Calculus 1/L***	Biology & limits of functions; biology & derivatives (Absolute Extreme Problems). Weekly one-hour *calculus lab*, using Matlab to work with applications of calculus to biology; use "Calculus for the life sciences" by Raymond Greenwell	**Quantitative Sciences 2:** ***Calculus 2/L***	Use systems of difference (later differential) equations to model and analyze biological phenomena (e.g. population dynamics, stability of equilibria, laws of cooling, predator-prey models). Matlab used to help gain *quantitative* and *conceptual* insight into problems
Enrichment: ***Journal Club***	Predicting the behavior of biomolecules; model the biochemical reactions involved in energy metabolism; read & discuss the text *"Why We Get Sick: The New Science of Darwinian Medicine"* by R.M. Nesse & G. C. Williams	**Enrichment:** ***Journal Club***	Read & discuss *Review Articles* that link content covered in courses; direct students to make connections between specific concepts in papers and the same concepts in their other courses.
English		**English II**	Rhetorical Analysis *Complications ;* Oral History Project, Research Essay based on Epstein *The Invisible Cure -- AIDS Africa*
Summer 1. Open for University Core Curriculum courses (UCC)			
SOPHOMORE: Fall	**Area/Themes**	**SOPHOMORE: Spring**	**Area/Themes**
Biological Sciences: ***Ecology***	**Direct causation:** Temperature, seasons, and behavior of organisms **Correlations of physical factors and biological phenomena:** Biome concept and biomes around the earth **Complexity in Natural Systems:** Jigsaw activity on species interactions	**Biological Sciences:** ***Genetics***	**Segregation, Variation, Complex traits:** Exceptions; Primary literature
Organic Chemistry 1/L	Basic principles to understand structure & function of organic molecules; concepts learned in this *chemistry of carbons* allow construction of greater meaning/ understanding of more complex biological principles	**Organic Chemistry 2/L**	Methods used to identify structure of organic molecules, reaction mechanisms, methods for synthesizing organic compounds, and insights on organic chemistry role in biology/industry/ medicine
Quantitative Sciences 3: ***Statistics 1***	Integrates real data from Biology and Ecology labs and other sources to be analyzed in class using statistical software (SPSS)	**Quantitative Sciences 4:** ***Statistics 2***	Integrates real data from Biology & Ecology labs and other sources to be analyzed in class using statistical software (SPSS)
Enrichment: ***Journal Club***	Read & discuss *Primary literature* that link content covered in courses. Emphasize and re-emphasize particular concepts that connect readings to the developing conceptual armatures.	**Enrichment:** ***Journal Club***	Read & discuss *Primary literature* that link content covered in courses. Emphasize and re-emphasize particular concepts that connect readings to the developing conceptual armatures.
English		**English II**	Rhetorical Analysis *Complications ;* Oral History Project, Research Essay based on Epstein *The Invisible Cure -- AIDS Africa*
First Year Experience	Life style transition to active learning. Research presentation on a Biological-Biochemical Method.		
Summer 2. Modeling & Simulation Workshop: This 6-credit hands-on computer laboratory course covers bioinformatics, deterministic modeling and statistical modeling.			

QBIC scholars take lower-division natural and physical sciences courses together, working within an integrated, conceptual framework (Table 1a-c). Teaching units within courses and labs use *active* and *cooperative learning* techniques and *problem-based learning concepts (*Penwell, R. A. et al, 2004*).* The program integrates mathematics, statistics and computing such that data generated in the biology labs are used in the statistics courses, teaching students how to gain valuable knowledge from the statistical analysis of biological experiments, and mathematical models are used to simulate biological processes to help in a better understanding and study of such processes. This connection is emphasized in *teachable units* and shows how sound biological theories are generated *(also see* Ebert-May and Hodder, 2008*)* with the help of the quantitative sciences. QBIC allows the teaching of mathematics and statistics from the perspective of interpreting experimental and observational measurements, motivates students to learn statistics and mathematics as they relate to biology, and teaches them how to be scientists (Table 1).

QBIC also includes a *capstone summer modeling and simulation workshop* at the end of the sophomore year. Using *biomedical engineering*, *computer science* and *statistics* tools in this capstone workshop, scholars are provided with the opportunity to consolidate knowledge acquired during their first two years in the program. Also, each semester throughout the four years of the program, QBIC scholars register for the weekly journal club course, and each section in this course consists of only 8-10 students (Figure 2). During interactive discussion with small groups of stu-

Table 1b. Part/Block II

JUNIOR: Fall	**Area/Themes**	**JUNIOR: Spring**	**Area/Themes**
Biological Sciences: ***Cell Biology***	Major compartments of the cell and their functions; transport mechanisms in and out of the cell Cell signaling, receptor and ligands; changes in cell behavior; interaction with extracellular environment Cell cycle regulation; cancer	**Biological Sciences:** ***Evolution*** Basic applications to pathogens and humans	No primary text. "Principles of Evolutionary Medicine" by Gluckman, Beedle & Hanson
Electives and/or UCC		**Electives and/or UCC**	
Quantitative Sciences 5: ***Physics 1/L***	Modeling interactions and physical systems in accordance with overriding scientific laws	**Quantitative Sciences 6:** ***Physics 2/L***	Modeling interactions and physical systems in accordance with overriding scientific laws
Enrichment: ***Journal Club***	Internal and external controls on cell development and fate. Read & discuss *Primary literature* that link content covered in courses.	**Enrichment:** ***Journal Club***	Evolution of sex and disease. Read & discuss *Primary literature* that link content covered in courses.
Directed Research - *intramural*		**Directed Research - *intramural***	
Summer 3. Directed Research – *intramural or extramural*			
SENIOR: Fall	**Area/Themes**	**SENIOR: Spring**	**Area/Themes**
Biological Sciences and Non-Major Electives, and/or UCC		**Biological Sciences and Non-Major Electives, and/or UCC**	
Enrichment: ***Journal Club***	Read & discuss *Primary literature* that link content covered in courses. Emphasize and re-emphasize particular concepts that connect readings to the developing conceptual armatures.	**Enrichment:** ***Science Café***	Science communication training, and becoming more aware of questions that the public have and what they know. To learn to, and *want to* lessen the gap in the public's understanding of science and scientific research and develop a culture of wanting to engage the non-scientist in talking about science with passion, like non athletes talk about sports!
Directed Research - *intramural*		**Directed Research - *intramural***	
Summer 4. Directed Research – *intramural or extramural*			

Table 1c
Sampling of Elective Courses that QBIC Scholars can choose from in the Four Required Categories

ECOLOGY	DIVERSITY	STRUCTURE	PHYSIOLOGY/BIOCHEMISTRY
Population Biology	Microbial Pathogenicity	Comparative Vertebrate Anatomy	Comparative Physiology
Microbial Ecology	Vertebrate Zoology	Neuroscience	Animal Behavior
The Biology of AIDS	Invertebrate Zoology	Plant Development	Biochemistry
Biogeography	Plant Systematics	Forensic Osteology	Developmental Biology
	Local Flora	General Parasitology	Immunology

dents in the Journal Club, the professor and/or a TA directs students to make connections between specific concepts in research papers and the same concepts in their other courses.

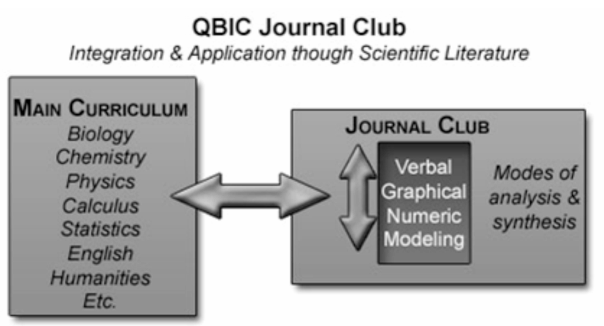

Figure 2. The goals of the journal club course are to help students understand where our scientific understanding of the world originates, how it has been accomplished and the many ways it is transmitted, as well as to appreciate *science as a process* equal in importance to the body of knowledge it has produced.

CURRICULUM CHANGES & INTEGRATION

We have worked within the existing course numbering system to create a series of integrated courses. Some courses such as Calculus I and II have switched to textbooks that are written specifically to introduce fundamental calculus topics within the context of the life sciences. In other courses, faculty have made a point of addressing how other fields are involved in discoveries of subject matter related to the biology curriculum. For instance, the chemistry curriculum is constrained by accreditation requirements, but still leaves the professor latitude to draw links to biological discoveries and processes. The intro biology lab courses in the first year have been reformed for the QBIC program to let students generate data from biology experiments that they will use in their statistics courses in the second year. The new Journal Club courses emphasize interdisciplinary work, and cover a broad subject range, with emphasis on using scholars' ideas to address unsolved problems (e.g., how to design a bioengineered HIV vaccine). Student course evaluations gave the Journal Club high praise for its interest and diversity.

The conceptual armature - some problems, some solutions, based on lessons learned from our first QBIC cohort: From the start, one of the planned facets of the QBIC program was to evaluate all components continuously and on a regular basis. Every component of the QBIC curriculum has been evaluated on a regular, continuous, and formative basis during the past two years, and changes have been made as needed on the basis of feedback from all stakeholders (students, faculty, and others). For example, although we designed specific points of students' integration into the curriculum, getting freshmen students to make connections within the curriculum proved harder than we anticipated. Part of the problem was that students come in with no conceptual armature, a framework of connected fundamental concepts to which understanding of the sciences is based. Students eventually build this framework on their own, but we sought to speed the process through deliberate connection. The two key issues, at least with freshmen, were getting faculty to make more specific connections between each other's courses, and getting students to realize when those connections had been laid before them. In Journal Club, we help students build a knowledge framework through *science books (i.e., Why We Get Sick. The New Science of Darwinian Medicine by R.M. Nesse and G.C. Williams)*; then *review articles* and finally we test the foundation of their knowledge through *primary literature*. Based on this knowledge, we approach the goal of strengthening connections both in the basic courses and in the Journal Club *(Figure 2).*

To improve integration of the basic courses, teaching-QBIC-faculty members maintain a journal and meet monthly to share ideas and observations about students, course content and possible adjustments in direction. These meetings have enabled us to make corrective changes and fine-tune our approach without waiting for end-of-semester feedback. QBIC faculty members strongly believe that better teaching fosters better learning, and that "poor teaching stifles, deadens and destroys whatever curiosity and enthusiasm students bring to their studies…the damage can be permanent". To this end, QBIC is committed to pedagogy reform. Current QBIC faculty members have participated in NIH, NAS/HHMI *(e.g. Handelsman et al., 2005; Pfund et al., 2009)* and FIU Academy for the Art of Teaching (AAT) (http://undergrad.fiu.edu/aat/about.html) -sponsored extramural and intramural pedagogy workshops. Also, FIU-AAT provides resources and support to foster the highest quality of teaching and learning.

We also designate one faculty member to facilitate specific integration between course curricula. This instructor makes it a point to keep track of the curricula in the other integrated courses. The professor then follows up on this by contacting the lecturing faculty with requests to emphasize and re-emphasize particular concepts that connect readings to the developing conceptual armatures/ frameworks.

QBIC 2007/2008 and 2008/2009 Reflections. Our 2007/2008 pilot and subsequent 2008/2009 QBIC academic years have provided exciting and very informative data. Overall, the QBIC format with its research-oriented academic courses (Figure 3) that are both quantitative and integrative shows tremendous promise.

QBIC Ecology - *"pattern and process in the natural environment"*

Figure 3. QBIC Ecology - QBIC scholars with TAs, Bryan Dewsbury (white cap) and Journal Club Facilitator Sat Gavassa (far left) in the Florida Everglades. Overall goals of the course are to teach students how to design experiments to address specific hypotheses; to recognize patterns in nature and elucidate the processes that generate these patterns; to introduce students to the uniqueness of the South Florida ecosystem.

This promising outlook is due to the dedicated time and effort (commitment) put into the program by faculty, teaching assistants (graduate and undergraduate) and staff, who, over the past two years, actively participated (and continue to do so) in numerous discussions and meetings on monthly and bimonthly bases to fine-tune the program. These constant and continuous discussions among multidisciplinary faculty are paramount to successfully facilitating an integrative curriculum. We have already seen that the greatest deficiency in students' preparation is in mathematics, followed closely by a crippling lack of effective study habits and a lack of critical reasoning skills. Even though students currently admitted into QBIC are better than average first year college students, they are still not fully prepared for their *first year of college*, especially one as rigorous. To achieve greater chances of academic success for incoming freshmen, and responding to feedback received from students and faculty in the first year of the program, QBIC faculty designed and implemented a 6-week summer "boot camp" for incoming freshmen that consists of a *mathematics enrichment* course, and a *transition to college for science majors'* course. The QBIC Bound Summer Session (QBSS) should play a major role in providing a *fast learning curve* for our entering scholars. This fall 2009 we welcomed two new cohorts (24 each) into the program plus the continuing cohorts of sophomores and juniors. QBIC's first and second years, warts and all, have been eye opening. One of the outcomes of this experience is that we are now beginning to implement some of the successful aspects of QBIC in non-QBIC biology labs and courses at FIU, and we look forward to even greater success in the coming years.

Sixty-nine percent of QBIC scholars from the inaugural class of 2007 entered their 3rd year of QBIC in fall 2009, and seventy-seven percent who entered as freshman students in fall 2008, entered their sophomore year. At the end of the 2007-2008 academic year, a comparison group of QBIC students with a matched comparison group revealed that a greater proportion of QBIC students matriculated in the Fall, were on the Dean's honor list in the Fall or Spring semesters, took more credit hours, and had a higher cumulative GPA (Table 2).

Table 2

A comparison of 2007-2008 QBIC cohort and a matched sample of students, matched post-hoc on admission attributes

Admission Attributes	QBIC	Comparison
Admitted to FIU for 2007-2008 academic year	25	25
Took classes Fall 2007 and Spring 2007	19	13
% on Dean's List Fall 07	44	15
% on Dean's List Spring 08	36	23
Mean number of credits per semester, 2007-2008	17.0	14.4
Mean cumulative GPA, 2007-2008	2.99	2.75

Note: From Tashakkori, Reio, and Rincon (2008) QBIC evaluation report (12)

CONCLUSIONS

It is our vision as framers and faculty of QBIC, that in time, the interdisciplinary and quantitative curriculum of this program will be a signature format for biological sciences education at FIU. Also, as we accumulate data, especially on outcomes, and disseminate/share information about QBIC, we hope that similar formats will be exported and adopted for biological sciences programs at other institutions.

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Inquiry Instruction and the nature of science: how are they interconnected?

Métodos investigativos de la enseñanza y la naturaleza de la ciencia: ¿cómo están conectados?

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Abstract

The nature of science and scientific inquiry are consistently mentioned throughout the NSES document (National Research Council, 2000). Teachers are encouraged to use inquiry teaching approach to achieve the goals of scientific literacy. Two major questions were investigated in this study: 1) what conceptions of the nature of science do pre-service teachers hold at the beginning of a semester-long science methods course and how do these conceptions change during the course? 2) What is the relationship between pre-service teachers' conceptions of the nature of science and their inquiry teaching at the beginning and end of a semester-long methods course? A significant statistical difference regarding pre-service elementary teachers' conceptions of the nature of science was found. A positive relationship was found between pre-service teachers' conceptions of the nature of science and use of inquiry instruction.

Key words: *scientific inquiry, science, pre-service teachers.*

Resumen

La naturaleza de la ciencia y la investigación científica se menciona constantemente en todo el documento NSES (National Research Council, 2000). A los profesores se les anima a utilizar el enfoque de investigación de la enseñanza para alcanzar los objetivos de la alfabetización científica. Dos asuntos importantes fueron investigados en este estudio: 1) ¿qué concepciones de la naturaleza de la ciencia que los maestros de preservicio tienen al principio de un semestre en el curso de métodos científicos y cómo esas concepciones cambian durante el curso? 2) ¿cuál es la relación entre las concepciones de los estudiantes de licenciatura sobre la naturaleza de la ciencia y enseñanza investigativa al comienzo y al final de una asignatura de un semestre? Se ha encontrado una diferencia estadísticamente significativa con respecto a concepciones de los estudiantes de licenciatura sobre la naturaleza de la ciencia. También existe una correlación entre concepciones de estos estudiantes sobre la naturaleza de la ciencia y el uso de los métodos investigativos de enseñanza.

Palabras clave: *enseñanza, métodos investigativos, la ciencia, licenciatura de ciencias.*

INTRODUCTION

This study examined pre-service elementary teachers' conceptions of the nature of science and the use of inquiry teaching strategies. The literature review indicates that students, as well as teachers, hold inadequate conceptions of the NOS (Abd-El-Khalick & Lederman, 2000;

Akerson, Hanson & Cullen, 2007; Forawi, 2003). Students in the United States are found to be doing poorly in international assessments in science and mathematics compared to those students of other industrialized nations (TIMSS, 2007). Teacher education programs should influence any positive change that we deem as appropriate to enhance students' knowledge, skills and conceptions of science.

Scientific literacy is stated as a major premise for the National Science Education Standards (NSES) (NRC, 2000) to be attained by all K-12 students. The concept literacy is not easily defined because its definition depends on its context. In general, literacy is the ability to read, write, speak, and listen. Scientific literacy aims to provide students with a broad foundation of scientific knowledge and skills to be able to live in an increasingly scientific and technological world. Scientifically literate people should be able to describe, explain, and predict natural phenomena, while understanding that science is an on-going process focused on generating and organizing knowledge (Holbrook & Rannikmae, 2007; Murcia & Schibeci, 1999). The promotion of student's understanding of science is a common feature most views of scientific literacy refer to.

'Inquiry is a multifaceted activity that involves making observations; posing question; examining books and other sources of information to see what is already known; planning investigation; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predications; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations'. (NRC, 2000, p. 13). Teachers, therefore, are encouraged to use inquiry instruction with students to develop a better understanding of science and to achieve the goals of scientific literacy.

Science educators most often use the phrase NOS to describe the interplay of disciplines informing science education about what science is and how it works. The NOS is a fertile hybrid arena that includes the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as social group and how society itself both directs and reacts to scientific endeavors (McComas, 2004).

The NOS is generally referred to the representations and values of scientific knowledge and modes of inquiry. Two major schools of thought that deal with the representations of scientific knowledge are realist and instrumentalist. Several theories were driven from these two directions (Kuhn, 1970; Matthews, 1997; Niaz, 2001). While realist theory mainly explains scientific knowledge as changeless, the instrumentalist tends to explain scientific knowledge as a developmental process of human imagination. Most studies of the nature of science were done on the representation of knowledge rather than the value of scientific knowledge (Abd-El-Khalick & Lederman, 2000; McComas, 2004). Research focused on, as these two major schools, representing the epistemological nature of science.

It is widely believed that unless science teachers recognize the nature of scientific enterprise it will be difficult for them to assist their students to gain a sound understanding of scientific concepts (Akerson, Hanson & Cullen, 2007). Equally important is that pre-service teachers need to have an adequate understanding of the nature of science. Tairab (2001) found that pre-service and in-service teachers held similar views regarding science and technology. He also noted the importance of examining other factors, such as teaching instruction, which influence pre-service teachers' understanding of the nature of science.

This study examined, in part, pre-service teachers' skills of science inquiry teaching. An assumption based on the NRC document (2000) indicates a relationship between inquiry teaching and the nature of science. This relationship has yet to be examined. Inquiry teaching, whether full or guided, allows students to independently learn science concepts and materials. Students, in inquiry classroom, are active in discovering meanings themselves with limited teacher assistance. I argue that if pre-service teachers are well introduced to the NOS and the use inquiry instruction, they will develop a similar understanding into their students. Teaching through inquiry, especially at the lower grades, will enhance students' understanding of the NOS because teaching science as a process as desired by the NRC position stated earlier will allow students to experience true nature of science as done by scientists and science practitioners.

The main premise of this study was to examine pre-service teachers' conceptions of the nature of science and their use of inquiry teaching approaches in an elementary science methods classes. Two major questions were investigated: 1) what conceptions of the nature of science do pre-service teachers hold at the beginning of a semester-long science methods course and how do these conceptions change during the course? 2) What is the relationship between pre-service teachers' conceptions of the nature of science and their inquiry teaching at the beginning and end of a semester-long methods course?

METHOD AND PARTICIPANTS

The sample size of this study consisted of 96 pre-service teachers enrolled in an Elementary Science Teaching Methods course in a Midwestern University during fall, spring and summer semesters of one academic year. Of these students, 26 (27%) completed the course in the fall semester, 24 (25%) in the spring semester, and 46 students (48%) in the summer semester over one year. The Majority of participants were female (83%), indicating a similar percentage of female elementary teachers in that region. There were 16 male pre-service teachers. All participants had similar instruction that focused primarily on guided-inquiry teaching strategies. The same instructor taught the course in all three semesters by providing scientific knowledge and inquiry teaching skills to participating elementary pre-service teachers. Inquiry teaching scores were calculated and recorded for each participating pre-service teacher, at the beginning and end of semester, based on the use of inquiry-teaching rubric that followed the guidelines specified by Martin (2003). Major aspects of the guided-inquiry teaching rubric included: scientific topic, age or grade level, science process objectives, materials, introduction of lesson, facilitation of group work, questioning technique, conclusion, discussion, reflection and relevance to life experience. The course and inquiry teaching description is provided in a later section in this study.

Students were administered the Modified Nature of Scientific Knowledge Scale (MNSKS) as a pretest on the first meeting day of the course in the semester and as a posttest at the end of the semester. The Nature of Scientific Knowledge Scale (NSKS) was originally developed by Rubba (Rubba & Anderson, 1978) to include six subscales or constructs that were appropriate to measure students' conceptions of the nature of science. The NSKS was modified by Meichtry (1993) to include only four of its six sub-scales to closely represent up-to-date diverse conceptions of the nature of science that included science as developmental (science is tentative), creative (scientific knowledge is partially a product of imagination), testable (scientific knowledge is capable of empirical test), and unified (sciences contribute to an interrelated network of laws, theories, and concepts). The modified NSKS consisted of 32 five-Likert items. The reliability was found to be.65 which was similar to other studies. (Forawi, 2000; Miechtry, 1993).

THE SCIENCE TEACHING METHODS COURSE

The course used in this study is a 3-credit-semester elementary methods course that prepares pre-service teachers to teach science to grades K-6, in a 4-year teacher education program. Students enrolled in the course were college seniors and graduate students seeking teacher certification at the elementary level. Modeling of guided-inquiry teaching strategies was facilitated throughout the semester through mini activities and complete lessons. Students worked in small groups to practice using inquiry teaching approach which followed the guidelines stated by Martin (2003).

Guided-inquiry teaching strategies focused around question(s) and used the science process skills to allow students to actively learn materials and concepts while they are 'doing' science. Pre-service teachers were taught to pose questions, facilitate group work, provide appropriate materials, relate concepts studied to real life, draw conclusions, and be good listeners. The students taught three inquiry lessons as part of the course teaching requirements in peers, individually (microteaching) and in groups. Each student received a score out of 200 points (40% of the course grade) for their inquiry teaching experience. A rubric developed by Martin (2003) was used to assess student inquiry teaching skills. The MNSKS scores were not included in the grades of the students. They were only used for the purpose of this study. Consent forms were obtained from pre-service teachers. The pre-service teachers were informed of the confidentiality of the use of the data.

Course content knowledge consisted of major scientific concepts such as simple machines, motion, magnetism, cell structure and function, habitats, ecosystems, energy, matter, atoms, and elements. The NOS was implicitly and explicitly introduced throughout the semester:

in the course introduction, discussion of reading materials related to NOS, and through the use of inquiry instruction. Explicit instruction on NOS was provided by teaching scientific concepts directly related to one or more benchmarks and aspects of NOS by lecture and discussion. While the implicit instruction of NOS was introduced indirectly through related scientific knowledge and skills covered in the guided inquiry activities. The rationale was that inquiry teaching strategies will provide students, in all different grades, with a great opportunity for developing better conceptions of the NOS through the active learning. Other concepts discussed in the course were constructivism and early childhood science learning, interdisciplinary science, national and state science education standards, assessment and electronic portfolios, and science misconceptions. These concepts were thought to enhance the inquiry teaching methods.

RESULTS

Table 1 shows means, standard deviations, and ranges of participants' pretest and posttest MNSKS scores. An average of 102 and 111 for students' pretest and postest scores showed a middle range of nature of science, according to previous MNSKS research. While none of the pre-service teachers' scores of the MNSKS fell within the realist conceptions area (64 or less), 7% of the pre-service teachers' scores fell in the instrumentalist area (128 or more). A greater range was recorded for posttest participants' scores (39). This great range suggested that students have experienced a change on their conceptions of the NOS as measured by the MNSKS.

Table 1

Summary of Participants' Means, Standard Deviations, & Ranges from Pre to Post Tests (n=96)

Source	Mean	SD	Max	Min	Range
Pretest	102	5.23	124	91	33
Posttest	111	6.19	134	98	39

The second result of this study showed the outcome of the ANOVA test. A high significant difference between the pretest and posttest scores was found for the participating pre-service teachers (F (1,96)= 23.89, p<.002). Table 2 represents a summary of the ANOVA test of participants' survey scores.

Table 2

Result of ANOVA test (n=96)

Item	Sum Sq.	DF	Mean Sq.	F	P
Pre-service NOS	6,721.04	1	6,721.04	23.89	.002

The third result indicated a positive correlation coefficient between students' conceptions of science and their use of inquiry teaching in the methods course (r=.52).

This means that the use of inquiry teaching strategies was positively correlated with pre-service teachers' conceptions of the nature of science.

DISCUSSION AND CONCLUSION

The first result of this study indicated a significant change on participants' conceptions of NOS from pre to post survey administration. This result is considered similar to research findings which indicated that science teachers often show instrumentalist views rather than the realist view of the NOS (Akerson, Hanson & Cullen, 2007). While this was a statistically significant difference, participating pre-service teachers' conceptions of the NOS have generally shown only a slight instrumentalist view, those who scored 128 and more were only 7% of the total sample size. The instrumentalist view represents scientific knowledge as developmental, tentative, parsimonious, and testable knowledge. Previous research has noted that pre-service teachers' common belief on NOS viewed scientific knowledge as static and final (Forawi, 2003).

The ANOVA result indicated a statistical significant improvement from pretest to posttest MNSKS. The explicit and implicit instruction of the NOS as well as the intensive instruction in inquiry teaching could be related to the improvement of the participant's MNSKS scores. Other factors could have played a role in the change of the participants' scores of the MNSKS, namely other science courses that students may have taken during that semester and the influence of instructor's conceptions of science. However, the clear attempt of the instructor/ researcher of this study was to examine the two major components of this course, inquiry instruction and NOS.

The correlation result (r=.52) of the study indicated a positive moderate relationship between pre-service teachers' conceptions of NOS and their inquiry teaching skills. The main purpose of the course was to develop pre-service teachers' inquiry teaching skills. Previous research supported the importance of developing K-12 students' ability to "do" science rather than memorizing facts (Forawi, 2000; NSTA, 1997; Ozkal, Tekkaya, Sungur, Cakiroglu & Cakiroglu, 2010). There have been conflicting results reported on the relationship between inquiry instruction and the NOS (Abd-El-Khalick & Lederman, 2000; Miechtry, 1993; Ortiz, 2001). This study further found a positive correlation between inquiry teaching skills and understanding of the NOS of elementary pre-service teachers using the described instruments.

IMPLICATIONS

The NSES were prescribed to help 'all' K-12 students to achieve scientific literacy through inquiry investigation and the development of adequate conceptions of the nature of science. The preparation of elementary pre-service teachers is considered an important goal in developing similar knowledge, conceptions, and skills into their future students. If pre-service teachers are well prepared to teach science as an inquiry process, they will develop better conceptions of the nature of science, as they did in this study.

The goal of the NSES to achieve scientific literacy for all in the United States has not been achieved (AAAS, 2008; TIMSS, 2007). One reason is the lack of appropriate preparation of teachers in inquiry and the nature of science. In this study, pre-service science teachers were found to develop both skills of inquiry instruction and conceptions of the nature of science. Developing skills of investigation, manipulation of materials, and viewing science as developmental, creative, testable and unified is essential to elementary students, because of the importance of building adequate conceptions of the NOS early on that will greatly impact the students' future science education.

This study investigated two major criteria called for by the science education reform agendas, the conceptions of the nature of science and the use of inquiry instruction, both of which deserve more attention, especially for pre-service elementary teachers. One result of this study indicated that participating pre-service elementary teachers' conceptions of the NOS have generally shown a slight instrumentalist view. Elementary pre-service teachers showed an increased of the NOS from the beginning to the end of semester. Pre-service elementary teachers may develop understanding about views of the nature of science while using "hands-on" inquiry teaching approach.

The preparation of teachers in using inquiry and subsequently promoting conceptions of science helps in achieving the goal of scientific literacy for students. When elementary students are allowed to investigate and discover learning for themselves their comprehension of concepts and processes are at a higher level. In holding students accountable for their own learning, they discover facts and concepts beyond the intended objectives and, in turn, learning becomes meaningful to them. Results of this study may be used to improve elementary science methods courses to better prepare science teachers.

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