Journal of Science Education
*Volume: I, Issue I, 2019, 39-50*

# Development of Successful Science Education Research: The Contribution of the Late Professor Alex H. Johnstone

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## Abstract

This is the first of a series of review papers. This paper reviews the very considerable contribution of the late Professor Alex H Johnstone to the world of science education research. The aim is to show the main areas he explored and the way he directed his research work which was almost entirely undertaken by his research students. Starting his research in the 1960s, he looked at the areas of difficulty that school students faced in understanding highly conceptual subjects like chemistry. He found the fundamental reason why such difficulties are to be seen and then applied this finding to all areas of teaching and learning at school and at university stages. In this, he made major contributions to formal teaching (like lecturing), group work, laboratory work and assessment. The impact of his work is evaluated and key aspects identified. For many years, he was the Director of the Centre for Science Education at the University of Glasgow, Scotland. Here, he supervised perhaps 100 research students from many countries. He received numerous awards and published a very large number of papers as well as twenty books. He directed research following approaches well established in other disciplines. Overall, he offered model for undertaking quality research which can guide and inspire us for the future.

***Keywords:*** science education, working memory, conceptual understanding

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## Introduction

After a long and illustrious career, Professor Johnstone died in December 2018 at the age of 87. After 13 years teaching chemistry at school level, Professor Johnstone was invited to start research programmes which explored the learning of chemistry and related subjects. Professor Johnstone was required to teach university chemistry but directed research in the learning of disciplines like chemistry, at both school and university levels. Professor Johnstone was the founding Director of the Centre for Science Education at the University of Glasgow, a Centre with international status. After transfer from the Faculty of Science to the Faculty of Education, it was undermined and closed by that Faculty, the world losing one of its best educational research centres.

Professor Johnstone published around 140 research papers, mostly in primary international status journals along with over 20 books. In addition, he contributed several book chapters, monographs, sets of teaching materials along with many reports, reviews and working papers. Professor Johnstone was a much sought-after international conference speaker, generating a vast range of conference proceedings. Professor Johnstone was recognised in many countries beyond his native Scotland with top awards for his services to education research. These included: the Nyholm Medal of the Royal Society of Chemistry, the Mellor Medal of the Royal Australian Chemical Institute, the Illuminati Gold Medal of the Italian Chemical Society, the Brasted Medal of the American Chemical Society, the Verhagen Titular Chair of the University of Limburg, Belgium.

A symposium took place in September, 2018 at Warsaw to celebrate his contribution to educational research in the sciences. The impact of his research is difficult to overstate. His papers - even his early papers - are cited repeatedly. His clear, creative insights – all based on tight research evidence linked to extensive teaching experience – have changed the teaching of the sciences at university levels in major ways. Sadly, his work has not been taken up so much in schools where school teachers are often mandated to follow procedures and practices that are frequently inconsistent with research evidence. Nonetheless, his major school textbooks did make a major impact for many decades.

## Objectives of This Series of Reviews

This paper seeks to review what we can learn today from Johnstone's remarkably successful career in science education research. We shall consider how Professor Johnstone reached some of his major breakthroughs, where these made an impact, and the kinds of strategies he employed in his research programmes. In subsequent reviews, we shall look at some of his specific findings which are widely considered to have revolutionised the way learning is understood today (Figure 1).

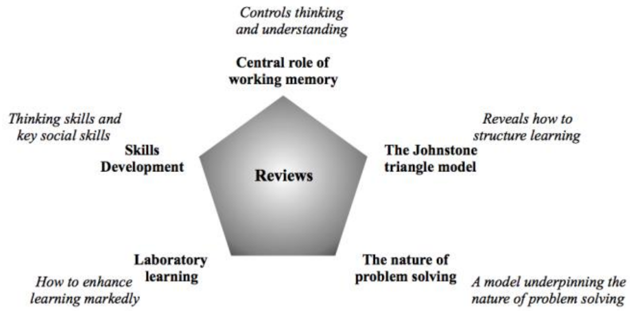


*Figure 1*: Themes for forthcoming reviews

Johnstone based his findings on tight research evidence and the set of reviews offered here (and subsequent issues) will reflect this. Each review will consider the research evidence but, as appropriate, will then update this by reference to later studies. The aim is that each review can generate an agenda for action for future research, based closely on what is now known.

## The Approach to Research

It is interesting to observe that, throughout the world today, much educational research is often not conducted in schools of education and faculties of education. There are major programmes of research being undertaken within subject departments in universities worldwide. These range from engineering and medical research related to learning in these areas, as well as much educational research in the major science disciplines, mathematics, and the learning of languages. Alongside this, there are numerous educational research centres where the centre works across several university departments. The former Centre for Science Education at the University of Glasgow worked right across all the subject disciplines in the Faculty of Science. Its international impact over several decades is difficult to underestimate but its approaches differed markedly from those employed in typical education faculties. Professor Alex H Johnstone was the first director of this centre and this set the high standards of the centre.

Overall, the research approach developed by Johnstone reflected much worldwide research in university subject departments but, in this, Professor Johnstone was an international pioneer. Professor Johnstone never lost the centrality of the learners in his research enquiries. In simple terms, his educational research often grew out of his teaching practice. Professor Johnstone was an acute observer, highly creative in his thinking but Professor Johnstone also had a deep empathy for learners. Professor Johnstone always responded positively when learners approached him when they were facing difficulties.

## Developing Research

In the late 1950s, as a young school teacher, Johnstone had a major input into the development of a new national curriculum in chemistry (Curriculum Papers 512, 1962) for all Scottish Schools. Scotland has one of the oldest education systems in the world and is European in structure (like the International Baccaleaurate) but very different from its neighbour England. In Scotland, 95% of all students attend state comprehensive schools, a system that works well. The curriculum of 1962 was incredibly successful and the enduring popularity of chemistry (along with the other sciences and mathematics) in Scotland owes much to this work (Johnstone, 1974). Working with a colleague, Professor Johnstone developed a set of school textbooks (Johnstone and Morrison, 1964-69) which changed the entire way chemistry was taught throughout his country. Professor Johnstone was also deeply involved with the difficult area of assessment and this generated another book (Johnstone*et al.*, 1970) as well as numerous reports and papers (eg. Bahar e*t al.*, 1999).

Based on the then known findings, Professor Johnstone worked with a colleague in developing a school-university text focussing on the difficult area of thermodynamics. This made the entire area accessible for learners (Johnstone and Webb, 1977). Later, in 1980, along with two colleagues he developed another school textbook which brought in findings from his research in influencing the way chemistry was presented (Johnstone*et al.*, 1980). This is perhaps the first school textbook in which the way the material was presented was based on research evidence related to understanding.

In all this, his aim was to develop conceptual understanding, at a level which allowed learners to be able to apply ideas, appreciating how they could be applied in wider society. In his curriculum thinking, Professor Johnstone was well ahead of his contemporaries. Sadly, many of his remarkable insights were lost as the educational establishment reverted to traditional (and often less effective) ways of presenting subject material.

## Formal Research

In 1969, Professor Johnstone started by considering where the school learners were finding it difficult to achieve understanding (Johnstone and Sharp, 1979). Professor Johnstone then took on many PhD students. Professor Johnstone allocated to each an area of known difficulty, with the goal in trying to find out how to reduce the difficulties in gaining understanding. For example, Johnstone and Percival (1976) started to look at lecturing and this was followed up by Johnstone and Su (1994). Johnstone and Mahmoud (1980) employed a simple way to pinpoint topics of difficulty, a method which was later applied in Pakistan in mathematics (Ali and Reid, 2012). Numerous useful insights were uncovered until, in the early 1980s, a PhD student saw patterns in her data that pointed to the underlying reason for the difficulties (Johnstone and Kellett, 1980). His following PhD student tested her hypothesis and confirmed that she was correct (Johnstone and El-Banna, 1986, 1989). This work has been summarised in numerous places (Johnstone 1991, 1997, 2000a,b).

Alongside this, Johnstone considered the area of attitudes in relation to learning in the sciences. Again, he allocated various projects to PhD students and, in one study, the way attitudes in relation to learning in the sciences changed from about the age of 10 to about age 14 was followed (Hadden and Johnstone, 1982, 1983a,b). This pinpointed precisely where the problems lay. It is interesting to note that this work was based on findings from a previous PhD student which, in turn, built on the findings from a previous Masters thesis (a Masters by research). The work was later followed up and expanded in Physics (Reid and Skryabina, 2002, 2003).

These studies illustrate the way good research is undertaken in most subject areas in universities. The research director or supervisor allocates the projects, usually following discussions with the student. Johnstone never employed projects proposals, he never set up research questions and he never expected methodology chapters in the theses his students wrote. This is why the outcomes from PhD programmes in the sciences and related disciplines are so successful. The supervisor is aware of what is known and where there are problems yet to be addressed. An intending

PhD student cannot know this unless he or she spends up to a year reading the literature.

Similarly, research questions more or less pre-determine what is going to be found and often this makes research trivial. Johnstone expected students to make genuine findings and that these findings would be sufficiently generalisable and important that they would be readily published in international journals. Most of his papers in such journals were co-authored with his PhD students (typical in most other university discipline areas). It is interesting to note the way he attracted research students from all over the world, his reputation as an outstanding supervisor being very well established.

If we look closely at methodology chapters in most theses in education, much of what is written is trivial and obvious, with thesis after thesis simply repeating each other. Johnstone never directed projects that simply gathered the opinions of others by means of questionnaires, interviews and focus groups.

When looking at attitudes in relation to science, Johnstone sometimes employed questionnaires or interviews but we need to recognise that attitude measurement is very different from the collation of perceptions. Thus, Johnstone never directed any research that simply looked at perceptions which are simply collated opinions. Indeed, in the same way that medical research aims to bring benefit for future patients, educational research must aim to bring benefits to future learners. Johnstone succeeded in an amazing way. Most PhD studies in education (and much educational research in general) rarely achieve this.

One of the great successes in much research in universities today is that it allows the research to move into the genuinely unknown. Research projects change and develop in ways that cannot be predicted or planned. Sadly, the widespread use of '*project proposals'* in education more or less closes the door to this genuine open-ness. Johnstone rejected this approach completely and Professor Johnstone rigorously applied the highest standards of research into the field of education and, as a result, made some amazing discoveries (eg. Johnstone*et al.,* 1981; Johnstone and Reid, 1981; Johnstone, 1983; Byrne and Johnstone, 1987; Johnstone and El-Banna, 1989; Johnstone, 1991; Johnstone and Al-Naeme, 1991; Johnstone*et al.,* 1994, 1998; Bahar*et al.*, 2000).

Over the years, Johnstone supervised perhaps about 100 research students. The theses that were generated by his students are frequently consulted by other researchers. Indeed, on many occasions, a PhD student starting work with him would be given a previous thesis, with the instructions to think about the possible next stages of enquiry arising from this previous work. In this way, PhD studies developed from each other to make a coherent whole. Sadly, this approach is rare in education today where the use of research proposals generate projects that rarely form a coherent whole with other studies.

It is also interesting to note the citation rates for many of his papers. The most cited papers are the ones which directly affect the practicalities of teaching. The number of citations, even of his older papers, is remarkable, indicating that the work is still seen as highly useful. In his later years, Professor Johnstone expressed amazement at the endless requests from all over the world for electronic off-prints of his papers, even his earliest papers.

## Real Research

Johnstone understood the nature of real research. It had to be conducted with the same rigour that is used in other subject areas. It moves into the unknown where it is impossible to predict what might be found. What marked out the work of Johnstone in science education was the way he used his ongoing teaching experience to identify key issues. Professor Johnstone focused relentlessly on the learner and how to bring benefit to future learners.

Professor Johnstone never became side-tracked with ‘*theories*’. The word ‘*theory*’ is confusing in that it has multiple meanings. Education texts often use the word in multiple ways, often leaving readers bewildered. In fact, many so-called educational ‘*theories*’ are often little more than the opinions, lacking a tight evidential basis. The excellent book by Aubrey and Riley (2016) illustrates the wide variation in the way the word is used.

Professor Johnstone never asked his students to collate perceptions gathered through questionnaires, interviews or focus groups: he saw that these merely gathering opinions. Professor Johnstone always aimed at gaining insights that had potential to benefit future learners. Professor Johnstone listened to his chemistry students. Professor Johnstone listened to his PhD students, most of whom were experienced teachers or lecturers. Professor Johnstone was always prepared to allow a PhD study to move in unexpected directions. Professor Johnstone took risks in seeking new ways to make useful measurements. Professor Johnstone stressed the essential nature of validity in interpreting all measurements, leaving reliability largely to look after itself (it usually does - see Reid, 2003). Professor Johnstone certainly never resorted to spurious statistics to support reliability.

## Impact

It is a worldwide observation that educational research rarely brings about any changes in teaching and learning in schools (Slavin, 2002; Gardner, 2011). Equally, it is interesting to observe, at least in science education and related areas, that research has made a very positive effect on university teaching and learning. One example relates to university laboratory work. In the 1990s, on the basis of what research had revealed about the central role of working memory in all learning, Johnstone predicted that specific strategies would enhance learning in university laboratories. Two PhD students tested this in different ways, one in physics, one in chemistry, with evidence that marked improvements in understanding had been generated (Johnstone*et al.*, 1994, 1998). A later review monograph looked at what was happening across universities in chemistry laboratory learning in three countries and found that the findings of Johnstone related to laboratory work in chemistry were being applied widely (Carnduff and Reid, 2003).

Johnstone recognised that school teachers are rarely free to implement research findings. They do not design the curricula, they do not control the textbooks, they do not design the assessment in national examinations and they do not even determine the resources available to them. There is evidence to show that when school teachers are given some genuine freedoms, then the outcomes for learners can be enhanced (Ali and Reid, 2012).

## Key Messages for Today

Johnstone wrote several papers that are worth studying in some detail. His writing showed great clarity, with the absence of meaningless jargon and spurious abstraction. For example, his paper on pre-learning in physics laboratories is an example of outstanding clarity (Johnstone*et al.*, 1998) while his incisive thinking and clarity of expression can be seen in Johnstone (2000).

Professor Johnstone employed statistics with great care and only employed it when appropriate. Professor Johnstone gained his central findings on limited working memory capacity by an elegant approach (Johnstone and El-Banna, 1986, 1989). In addition, Professor Johnstone was highly creative in making measurements (Johnstone *et al.*, 1994).

Professor Johnstone carefully avoided assuming any *'theoretical'* position (which can bias deductions), also avoiding the use of research proposals, research questions, hypotheses, as well as methodology chapters. These can be shown to be restrictive and counter-productive. Professor Johnstone drew his conclusions based tightly on evidence, with clear evidence of validity (although he rarely used the word). This can be seen in the way data were analysed in the three papers related to attitudes to science (Hadden and Johnstone (1982a, b; 1983). In these papers, Professor Johnstone did not make the statistical errors which are common in many education papers in the handling of ordinal data.

Professor Johnstone directed projects with students and they learned how to do research by *doing* research. The projects undertaken were directly relevant to the actual practice of teaching and learning and were likely to offer insights that might enhance future learning. A study of the titles of collations of these theses with the titles of the papers that came directly from them confirms the kind of work he directed so successfully.

## Conclusion

Overall, Alex H Johnstone brought the rigorous research approaches common in most scientific research and applied these in seeking to gain new insights on all aspects of learning in the sciences and related subject disciplines. He based his research on the needs and aspirations of students, school and university students. Professor Johnstone communicated his findings, verbally and in writing, with great clarity. Professor Johnstone allowed his creative mind, his endless sense of humour and his love of learning to inspire large numbers of researchers worldwide and brought enormous benefits to successive generations of learners. His standards, his humanity and his rigorous approaches give us a model for today and we have a responsibility to build his findings for the benefit of future students.

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***Citation of this Article:***

Reid, N. (2019). Development of successful science education research: The contribution of the late professor Alex H. Johnstone. *Journal of Science Education, 1*(1), 39-50.