ALCHEMY: MAGIC AND ILLUSION IN SCIENCE EDUCATION

R. Tynan

Liverpool John Moores University (UNITED KINGDOM)

Abstract

Magic for entertainment can be defined as a performance art based upon demonstrating phenomena seemingly impossible according to science. In school, science teachers need to engage learners and convince them of the merits of science and technology. Magical entertainment and science appear incompatible, one involving honest deceit and the other the quest for knowledge about reality. Historically, all forms of magic and science were once conjoined by those who practiced Alchemy. A modern-day Alchemy fusing Science and Magic for entertainment has the power to engage school age learners, helping them to develop and remember science concepts [1] [2].

The author has worked in teacher education since 2007 and was previously a secondary school science teacher for twenty-seven years. He is also a third-generation magical entertainer and member of The Magic Circle, whose parents and grandparents were full time professional magicians.

Arising from his own use of magic and illusion in science lessons, the Alchemy Lecture materials arose from materials and activities that evolved during several education projects and delivered activities, sessions and lectures to a variety of audiences of differing ages and interests. So far these have included enrichment activities for primary school science learners, examination revision sessions for secondary school learners, science outreach projects for secondary learners in deprived areas, creativity in science sessions for pre-service teachers, and entertainment and interest lectures for magician organizations and science professional bodies.

The Alchemy Lecture materials can be organised according to several themes according to audience age range and interests although all themes can be amended to enable all to access and engage with its activities. The themes are:

The history of alchemists: what science and natural magic had in common and why it couldn't last.
Scientific and technological explanations for supernatural phenomena in history.
Magical illusions with explanations to be found in school science and mathematics curricula.
Using magic illusions to help develop science concepts.
The chemistry of pyrotechnics.
Paranormal research, sceptics and the partnership between scientists and magicians.

These pedagogical approaches to science learning will be discussed in the proceedings paper and selected interactive examples shared in the presentation.

Keywords: Magic, mentalism, illusion, science learning, engagement, motivation, problem solving, alchemy, concept development, creative thinking.

1 INTRODUCTION

Magic and science have more in common than it first seems. Natural magicians seek to predict and control outcomes in their environment by use of their voice and objects, in a world of spells, amulets, mandalas and arcane knowledge [3]. Scientists seek to predict and control outcomes in their environment using theories regarding the behaviour of forces, materials, energy and living processes. Medieval alchemists studied magic and science simultaneously, using experiments as their arbiter of facts for both [4]. Alchemists often relied on rich patrons for their survival, so it was important that they provided them with useful technology whilst they continued their progress towards the major work of alchemy, the discovery of the philosopher's stone [4]. Many early scientific discoveries such as the distillation of alcohols and purification of phosphorus were the result of alchemist activities [4]. However, science developed away from alchemy over time, as it alone provided repeatable experimental evidence

so that outcomes could be reliably predicted [4]. There have been some notable alchemists including Sir Isaac Newton (1642-1727) and Ernest Rutherford (1871-1937) whose scientific achievements have been well documented [4]. Rutherford is often cited as the only alchemist to have turned base metal into gold but only in a nuclear reactor [4].

It is probable that the first examples of performance magic were linked to emotionally charged religious practices [3]. Magic performances as entertainments probably arose simultaneously or soon after [3]. It is often supposed that early magical entertainers were always in danger of being accused of occult powers, but Lamont and Steinmeyer [5] argue that audiences and the general public throughout history have never experienced any real difficulty distinguishing between natural magicians, magical entertainers, and charlatans. Charlatans claim the ability to demonstrate supernatural powers but use performance magician tricks and illusions to achieve this and they are generally shunned by performance magicians. Magical entertainers regard themselves to be 'honest deceivers' with an ethical code regarding how and when it is appropriate to present their skills. Rational modern audiences will suspend disbelief and respond emotionally during a magic show or may treat illusions as a logic puzzle [6] [7]. However, levels of superstition and belief in the paranormal can still be high and appear irrational [6] [7]. It is interesting that performance magicians are now often consulted in scientific studies of the paranormal to double check that conditions are fully controlled and to offer advice on methods for reproducing paranormal phenomena using trickery.

Currently a modern alchemy is developing between performance magic and science education where magical entertainment is used to engage science learners and facilitate their understanding and recall of science concepts. There is increasing evidence that pedagogical interventions involving performance magic can have a range of educational benefits for learners in a range of subjects and educational areas [1] [2]. The author's background as a third-generation performance magician enabled him to include magic stunts, effects and illusions in science lessons when he became a teacher, albeit initially as an incentive to complete work. However, it was not long before the magic was included for particular educational purposes. When the author became a teacher educator, the current Alchemy materials were developed over two decades as a novel approach to science outreach activities in primary and secondary schools in the northwest of England and later extended to be accessible and useful to other organisations such as the Royal Society of Chemistry and Magic Societies around the United Kingdom (UK). The activities can be delivered to all age ranges, but the content focus can be altered to suit the interests of different audiences. The common aim of the materials is to engage the audience with aspects of science, exploring science concepts and making them memorable through a link to magic effects or illusions. The ethical code of magicians dictates that only effects already available in the public domain can be revealed and taught when the lecture is delivered to non-magician audiences. As performance magic is now a world-wide hobby activity, this is less about keeping secrets to maintain public interest in watching magic and more about avoiding infringing the commercial and intellectual property rights of professional magicians, inventors and builders.

2 METHODOLOGY

This study is an initial instrumental case study, constituting pedagogical practitioner research focusing upon a theme rather than a case. It is based upon document analysis and participant observation of a series of activities linking performance magic and science education, developed over several decades and collated in the Alchemy Lectures. As such, it poses no ethical issues using British Education Research Association (BERA) guidelines [8]

The main research questions were:

Can teaching magic effects based upon scientific *modus operandi* help learners understand science concepts and make them more memorable?

Can mind experiments demonstrated through magic effects help learners understand and remember science concepts?

Can the science used in paranormal investigations help learners understand and remember science disciplinary knowledge?

Examples of the Alchemy Lecture materials discussed that could illuminate these research questions have been selected from these areas:

The history of alchemists: what science and natural magic had in common and why it couldn't last.

Scientific and technological explanations for supernatural phenomena in history.

Magical illusions with explanations to be found in school science and mathematics curricula.

Using magic illusions to help develop science concepts.

The chemistry of pyrotechnics.

Paranormal research, sceptics and the partnership between scientists and magicians.

3 MAIN ARGUMENTS

The Office for Standards in Education, Children Services and Skill (Ofsted) recently reviewed and reported upon science education in England [9]. Although teachers in England are not expected to adopt Ofsted terminology in their daily work, inspectors will be using the terms substantive and disciplinary knowledge when referring to existing science knowledge and the research methods leading to new knowledge respectively [9]. The report highlights that strong science teaching shared some common elements including clear aims for activities, considered sequencing, the integration of substantive and disciplinary knowledge, predicting misconceptions and relating new learning to other parts of the curriculum [9]. It also suggests that more curriculum time should be allocated to exploring concepts and reviewing them [9]. The use of the Alchemy Lecture materials and activities are consistent with the recommendations of this report when used in conjunction with a variety of pedagogical strategies.

The general approaches include the illustration of historical links between science and magic, teaching magic effects that have *modus operandi* explained by school curriculum science, using tricks and illusions to conduct mind experiments that explore science concepts, exploring the chemistry of pyrotechnics, and the scientific investigation of paranormal phenomena. Some examples of these approaches are briefly described and discussed below.

3.1 Historical approach: The Alchemists

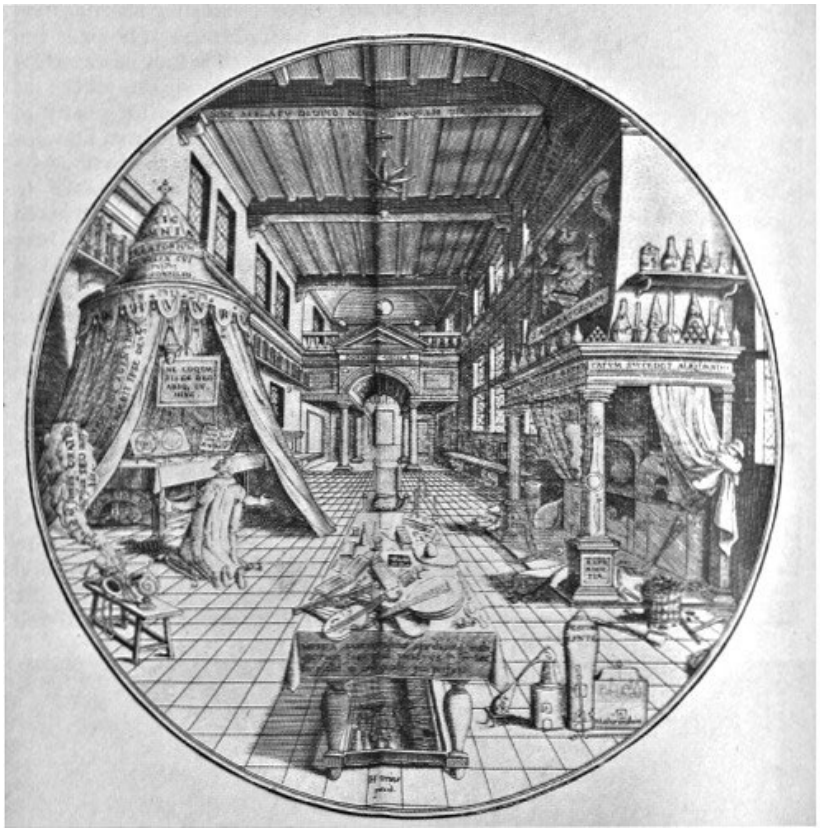

Figure 1 The Alchemist's Laboratory depicted by Heinrich Khunrath in Amphitheatrum sapientiae aeternae, 1595

Khunrath's depiction of a medieval alchemist's laboratory (Fig. 1) provides an excellent starting point for a discussion of the nature of alchemy. The table of musical instruments is central due to the mathematical nature of harmony, and the precision and accuracy needed to build and maintain high quality instruments. Also in the fore ground is a distillation apparatus. Various jars and containers hint at chemicals and specimens collected or produced in the laboratory. However, the alchemist is also shown practicing magic, using spells and ritual. Alchemists divided their time between minor and major works, all aimed at achieving their ultimate goals of transforming base metals into gold and producing an elixir of perpetual youth [4]. Depending on patronage, they would also use their investigations to invent and develop other useful technology [4]. There were several reasons scientists diverged from alchemists [4]. However, the Christian church's extreme antipathy towards all forms of magic would have increasingly caused alchemists to keep their works secret, and patronage was increasingly directed towards the arts and more reliable sciences [4]. Discussion of these ideas has been successfully used to explore the similarities and differences between natural magic and scientific investigations and develop science disciplinary knowledge.

A narrative account of famous scientists with and interest in alchemy can also develop both substantive and disciplinary knowledge. Did Sir Isaac Newton (1643-1727) really report seven instead of six colours when he split white light with prisms because seven is an important number in Alchemy? Although theoretically possible, was pioneer nuclear physicist Ernest Rutherford (1871-1937) the only alchemist to transmute base metal into gold in a nuclear reactor? Whether these are myths or true, researching historical scientists can develop learners' substantive and disciplinary knowledge of the research areas involved: light, radioactivity and the structure of the atom.

3.2 Historical approach: Heron of Alexandria (c. 10-70 CE)

Examples of the historical use of science and technology to achieve illusions of supernatural phenomena can be used to develop learners' understanding of substantive science knowledge. Fig. 2 is an illustration of Heron of Alexandria's mechanism for automatically opening temple doors when a brazier is lit outside the doors and closing them again when it extinguished. Heron was a Greek Egyptian mathematician and prolific inventor. He also invented a coin operated holy water dispenser. A discussion of the workings of the apparatus developed learners' understanding of the expansion of liquids, balanced and unbalanced forces, hydraulics, siphoning, pulleys and torque. The doors open and close due to the changing differences in weight between a counterweight and a water container as water in the brazier heats up or cools down. Pulleys and a rope enable the downward motion of the weights to be converted into rotational movement. The hot water expands, and when the weight of the water container exceeds the counterweight, the doors open. As the water cools again is siphoned out of the container until the counterweight is heavier to close the doors. Lamont and Steinmeyer [5] suggest that this may not have been intended to deceive the gullible but to add theatre to a temple visit.

Figure 2 Heron of Alexandria's invention number 37, Pneumatics

3.3 Magic effects with explanations to be found in the public domain often in school curricula

The Alchemy Lecture usually contains a series of tricks, effects and illusions that fit into this category. In this short paper there is only room to describe the use of one. Usually a magical stunt, experiment or effect is demonstrated, then the scientific *modus operandi* is revealed and its location in the school science curriculum in England discussed. The audience is invited to learn and practice the effect on each other before moving on to the next. This section has wide ranging appeal to school age learners, teachers, magicians and scientists. The example chosen is the introductory effect, which has less full audience participation than those that follow but sets out the aims of the section very clearly and involves an apparatus often found in secondary school physics departments.

A volunteer inspects a metal tube with holes and small metal plug (Fig. 3), both described as brass by the lecturer. They are asked to participate in an experiment to slow down time. The holes are sight holes so that the volunteer and audience can see the passage of the plug down the tube. The lecturer holds the tube vertically and challenges the volunteer to catch the plug as it falls out of the bottom, once it is released. The lecturer demonstrates by releasing the plug, which falls through the tube in less than a second and catching it with their other hand. The volunteer can place their hands anywhere and usually opt for a position just below the bottom of the tube. They, of course, meet the challenge easily and are applauded by the audience. The lecturer then asks the audience to concentrate on slowing down time and asks the volunteer to repeat the challenge but starting four or five paces away from the tube. As time will be slowed, they should be able to walk towards the tube and catch the plug easily. Although all participating will be skeptical, the plug is released and passes very slowly down the tube with the volunteer catching it on exit. An apparent demonstration of slowing time down!

Figure 3 Newton's Nightmare

The secret is then revealed. The lecturer was not truthful about the materials involved at the start. The tube is actually made from copper and on the second occasion the lecturer swaps the brass plug for an identical plug made from a neodymium alloy, a super magnet. Fig. 4 shows a slide (partly animated in the presentation) used to locate the secondary school science that explains how the magnet moving down the tube induces an electric current in the copper tube and a second associated magnetic field. The two magnetic fields interact to slow the movement of the plug.

The apparatus is called Newton's Nightmare as the plug apparently defies gravity. It can be purchased quite cheaply from gadget and joke shops in the UK. Our own anecdotal evidence is that this is an engaging and memorable demonstration involving some challenging physics substantive knowledge in its explanation. Revealing its *modus operandi* does not infringe commercial rights as it is cheaper and easier to buy than make from first principles. In science departments a slightly different version may be encountered with a shorter, wider copper tube. In this version the plug is spun round the inside of the tube (like a roulette wheel ball) and because of the induced magnetic field induced in the copper maintains its motion for extended periods of time.

Figure 4 The explanation

3.4 Magic effects that can be used as scientific mind experiments

An example of a magic effect that can be used for a mind experiment is any version of the linking rings. This is a memorable way to explore novel applications of science concepts in the last stages of concept development (Fig. 5).

Figure 5 Linking two rings to explore science concepts

A demonstration of linking rings can be used to explore several areas of substantive and disciplinary knowledge. The question posed by the mind experiment is: if atoms are mainly space and particles in solids vibrate around a fixed point, if you stop their motion by reducing the temperature to absolute zero could two metal rings pass through each other? Lots of strange things happen to materials at very low temperatures.

The areas of substantive knowledge embraced by a discussion of this mind experiment are particle theory, solids, liquids, gases, changes of state, supercooling, atomic structure, kinetic energy,

temperature and heat. The disciplinary knowledge arises from questioning the assumptions made in the question. For examples Rutherford's experiments with electron beams and gold leaf are classic investigations establishing the compact nature of the nucleus.

3.5 Magic pyrotechnics

If a venue accepts the risk assessments, magic pyrotechnic products can be used to explore many aspects of science. Magical apparatus is available to ignite puffs of powder, traditionally lycopodium spores, to demonstrate the combustion triangle and the effect of increased fuel surface area. Other apparatus can be used to demonstrate flash products (Fig. 6). Polymerisation and substitution can be explored through a discussion of these nitrocellulose-based products. The addition of metal filings to produce different coloured sparkle effects can be used to support the learning of flame tests.

Figure 6 Chemistry outreach event, using flash string

Fig. 7 is a diagram of a two-monomer section of cellulose fully nitrified. Depending upon the age and science interests of the audience more, or less, chemistry can be included in the presentation: glucose structure, alpha and beta isomers of ring forms, condensation reactions, substitution of nitrate for hydroxyl groups in the polymer. Nitrocellulose can be made from any plant-based material containing cellulose and magicians use flash string, cloth, cotton wool and paper in performances as appropriate. All share the common properties of burning rapidly and completely with a bright orange flame at a relatively cool temperature leaving little or no ash. Igniting small quantities in the hand is safe, especially if commercially produced flash products and igniters are use.

However, its properties and historical development can make an engaging investigation for chemistry learners. If the majority of glucose monomers in a cellulose fibre have all three available hydroxyl groups replaced by nitrate groups, nitrocellulose contains around 14% nitrogen. Initially developed as a weapon, it was considered too unstable and unsuitable. Percentage nitrification above 12.6% was considered explosive. Magician's flash products contain around 11% nitrogen (two substituted nitrate groups per monomer) and are not explosive but still highly combustible. In 1862 Alexander Parkes developed a transparent form of 11% nitrocellulose, called Parkesine, that was used by the early motion picture industry. The Parkesine was likely to combust in the damp, hot conditions found in a film projection box with any build-up of static electricity and/or friction or in the event of a jammed film. It was eventually replaced by safer acetate-based Celluloid developed by John Wesley Hyat in 1868. It was important for projectionists to know which type of film they were using as a Parkesine couldn't be smothered using a fire blanket (nitrate is an oxidant) and Celluloid couldn't be extinguished using water.

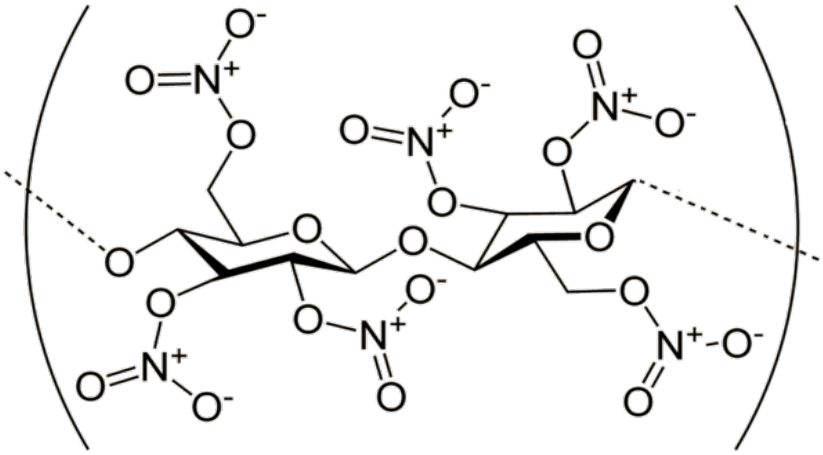

Figure 7 Nitrocellulose

3.6 Magicians collaborating in paranorormal research

The Amazing Randi (1928-2020) (Fig. 8) was a Canadian American magician who became the most famous paranormal sceptic since Harry Houdini. He investigated paranormal, occult and supernatural claims and was co-founder of the Committee for Sceptical Inquiry (CSI) and The James Randi Foundation for Education (JREF). The JREF's One Million Dollar Paranormal Challenge for any paranormal, occult or supernatural phenomena demonstrated under test conditions acceptable to both parties sought to identify unexplained phenomena that a performance magician or mentalist could not replicate using natural means. Paranormal researchers using scientific test conditions were repeatedly fooled by charlatans until they collaborated with performing magic advisers who added further controls that considered known *modus operandi* from their specialist performance fields. Claims by exponents of the paranormal that their powers have been scientifically tested have not stood up to independent verification. The JREF prize money remains unclaimed.

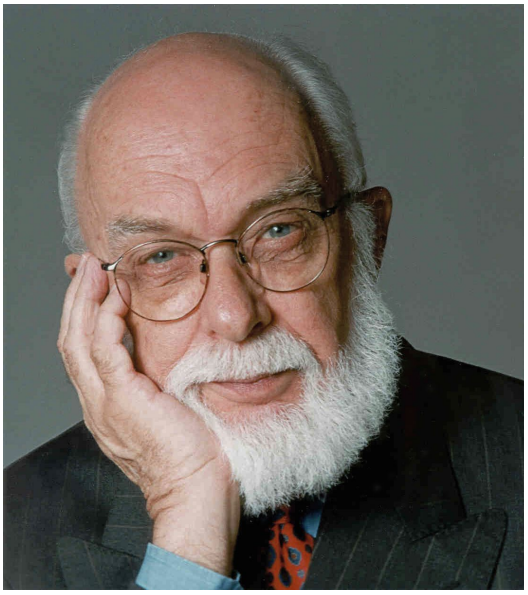

Figure 8 James Randi c. 1990 by James Randi Educational Foundation

During some versions of the Alchemy Lecture packs of Rhine Cards (Fig. 9) have been distributed to the audience on order to replicate a simplified extra sensory perception (ESP) trial. Science disciplinary knowledge can be developed whilst setting up controlled test conditions and, for older audiences,

statistical analysis can be introduced to make objective decisions about the significance of success rates greater than those due to random guessing (Fig. 9).

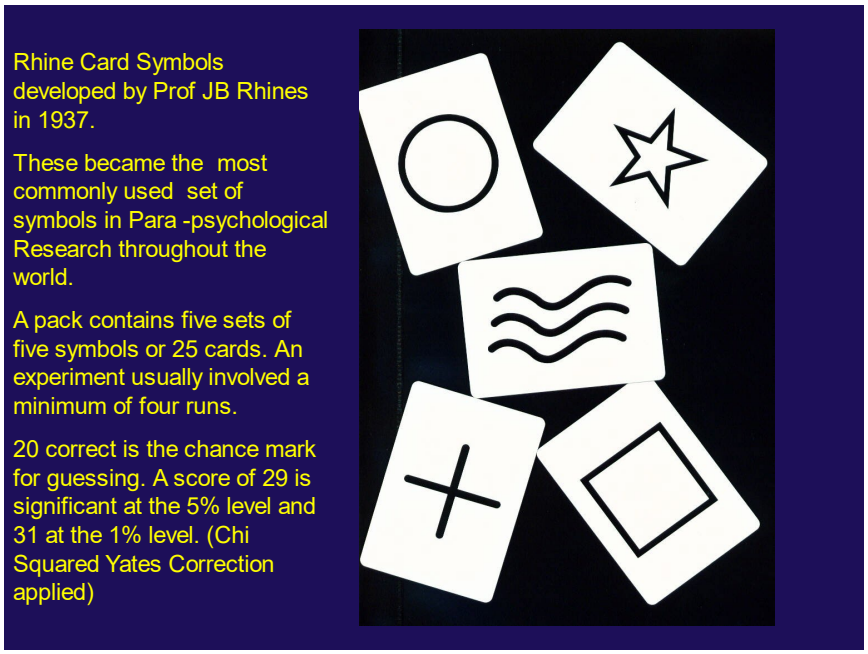

Figure 9 Testing extra sensory perception (ESP) with Rhine Cards

The scientific evidence for other paranormal phenomena can also be discussed and scientific explanations for phenomena researched. For instance, why is the experience of ghosts an individual phenomenon. Two people in the same place and time may experience a haunting but never agree on what they saw, heard or felt [7]. Similarly, it appears quite easy to convince rational people that fortune tellers and mediums have seen their future or know things about their past they couldn't possibly know. This is despite the traditional methods passed down through generations and often rediscovered by charlatans and con artists are well researched and often reported [6] [7]. The section can also be used to compare apparent paranormal demonstrations achieved through illusion with their characteristics that can be scientifically verified, and this allows a thorough exploration of science disciplinary knowledge.

4 CONCLUSIONS

The Alchemy Lecture materials (Fig. 10) are adaptable and flexible and have been successfully delivered in various formats and contexts in the UK to Key Stage 3 learners, Key Stage 4 learners, 16–19-year-old learners and adults.

From event feedback, the approach engages audiences and stimulates interest in science and performance magic. So far, we only have anecdotal evidence that it helps some learners recall and understand science concepts and methodology.

The wider utility of the materials has been indicated by teacher educators and magicians who have taken or further adapted some of the activities and demonstrations for inclusion in their own Science and Magic presentations.

The Alchemy materials have been delivered in a range of contexts in conjunction with a chemistry outreach project to schools in deprived areas of Liverpool funded by the Royal Society of Chemistry. The Liverpool Project has recently made contact with ScotCHEM who bring together the chemistry base in Scotland (universities, industry and government) and have a similar outreach project, the Magic of Chemistry. ScotCHEM's aim is to train more science teachers in the use of magic effects that explain substantive and disciplinary chemistry knowledge. Representatives of both projects have made reciprocal visits and it is hoped that a collaboration will develop that allows both schemes to share materials and evaluate the impact of their magic and science projects as they develop.

Figure 10 Royal Society of Chemistry Liverpool Christmas Lecture

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