Chapter 65
Teacher Explanations

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Science teachers' explanatory frameworks – the ways in which they use analogy, metaphor, examples, axioms and concepts and these elements are tied together into a coherent whole – are an increasing focus of interest in science education research. This chapter reviews some of the literature generated as a result of that interest.

There is, however, a surprisingly small amount of existing research literature in relation to what would seem to be a central topic in science education. A search of the ERIC clearinghouse of educational research with the term 'science teach* explain*' yields 1362 hits, but the majority of these focus on student explanations (e.g. Margaretha Ebbers and Pat Rowell 2002) and other issues such as students' generation of analogies (e.g. David Wong 1993a) rather than teacher explanations. Fewer than 35 papers focus in some way on the issues of teacher explanations in science. Some of the work on student explanations is tied in with the growing emphasis on argumentation in science education.

This dearth of research on teacher explanations in part could be because a strong and welcome emphasis on student learning – including constructivist, constructionist and enactivist perspectives – in recent science education research has shifted attention away from the actions and activities of teachers. One purpose of this chapter, however, is to suggest that teacher explanations are not necessarily antithetical to inquiry learning or tied to lecturing, and that teacher explanations are a fruitful field for further research.

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Types of Explanation

Much of the research reported here focuses on verbal explanations given *by* teachers *to* students, often in a lecture-like or demonstration context. David Treagust and Alan Harrison (2000a, b) analysed Richard Feynman's (1994) lectures on physics in exploring the features of explanations, and Zoubeida Dagher and George Cossman (1992) focused on teachers' verbal explanations.

These are not the only kinds of explanations that are given in classrooms, of course. Explanations are often collaboratively generated as part of class discussions, constructed from fragments offered and examined by students and teachers. Students explain scientific ideas to other students (e.g. Lyn Dawes 2004), and this too is an important avenue for developing understanding on the part of both the explainer and the receiver of the explanation.

Teachers also use diagrams and demonstrations to illustrate their verbal explanations, and it could be argued that a proper analysis of the explanation needs to include the whole 'verbal+visual' situation. There is increasing research interest in studying the use of 'scientific visualisations' – computer-based animations and simulations – in science education. John Gilbert et al. (2008) have collected and analysed much of this research, and it can be argued that the use of visualisations falls within the more general discussion of science teaching explanations.

Features of Explanations

David Treagust and Allan Harrison (1999) discussed the issue of explanations in science and science teaching. They noted that secondary school students often confuse explanation with description (Horwood 1988) and drew on David-Hillel Ruben's (1990) work on the philosophy of explanations in discussing explanatory frameworks. Treagust and Harrison note that:

- There are important philosophical and epistemological differences between science explanations and science teaching explanations.
- Science explanations are strictly characterised as theory and evidence-driven, use correct scientific terminology and can include analogical models.
- Science teaching explanations differ in rigour, length and detail, involve varying degrees of 'explain how' and 'explain why', are sometimes open-ended, include human agency and can raise new questions as they answer previous questions.

Strasser (1985) draws a distinction between 'explanation', which he identifies as the mode of the natural sciences, and 'understanding', which he identifies with the 'human sciences', hermeneutics and phenomenology. This distinction is useful in discussing the differences between science explanations, which are law-like, highly generalised and rigidly logical, and science teaching explanations, which can be more fluid and can draw on analogy, anthropomorphism and teleology in order to connect with students' prior understandings and life contexts.

Ruben's (1990) book *Explanation* is in the field of academic philosophy and, although it is interesting and illuminating, it rapidly moves too far into the technical language and esoteric concerns of that discipline to be of direct use to the field of science education.

Judith Edgington (1997) asks 'What constitutes a scientific explanation?' She notes that philosophers, scientists and science educators are all interested in this question, but that each group focuses on different facets of the issue and has different perspectives and concerns. She reviews the literature on explanation in science education, and notes that there is little past research on these issues and considerable potential for future research to be conducted.

Studies of Science Teacher Explanations

The papers briefly discussed above are largely philosophical explorations of the concept of explanation in general and in its application to science education, along with attempts to systematically lay out some of the issues around science teaching explanations. Papers reviewed in this section are more direct research studies of actual explanations offered by teachers to students in classrooms.

Science Disciplines and Levels of Education

Of the 24 studies reviewed here, two are specifically in the field of biology education, eight in physics and five in chemistry. Only one is in the field of earth science. One paper is in elementary science education and another in middle school, whilst six are in high school contexts. The remaining papers identify no specific science discipline and pertain to teacher education or other domains and levels of education.

Types of Teacher Explanation

Dagher and Cossman (1992) observed and audiotaped the science classes of 20 high school teachers and analysed the transcripts using a constant comparative method. They identified 10 different classes of explanations, which they described as analogical, anthropomorphic, functional, genetic, mechanical, metaphysical, practical, rational, tautological and teleological. There is not enough space here to explore all of these different types of explanations individually, but attention has been paid elsewhere in the literature reviewed to the use of analogy, anthropomorphism and teleology in explanation, as well as to avoiding tautology in explanation.

Explanation and Technology

A number of studies have explored issues arising when explanations are given in contexts other than face-to-face, including in web-based teaching and even in situations where the computer itself is developing and delivering explanations.

Daniel Suthers (1991) surveyed a variety of artificial intelligence techniques used for generating explanations for teaching purposes and developed a computer programme – PEG, an acronym for Pedagogical Explanation Generator – that was able to draw on a data set in the physical sciences to provide explanations for students. Whilst we might harbour some doubts about the ability of computer-based explanations to ever supplant human abilities to create, tailor to the context and situation and adapt explanations, Suthers does not claim that that outcome is possible or even desirable. Rather, he suggests that the automated explanations are one 'explanatory resource' amongst many available to students. In many ways, the most interesting feature of this paper is the discussion of the different approaches that have been used in the attempt to allow computers to construct explanations, because it seems plausible at least that these might be analogous to some of the strategies that human explainers use when developing explanations.

Shawn Glynn et al. (2007) explored the use of analogies as explanations in web-based science education contexts. Their paper outlines what analogies are and how they are used in explanation, as well as exploring science teachers' use of analogies. It offers some exemplars of good web-based explanations, as well as guidelines for constructing new analogical explanations on the web.

Victor Sampson and Douglas Clark (2007) describe an online teaching strategy that they describe as 'personally seeded discussion' (i.e. intended to group students into small discussion clusters based on their responses and modes of scientific reasoning). In particular, the software groups students on the basis of their *different* explanations for a particular phenomenon and then asks them to seek consensus. The discussions are focused on helping students to develop a strong understanding of how scientific knowledge is generated, justified and contested and to involve them in scientific argumentation. This work uses teacher explanations both as teachers participate in online discussions and implicitly in the materials developed, and teacher explanations serve as models for students as they learn to explain and argue for their scientific ideas.

Zacharias C. Zacharia (2005) investigated the effect of interactive computer simulations of scientific phenomena on the nature and quality of the explanations offered by science teachers in a postgraduate course on physics content for practising teachers. Zacharia used the Predict-Observe-Explain sequence with the teachers in relation to both the computer-based simulations and more traditional textbook-based assignments on the content, and found that, when the teachers interacted with the computer-based simulations, the explanations that they constructed were richer, more detailed, scientifically more accurate and involved more formal reasoning. This work obviously has implications for science teacher education as well as for the use of technology.

Analogy

Significant research attention has been paid to the use of analogies in teaching science – this work forms the largest single body of literature in relation to explanation in science education.

Paul Thagard (1992) applied a theory about how analogies are used in thinking to the pedagogical use of instruction. The theory is focused on viewing analogies as the 'satisfaction of multiple constraints'. Thagard's theoretical perspective explores approaches to explaining why good analogies are good and bad analogies are bad, in terms of the pragmatic, semantic and structural constraints that form their context. His scheme for judging the quality of analogies, like schemes for judging other kinds of explanations, is valuable in science education and has not yet been sufficiently operationalised into a programme of research.

David Wong (1993b) asked 11 students who were training to be secondary school science teachers to generate explanations for a piston-and-cylinder device and noted features of the analogies that they generated in this situation where knowledge was being generated from fragmented, incomplete prior knowledge rather than from a well-organised and well-understood field of knowledge. Wong summarises his findings as follows:

> The results provide empirical support for the generative properties of analogies; that is, analogies can stimulate new inferences and insight. Furthermore, under specific conditions, individuals can productively harness the generative capacity of their own analogies to advance their conceptual understanding of scientific phenomena. (p. 1259)

Samson Nashon (2004) recorded the kinds of analogies used by three Kenyan Grade 10 physics teachers. He determined that many of the analogies used were connected to the students' life worlds – Nashon uses the term 'environmental' – whilst a number were also anthropomorphic in nature. Nashon prefers teachers to use what he identifies as 'scientific' analogies, in which both the target concept and the analogy fall within the domain of scientific knowledge. However, it could be argued that analogies that use features of the students' own life experience to help them to understand the target scientific concepts might be valuable both in enhancing understanding and in keeping students interested in science. Nashon also notes that careless or unskilled use of analogies can lead to misconceptions, and to students carrying misunderstandings about the analogue across to the target concept. He suggests that teachers should plan their use of analogies carefully and explore with students their understanding of the analogue and the analogy in order to ensure that their understanding of the target concept is as robust and scientifically accurate as possible.

David Brown and John Clement (1989) suggest that much research on analogies in science education focuses on situations in which students do not have any knowledge or understanding of the target concept. By contrast, they explored the situation in which students already believed that they understood the target concept. They note that, in this situation, it is conceptual change in Posner et al.'s (1982) terminology, rather than conceptual development, which is the goal of the instruction using analogies. In conducting four case studies of tutoring interviews, Brown and Clement identified four factors important for success in using analogies to overcome misconceptions:

1. A useful anchoring conception
2. Explicit development of the analogical connections between an anchoring example and the target situation
3. Interactive engagement and dialogue about the analogy with the student, rather than simply presenting it in a text or lecture
4. The student's active construction of a new explanatory model of the target situation

Rodney Thiele and David Treagust (1994) examined the ways in which four chemistry teachers used analogies to explain concepts. They identified the types of analogies used, and if they were used well or less well, and explored the implications of using case studies similar to this one in teacher education to teach trainee teachers how to use analogies skilfully.

Noah Podolefsky and Noah Finkelstein (2007) offer an approach for building frameworks of linked analogies to scaffold student learning in physics, particularly the learning of difficult, abstract concepts. They compared the results of a comparison of the approach that they advocate with a non-analogical approach to teaching the same concepts, and showed significant advantages of their approach for students' conceptual learning.

Multiple Representations in Chemistry Education

There is not enough space in this chapter to explore all the ways in which verbal and written explanations have been complemented by visual and tactile representations, or to explore the ways in which teachers use explanations in parallel with experiments and demonstrations. There is value, however, in looking specifically at the issue of multiple modes of representation in chemistry education. The key feature of many or most explanations in chemistry is the way in which properties and processes at the atomic and molecular levels are the causal explanations for the changes observed at the macroscopic level, and the way in which these processes are represented symbolically using diagrams and chemical equations.

Austin Hitt and Jeffrey Townsend (2004) suggest that students struggle to understand chemistry concepts because they do not have direct sensory access to phenomena at the atomic and molecular levels, and struggle to translate their developing chemical knowledge across the microscopic, macroscopic and symbolic levels of meaning. Hitt and Townsend describe modelling clay with students in order to explore the molecular world and construct explanations for chemical phenomena, and they claim that this approach has significant potential for enhancing students' understanding.

David Treagust et al. (2003) also take up the issue of chemistry explanations and multiple levels of representation. They explored students' instrumental and relational understanding of chemistry concepts after instruction in a Grade 11 chemistry class using analogies and a variety of other forms of explanation. The paper uses examples of teacher and student dialogue to demonstrate the ways in which both symbolic and submicroscopic (molecular level) representations are used in explanations. The study suggests that both levels of explanation are important to developing good understanding in chemistry. Treagust et al. also report that the meanings ascribed to particular representations by students do not always mirror those intended by the teacher.

Anthropomorphism and Teleology

In a number of papers, the roles of various features of everyday explanations that are usually considered inappropriate in scientific explanations were considered along with the influence of these kinds of explanations in science teaching. Treagust and Harrison (1999) suggested that anthropomorphism and teleology might in fact be valuable features of science teaching explanations if used judiciously.

As far back as 1979, Ehud Jungwirth (1979) was exploring biology teachers' use of anthropomorphic (ascribing human attributes and motivations to scientific objects and processes) and teleological (implying that scientific processes are purposeful) explanations. In particular, Jungwirth focused on whether the students were able to 'see through' such explanations in order to understand the correct scientific explanations for the phenomena, or whether they accepted the teachers' anthropomorphic and teleological explanations as factual.

Maria Kallery and Dimitris Psillos (2004) interviewed Greek teachers of junior elementary students and asked the teachers to complete written tasks in relation to the issue of anthropomorphic and animist (scientific objects and processes being described as though they were living things) explanations. The teachers expressed the view that using these types of explanations can be cognitively – and, in the case of some animist explanations, emotionally – harmful to young students. At the same time, however, Kallery and Psillos observed that the teachers did use anthropomorphic and animist explanations in their teaching. The participating teachers ascribed this to their low levels of content knowledge and pedagogical content knowledge in science.

Vicente Talanquer (2007) explored the use of teleological explanations in chemistry textbooks and concluded that such explanations are used, and that they sometimes can be valuable pedagogically as a means of helping students to understand the energetically 'preferred' direction of particular reactions. He also suggested that, where teleological explanations are not used carefully and the underlying laws governing the behaviour of the system elucidated for students, this form of explanation can lead to students developing misconceptions about the phenomena or overgeneralising the explanation.

Dagher and Cossman (1992) also identified 'tautological' explanations in their study of teachers' classroom explanations, giving as an example 'Chromosomes are in pairs so that they can pair' (p. 366). Ehud Jungwirth (1986) reviewed three studies addressing the problem of tautological explanations – explanations which manipulate the pieces of the thing to be explained without adding any new information or clarity – and reported an intervention programme with practising teachers that showed that they could be taught to avoid offering tautological explanations.

Teacher Education, Teacher Knowledge and Teaching Explanation

Several studies explored issues related to teacher knowledge and teacher explanations, including the explanations constructed by beginning teachers. Other papers considered the ways in which scientists explain ideas and compare those explanations with science teaching explanations, or describe criteria for judging the quality of explanations.

Alan Goodwin (1995) studied the explanations given by both science textbooks and beginning teachers who were graduates of science degrees. He found that both classes of explanations included logical flaws, as well as errors of scientific fact, and noted that it is important for students to be able to critically examine the explanations offered to them. Whilst I would agree that this is an important skill, it is one that needs to be developed throughout a student's scientific learning journey. Therefore, it is still important to seek to improve the quality of the explanations given by teachers and textbooks so that students can develop appropriate scientific knowledge.

Thomas Russell (1973) explored the messages about the nature of authority that were implicit in teachers' scientific explanations and arguments. He described a scheme for categorising arguments and identifying the hidden views about the nature of authority – essentially, the distinction between students accepting ideas based on the authority and position of the teacher or on the basis of the 'warrants' or forms of evidence from within the discipline that are advanced to support it – that played themselves out in three 'teaching incidents' which are described and analysed in the paper.

George Brown and John Daines (1981) elicited the opinions of 93 lecturers on the question of whether explaining is a skill that can be learned (or, presumably, something innate). In general, the respondents felt that most of the 40 listed elements of explaining *could* be learned, to varying degrees. Brown and Daines found that there were significant differences between the views of science and arts lecturers, but little difference between the views of relative neophytes and more experienced academics. They suggested that these views could have arisen from the ways in which the lecturers had experienced lecturing and explanation as students themselves. Their work has been influential since it was published and is frequently cited in adult education and higher education contexts.

Laurinda Leite et al. (2007) explored the explanations given for phenomena in the liquid state by teachers and prospective teachers in Portugal, Spain and Italy. They found that the explanations given by both groups in all three countries were poor (i.e. did not correspond with a correct scientific understanding of the phenomena), although the in-service teachers displayed fewer misconceptions than their preservice colleagues. The authors suggest more explicit attention to liquid-state concepts in science preparation, implying that they believe the problem is with the teachers' content knowledge in this field rather than with their skills in explaining the concepts to students.

This is a distinction that is sometimes found in the literature: If students are having difficulty understanding teacher explanations, or if the explanations offered are of poor quality, is the problem with the teacher's knowledge of the relevant scientific concepts, or with his/her skill in constructing explanations? Some ingenious research to address this issue would make an important contribution to the literature of teacher explanations in science.

Katherine McNeill and Joseph Krajcik (2008) focused on the activities of teachers who were explicitly teaching their students how to construct scientific explanations. Thirteen teachers working with 1,197 grade 7 students in a project-based chemistry unit were videotaped as they introduced the idea of scientific explanations to their students through modelling, making the rationale for explanations explicit, defining explanation and connecting scientific explanation to everyday explanation. McNeill and Krajcik found that different teachers used different instructional strategies in introducing this concept, and that these differing strategies led to differing results in terms of students' understanding of scientific explanation.

Combining Information in Explanations

Richard Mayer and Joshua Jackson (2005) conducted an experiment in which two groups of students were given a booklet containing text and illustrations that provided a qualitative explanation of the phenomenon of the formation and movement of ocean waves. One of the two groups had this information supplemented in an expanded form of the booklet with some further illustrations and some quantitative equations for the phenomenon being explained. Mayer and Jackson found that the students presented with the quantitative information developed much weaker qualitative understandings of the relevant phenomena than did the students who were given only the qualitative information. This suggests that the order and organisation of the various elements of an explanation are important to learning.

Judging the Quality of Teacher Explanations

Stephen Norris et al. (2005) explored the use of 'narrative explanations' in science education and developed a theoretical framework for categorising and conducting research into such explanations. Their discussion explores questions of the nature of narrative and of explanation, and offers criteria for judging the effectiveness of narrative explanations in science education.

Hannah Sevian and Lisa Gonsalves (2008) developed a rubric for judging the quality of scientific explanations. Although it was initially developed for the explanations given by science graduate students who were moving into science teaching roles within universities, Sevian and Gonsalves suggest that it can be of value for 'evaluating, or self-evaluating, science explanations by science professors and researchers, graduate students preparing to be scientists, science teachers and preservice teachers, as well as students who are explaining science as part of learning' (p. 1441). Sevian and Gonsalves claim that, because their rubric separates the content knowledge and pedagogical knowledge elements of teachers' science explanations, it offers significant research potential for distinguishing (and remediating) flaws in teacher explanations that are due to poor content knowledge from those due to poor explaining skills.

Future Research

A variety of different approaches has been used in conducting research on teacher explanations, ranging from videotaping and closely analysing actual explanations (e.g. Geelan 2003) to conducting philosophical discussions of the topic divorced from empirical evidence (e.g. Norris et al. 2005). Treagust and Harrison (2000) analysed the lectures of Richard Feynman, who was widely regarded as an exemplary explainer.

Approaches have typically fallen into the two dimensions of 'what is' and 'what should be' – either seeking to understand the nature and features of explanations as they are 'in the wild' or seeking to describe, and to some extent prescribe, what constitutes a high-quality explanation.

There also exists research on explanations that is linked to other issues such as the use of educational technology (including distance and flexible modes of instruction) and to particular issues in the science disciplines such as multiple representation in chemistry. Issues of teacher content knowledge and explanation skills also need to be further elucidated.

An enormous amount of research remains to be done in this field – the surface has barely been scratched. Many of the key definitional and philosophical issues, if not exhausted, then at least have been sufficiently addressed to allow research to focus on finding good-quality empirical evidence to support much better understanding of the features and skills within the profession, and to find ways of teaching explanation to beginning science teachers that enhance science education.

Two frameworks that seem to me to have particularly rich potential for future research are the evaluative rubric developed by Sevian and Gonsalves (2008) and Thagard's (1992) work on analogies. The Sevian and Gonsalves framework is subtle and sophisticated enough to allow researchers to distinguish better between poor explanations resulting from poor content knowledge and those resulting from poor explanatory skills, so that attention in teacher education and professional development can be more precisely targeted for improving the quality of explanations. It also offers a scheme for explaining the important features of explanations to prospective science teachers in science education courses. Thagard's work offers similar potential in the narrower field of analogies, and allows the quality of analogies to be judged in some defensible way.

Combining these frameworks with continued close analysis of the explanations offered by classroom teachers, whether or not that close observation is aided by technological tools, such as video, offers huge potential for improving our knowledge of explanation.

Conclusion

Teacher explanation in science education has existed as a field of research interest at least since the 1970s, yet there remain too few studies scattered across too many issues to really serve science education at all levels. The research findings reviewed here are encouraging and compelling, and offer some guidance for teaching and teacher education, but there is much work still to be done.

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