Explaining topics in physics: an international video study

David R Geelan
School of Education
The University of Queensland
Brisbane QLD 4072, Australia
d.geelan@uq.edu.au

Abstract: Explanation is an under-researched area in science education. The ways in which successful physics teachers explain physics concepts to their students were studied in Australia and Canada using video analysis of classroom teaching. This paper outlines the technical features and analytical approach of the study as well as describing the findings.

Introduction
It seems plausible that explanation is at the centre of science education – the role of science is to explain the natural world and a large part of the role of science education is to offer explanations to students of the ways in which science fulfils that role. Yet explanation in science education has been the focus of very little research (Geelan, in press), with fewer than 40 papers devoted to it appearing in the ERIC index. Within this, only 8 papers relating to explanation in physics education were found.

This may have something to do with the ‘constructivist turn’ in science education from the mid-1980s, which has focused research attention much more strongly on student activities than on teacher activities such as explanation. Whatever the cause of the phenomenon, there is ample opportunity for research to be conducted about the ways in which physics teachers explain concepts to their students.

Explanations include more than just lecture-style verbal exposition of ideas, and can include demonstrations, discussions, computer-based visualisations and other media, however the present study focused on verbal explanations given by students to teachers. In some instances these were delivered in a lecturing style while in others the interaction was much more like a group discussion, and in some cases there were even elements of Socratic dialogue in the approach adopted by the teachers.

Video is an appropriate medium for this research project since it allows the close, repeated analysis of teachers' verbal explanations along with the students' reactions and responses and the teacher's actions, body language and use of other media such as diagrams and calculations on the board.

Literature Review
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 draw on David-Hillel Ruben’s (1990, 1993) work on the philosophy of explanations to discuss issues around 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 characterized 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. (adapted from p. 1158)

Treagust and Harrison (2000) also analysed Richard Feynman’s (1994) lectures on physics in exploring the features of explanations.

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 practicing 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 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.

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' lifeworlds – Nashon uses the term
‘environmental’ – while 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 to ensure that their understanding of the target concept is as robust and scientifically accurate as possible.

These few studies almost exhaust the existing research on explanations in science education, and since Nashon’s work focuses more narrowly on analogies and Zacharia on a particular technological approach, the field of research on teacher explanations, broadly defined, remains very slender in existing work and very open for further research.

Methodology
The present research project began in Perth, Western Australia, in 2000, then shifted to Edmonton, Alberta in 2001. It focused on Year 11 physics classrooms in both cities. Four teachers in four schools were studied in Perth as part of a larger study (Geelan, 2003; Geelan, Wildy, Louden & Wallace, 2003). That study focused my attention on issues around teacher explanation as one of the explanatory factors for the ways in which particular teachers supported their students to achieve at a high level in external high-stakes Physics examinations, which in turn gave the students access to university courses leading to well-paid and well-regarded professions such as medicine.

When I moved to the University of Alberta during 2001 I pursued this interest with a study of 12 teachers at six Edmonton high schools. The schools and teachers were chosen on the basis of their past success in helping students achieve in physics. This approach was adopted, although I recognise that it contains some problematic assumptions about how well such external high-stakes exams measure conceptual knowledge of physics, for two reasons:

1. Students enter senior physics courses with the expectation of success, an expectation shared by their parents, usually defined as a high mark and very often defined in terms of access to particular university courses. It is important that teaching and learning honours these aspirations, while at the same time attempting to foster deep physics learning and understanding on the part of students.

2. I am suspicious of ‘exemplary teacher’ programs and descriptions of ‘exemplary teaching’, both because teaching is so strongly contextual that contextless prescriptions of excellence seem impossible and because so many of the published studies seem to define the term as ‘teaching as I (the researcher) would teach’ rather than in terms of any more empirical criterion.

The goal, then was to gather a number of examples of ‘successful teaching’, defined by success on a measure that is used by teachers, students and parents, and then to explore the facets of those examples. Rather than a single description of ‘exemplary practice’, the study sought examples of explanatory frameworks and practices that were well adapted to particular contexts and situations, as well as looking for any features that might appear consistently across different contexts.

One interesting feature of the study is that, aside from the different accents in the speech of the teachers and students, the Australian and Canadian cases are almost indistinguishable from one another. The cultures of the two countries are quite similar, and the cultures of senior secondary schooling and of physics education are also very strong influences on what happens in classrooms. There were greater differences between particular Australian classrooms and other Australian classrooms (and similarly for Canadian classrooms) than between the Australian and Canadian classrooms. This means that, although this is an international study, it does not feature a comparison between the two countries – there were simply no points of difference in which to ground such an analysis. Instead, the data sets from the two countries were combined to yield a larger data set of 16 teachers in total. Physics classes participating in the study typically had between 15 and 25 students. Despite active efforts to identify and recruit them, there were no female physics teachers in the classrooms involved in the study.

A grounded theory approach (Charmaz, 2000, 2001) was adopted when coding the video lessons. That is, the video was transcribed and repeatedly watched, and themes that occurred in multiple lessons and multiple classrooms listed. A hierarchy of emergent themes and issues was developed, and then each video segment was coded, as described below. The process of constructing categories and coding video was iterative, and was continued until the coding scheme was sufficiently comprehensive to capture all of the key features of the explanations offered in the lessons.
Technology
All lessons were recorded from the back of the classroom with a MiniDV camcorder on a tripod. This approach reduced the impact on teachers and students and made the recording as unobtrusive as possible. The cameras used were able to record teacher voices clearly from the back of the room without using an external microphone and available light was used. Two graduate students were employed to record video during the project and the author also recorded some lessons. One of the graduate students set up the camera on a wide angle and did not touch it during the lessons – these videos were less useful from a research perspective from those taken by more active camera operators who zoomed in on the teacher’s face or hands or on diagrams on the board.

Digital video uses a large amount of hard drive capacity – about 15 GB per hour. The original MiniDV tapes were kept as a full quality data backup but the video was generally digitised on a Mac and compressed using Quicktime Pro to a form of Quicktime video that was about 500 MB per hour, which allowed each hour of video to be backed up on a CD. This was also necessary for the first of the two qualitative video analysis packages used to analyse the video.

vPrism from LessonLab was initially used to analyse the video. This software package was developed for, and used extensively in, the TIMSS video study (Knoll & Stigler, 1999). For the purposes of this study it had a number of issues and problems, and eventually LessonLab abandoned updates to the software and it became unusable. The decision was made to shift the project video and transcripts to the open-source video analysis package Transana, which was purpose-designed for educational research. Transana had several benefits over vPrism for the purposes of this project, including being open source and well supported and being able to manage larger segments of video.

Important features of the analysis software included the ability to code for both single instants and for extended sections of video from a few seconds to a few minutes, as well as the ability for codes to overlap. For example, a particular section of video might exemplify both open-ended questioning and the use of an analogy, and both things needed to be coded for analysis.

Specific features coded included:
- the use of analogies and metaphors, with a separate code where teachers paid explicit attention to the ways in which the analogical concept was unlike the target concept (i.e. the places where the analogy breaks down),
- instances where teachers worked through calculations on the board,
- use of diagrams and of electronic animations or simulations,
- use of apparatus and demonstrations in explaining,
- use of anthropomorphic and teleological language,
- teachers’ use of hand gestures or body movements to illustrate their explanations,
- appeals to earlier learning in the course,
- drawing on knowledge from other courses the students are taking (usually, but not always, mathematics),
- explicit allusions to assessment such as ‘you’ll need to know this for the test’ or ‘this is how I would do this problem in an exam’,
- use of questions including open- and closed-ended questioning,
- jokes and humor, including pop-culture allusions.

Time coding could potentially have been used as a means of adding a quantitative dimension to the video analysis – measurement of the proportion of time spent doing calculations on the board, versus helping students with calculations in their seats, for example. This was not done, simply because the video recording of the lessons occurred on a somewhat opportunistic schedule, when it was possible for the researchers to get to the school, and since the focus of the study was on teacher explanations the camera was often turned off during student experiments or ‘seatwork’. This meant that there was no sensible ‘timeline’ for the study in each classroom as a whole to which particular activities could be compared to analyse the proportion of time spent on them. This meant that the study was entirely a qualitative analysis of the features of teacher explanations as they were observed in the recorded classes.

Results
A minimum of two hours of video were recorded in each classroom in the study, which usually corresponded to 2-4 timetabled physics classes over a few days, however in some cases up to four hours of video were recorded, transcribed and analysed.
The resulting approximately 40 hours of classroom video was complemented by audio or video recorded interviews with each of the teachers and with one or two focus groups of 3-5 students from each class, but the interview data are not discussed in this paper and will be published separately. Students, parents and teachers in Canada also completed surveys about their aspirations and the role and importance of physics learning – those data will also be reported elsewhere.

This paper is focused on the features of physics teacher explanations in relation to particular topics or physics concepts, as well as on more general features of physics teacher explanations. The classroom video was recorded at a number of different times across several school years, which meant that most of the key topics in Year 11 physics – all of which were common to Canadian and Australian syllabuses – were captured on video and analysed. Table One summarises some of the distinctive features of explanations given by teachers in relation to particular physics topics.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Features of explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics – simple motion</td>
<td>Use of demonstrations with objects such as balls and dynamics trolleys moving in the classroom</td>
</tr>
<tr>
<td></td>
<td>Use of student experience of sport or other activities, and students’ existing conceptions about motion</td>
</tr>
<tr>
<td></td>
<td>Challenge to Aristotelian views of motion</td>
</tr>
<tr>
<td>Dynamics – motion, force and energy</td>
<td>Appeal to the idea of ‘doing work’ and how much work it takes to achieve a particular result</td>
</tr>
<tr>
<td></td>
<td>Use of the idea of ‘power’ as related to cars and motorcycles</td>
</tr>
<tr>
<td>Electricity – static, current, simple circuits</td>
<td>Very persistent (used in every case) analogies between electric current and water currents</td>
</tr>
<tr>
<td></td>
<td>Extensive use of circuit diagrams and explicit attention to the conventions of drawing and analysing circuit diagrams</td>
</tr>
<tr>
<td>Waves – types, calculations</td>
<td>Demonstrations using springs, strings, pipes and musical instruments</td>
</tr>
<tr>
<td></td>
<td>Use of analogies between easily observed transverse waves in springs and more difficult-to-visualise longitudinal (compression) waves</td>
</tr>
<tr>
<td>Gravitation</td>
<td>Appeal to students’ imagination of being out in space</td>
</tr>
<tr>
<td></td>
<td>Reference to science fiction movies</td>
</tr>
<tr>
<td></td>
<td>Links to circular motion, whichever topic was taught first</td>
</tr>
<tr>
<td></td>
<td>Reference to the history of science and the geocentric/heliocentric controversy</td>
</tr>
<tr>
<td>Circular and Simple Harmonic Motion</td>
<td>Demonstrations swinging objects on strings</td>
</tr>
<tr>
<td></td>
<td>Analogies between circular motion and SHM</td>
</tr>
<tr>
<td></td>
<td>Links to planetary orbits and gravitation</td>
</tr>
<tr>
<td></td>
<td>Embarrassed references to an unfamiliar technology called a ‘record player’</td>
</tr>
<tr>
<td>Light – nature, reflection, refraction</td>
<td>Many demonstrations using laser pointers</td>
</tr>
<tr>
<td></td>
<td>Analogies between:</td>
</tr>
<tr>
<td></td>
<td>- particle nature of light and objects such as balls</td>
</tr>
<tr>
<td></td>
<td>- wave nature of light and water waves</td>
</tr>
</tbody>
</table>

_Table One – Distinctive explanatory features related to specific physics topics_

These features occurred to varying degrees across all topics, and this sample may be biased by the fact that we typically saw each teacher teach only one topic, and typically saw only a few teachers teach each topic. This means that what appeared to be topic-based differences may lie more in the personal explanatory styles of individual teachers. Nonetheless, some topics do seem to lend themselves to particular explanatory styles more than others. The phenomena of simple motion are much simpler for teachers to demonstrate directly to students in the classroom by dropping, bouncing or throwing objects, for example, whereas the phenomena of electricity tend to be observed ‘second-hand’ as students read a meter or see a light glow. These differences mean that teachers are much more likely to use analogies to explain the concepts of electricity than of motion, and in fact to use analogies drawn from students’ knowledge of motion to help clarify other phenomena.

In addition to the differences based on topics there were differences in the ways in which physics teachers
tied physics concepts to the students’ everyday lives and experiences. More of the analogies used in the Edmonton classrooms involved ice hockey, or objects sliding on ice. Edmonton is approximately 1000 km from the coast, so ocean waves and the surf were not often appealed to in the attempt to explain waves, whereas Perth is a beach city and all the students had regular experience of going to the beach and watching waves.

In addition to some of these differentiated features of the explanations used in the different classrooms, there were a number of features that were general to most or all of the teacher explanations observed. These included:

1. **The ‘move to mathematics’** – teachers often began explanations of phenomena in a qualitative mode, perhaps with a demonstration or with asking the students to imagine a hypothetical physical situation, but most moved quite quickly to formalise the qualitative information with symbols, units, equations and calculations. A calculation was often delivered as part of an on-going verbal explanation. Some teachers noted that an individual calculation was only one possible example of the phenomenon being explained, while for other teachers this was not always made explicit. This sometimes meant that students struggled to transfer their understanding of the concept to new contexts.

2. **Attention to the requirements of success in exams.** All the teachers in the study valued physics for its own sake and as a way of seeing the world, but they all also recognised that these students aspired to succeed in physics and gain entry to particular university courses. In both Western Australia and Alberta a large part of this success is predicated on a high-stakes externally-administered examination. The schools chosen to participate in the study were those that had been successful on these examinations in the past. That meant that all of the teachers paid explicit attention to this issue, with comments such as “in an exam, I wouldn’t set it out this way, I’d do it more simply and quickly”. Different teachers did do this in different ways and to different extents, however.

3. **Use of analogies.** There has been some research attention paid to the use of analogies in physics teaching explanations (e.g. Nashon, 2004; Podolefsky & Finkelstein, 2007; Thagard, 1992; Treagust & Harrison, 1999, 2000). Analogies were used extensively by all the teachers in the study. Most were careful to pay attention to the ways in which the analogy worked – the similarities between the analogue and the target concept – but fewer paid careful and explicit attention to where the analogy broke down, or to the differences between the analogue and the target concept. It is possible that this sometimes introduced student misconceptions. Generally, however, analogies were an important facet of teacher explanations, skilfully used.

4. **Storytelling and references to the history of science.** Many teachers used narratives of particular incidents – such as Archimedes arising from his bath after solving the density problem or the (probably mythical) falling apple observed by Newton – as part of explanations of the related concepts. Fewer used narratives of historical controversies in the history of science such as that between Galileo and the church over whether the earth was at the centre of the solar system or that between Newton and Huygens over whether light was a wave or a particle, however where these debates were described they were accompanied by quite sophisticated ideas about the nature of science and the importance of evidence in deciding scientific questions.

5. **Role of technology.** Various technologies, from chalk on a chalkboard to ticker-timers, have always been part of explanations in physics teaching, but the use of several newer technologies were notable in the classrooms studied. The advent of very cheap laser pointers has revolutionised the study of light, since it is possible to clearly see the path of a laser beam even in a classroom that cannot be completely blacked out. Laser pointers were used extensively in each classroom in which light was the topic being studied. The advent of data projectors has effected physics teaching explanations in a number of ways. Where the projector is used to delivery a very linear, text-heavy explanation of a phenomenon that students are then asked to copy, it could be argued that this technology is impoverishing physics teaching explanations. Fortunately this phenomenon was rarely observed. More often the data projector was used to bring in video clips to illustrate the phenomena being explained and to show scientific visualisations (animations, and simulations) of both visible and invisible (because too large, small, slow, fast or abstract to see) phenomena. In several instances it was also combined with motion sensors or other kinds of ‘data probes’ to provide immediately graphing of motions in the classroom, with attention being paid to the relationship between a motion and its graph(s).

6. **Humour.** Different teachers had different personal styles, and physics teacher humour tends to be quite dry, but many of the teachers used humour with their students to help build relationships and improve classroom climate. Some used quite sophisticated ‘physics humour’ to test and reinforce physics concepts.

There were more specific features of explanations, relating to the ways in which teachers pursued particular questions with students and with where they directed questions to students, and to approaches to classroom organisation. Different schools within the study had different cultures, drew on different student populations and
catered to different aspirations. Each teacher also had his own professional and personal style and set of knowledge and skill.

**Conclusion**

Explanation in science education is a field that has the potential to offer considerable new insight into science teaching and learning and to contribute to science teacher education. Research in the field has been sparse to date, and there remains the scope for much more research to be done, including in other science disciplines such as chemistry, biology and earth sciences.

One thing that has been borne out by the study is the folly of seeking a single ‘best practice’ or ‘exemplary’ approach to explanation in physics education. While there are common features of high quality explanations and while this study definitely identifies some issues for attention in science education, such as attention to the use of technology, to where analogies break down and to the ways in which calculations are used as part of explanations, each teacher, each class and each school is different, and it is necessary to combine high quality content knowledge of physics with attention to the features of explanations to develop an appropriate explanation for this class on this day.

The use of classroom videotapes, combined with a qualitative analysis software package such as vPrism or Transana, has the potential to allow researchers to analyze in detail the fast-moving practices of classroom teachers, the professional judgments that inform those practices from moment to moment (Griffiths and Tann (1992) refer to such judgments as ‘reflection in action’), and the explanatory frameworks that help teachers to increase students’ understanding of difficult concepts.

**References**


