A method and framework for video-based pedagogy analysis

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Background: Bringing about conceptual change in school science classrooms is difficult for teachers. Researchers in this field have struggled to influence classroom practice.

Purpose: The present research presents a method and a framework for video-based pedagogy analysis.

Sample: Six groups of 11-year-old pupils took part (three girls and three boys) in each expert micro-teaching interview, led by a science specialist (Advanced Skills Teacher). A 'Concurrent Verbal Protocol and Retrospective Debriefing' interview (Taylor and Dionne, 2000) happened with the teacher approximately one month later. Six teachers and thirty-six pupils participated altogether.

Design and method: Three research methods (expert micro-teaching, verbal protocols and retrospective debriefing) were used. Data were video-recorded and managed using NVivo. About fifteen hours of video data were analysed using grounded theory methods. The interpretivist theoretical perspective (symbolic interactionism) was underpinned by a social constructionist epistemology. What can be considered evidence is inevitably affected by the researcher's methodological position. So what constitutes reliable evidence can be contentious. Appropriate criteria for evaluating the grounded theory emerging from this study were used. Interpretivist approaches for investigating conceptual change in school science are necessary to complement positivist literature. This approach, proved successful in other fields (Pressley, 2000), is new to this context.

Results: Findings are presented as a framework for pedagogy analysis which uses the concepts: means (including information, misinformation and disinformation), strategy (on a spectrum from micro-strategies, through tactics to macro-strategies; and also involving cooperative and oppositional interactions), ends (personal, political and logistical), and accidents.

Conclusion: The method allows teachers to help the researcher understand incidents in video-data that are not evident to any external observer. The

framework could help strategic dialogue between teachers, student teachers, mentors, teacher educators, and educational researchers.

Keywords: video-based; pedagogy; analysis; conceptual change; grounded theory

Introduction

Stimulating conceptual change in the complex social context of school science lessons is difficult for teachers. This paper presents a method and framework for video-based analysis of classroom pedagogy with the aim of improving strategic dialogue between teachers, student teachers, mentors, teacher educators and educational researchers. The research question examined in this paper is: how do experienced science teachers interact with small groups of children when the pupils express and discuss scientific 'misconceptions'?

The problem

Conceptual change researchers have found it difficult to influence classroom practice (Duit *et al*., 2013). One reason for this could be key terms like 'strategy' are used to mean different things within the research literature (see below).

Significance

This research matters because clarity as to what instructional strategy can mean would benefit 'strategic dialogue' (Lykke, 2001) among teachers, student teachers, mentors, teacher educators and educational researchers.

Key terms

The meanings of the terms 'misconception' and 'strategy' are contested in the literature (Gallie, 1956). Children often have 'misconceptions': scientific ideas that influence new learning, and which differ from those of professional scientists (diSessa, 2006). The term is frequently used by teachers and educational researchers. It is not

meant pejoratively. Science education researchers, alongside educational and cognitive psychologists, have catalogued a myriad of misconceptions (see Driver *et al*., 2015). For example, numerous studies have identified the misconception that plants get their food from the soil and that roots are the organs of feeding (ibid.).

Educationalists use the term 'instructional strategy' in varied ways. For example, some understand strategy as a plan:

> We see strategies in terms of overall plans which guide the sequencing of teaching within a particular topic. (Scott, Asoko and Driver, 1991, 1)

Others like Forsyth, Jolliffe and Stevens (1999, 84) allow 'only' three types of strategy: whole class teaching, group work and individual tuition. These conceptions of instructional strategy differ from what I call the 'Clausewitzian' understanding of instructional strategy which emerged during the research reported here. This paper will now outline the theoretical approach by explaining what we know, what we do not know, and the theoretical perspective and epistemology underpinning this present study.

The theoretical approach

What we know

Conceptual change research has a long and disputed history with many valuable findings of use in the classroom (diSessa, 2006; Vosniadou, 2013). Piaget began the interest in children's ideas which is now known as 'conceptual change' research. Traditional epistemology saw knowledge as 'justified, true belief' (from Plato's Theaetetus). Piaget argued that concepts evolve and that studying the growth of human understanding may be more useful than attempting to establish unchanging principles (Gruber and Vonèche, 1977, xxii and xxxvii). This 'genetic epistemology' engendered the misconceptions movement within science education, developmental psychology and

experimental psychology. Started in the late 70s, this movement became prominent in the 80s and tailed off in the early 90s according to diSessa (2006, 272), though it still influences many teachers and researchers today (for example Gurel, Eryılmaz & McDermott, 2015).

Conceptual change represents one particularly challenging type of learning:

> [Learning is] any process that in living organisms leads to permanent capacity change and which is not solely due to biological maturation or ageing. (Illeris, 2007, 3)

Three 'traditional' areas of research into conceptual change were identified by Sinatra (2005, 108): the exploration of cognitive factors (for example Vosniadou and Brewer, 1992) which included the attempt to list children's 'misconceptions' in science (for example Duit, 2009); a developmental perspective which examined the origins of children's naïve thinking (for example Carey, 1985); and the exploration of conceptual change pedagogy (for example Posner *et al.*, 1982). This research field has been described by Taber (2006, 134) as the 'Active Construction of Knowledge in Science Research Program' (ACKiS RP). This field contains competing theoretical perspectives (Özdemir and Clark, 2007).

What we do not know

Researchers have long sought effective strategies for conceptual change (Scott, Asoko and Driver, 1991; Sinatra, 2005). Yet,

> More classroom intervention studies [are necessary] studying the effectiveness of various strategies aimed at promoting conceptual change. (Driver and Erickson, 1983)

Current methodologies for exploring conceptual change strategy do not always

investigate teachers' complicated thinking processes while they attempt to promote conceptual change (Limón, 2001). This is problematic. Researchers may be missing data from teachers that could help them understand instructional strategy better. For example, one study that investigated instructional strategies for conceptual change encountered difficulties and the authors suggested the solution is small-scale qualitative studies like this present research (Smith, Blakeslee and Anderson, 1993). Those authors acknowledge that their methodology struggled to capture the rich dynamics in relationships between pupils and teachers, and between the pupils themselves, during which learning happens. Instructional strategy, from what I call a Clausewitzian perspective, involves multiple participants interacting. Teachers use strategies, but so do pupils. Limón, an educational researcher, makes a similar point to Clausewitz:

> In general, most of the analyses performed to evaluate the efficacy of conceptual change instructional strategies look at the learner but not at the teacher. Apart from the theoretical problems, it is important not to forget that the implementation of conceptual change instructional strategies takes place in a real setting. (Limón, 2001, 376)

Instructional strategy has been researched for a long time (for example, Posner *et al*., 1982), but little educational research draws upon insights from the military. The Greek word *stratēgia* means 'generalship', and military strategists have debated potential meanings of the word 'strategy' for centuries.

> In trying to decide between alternative strategies, we are often faced with a comparison of apples and oranges, because the choices do not address the same factors. Only with a mutual understanding of what comprises military strategy can we hope to improve our strategic dialogue. (Lykke, 2001, 179)

Similarly, educationalists use the term strategy to mean very different things. This present research offers a Clausewitzian understanding of instructional strategy. Military

metaphors like 'strategy' must not be taken too far of course (Saltman and Gabbard, 2010). Pupils are not soldiers, teachers are not generals and a classroom is not a battlefield.

The theoretical perspective and epistemology

This work had an interpretivist theoretical perspective (symbolic interactionism) and was underpinned by a social constructionist epistemology.

> With deep roots in symbolic interactionist sociology and pragmatist philosophy, the grounded theory method can be viewed as a theory/methods package with an interpretive, constructionist epistemology. (Clarke, 2003, 559)

So the methodology is Straussian Grounded Theory (Corbin and Strauss, 2008).

Research design

This research sought to find out how six experienced science teachers, each working with a small group of six children, tried to bring about conceptual change when the pupils expressed scientific 'misconceptions'. Hence this study used a detailed qualitative video-based research design which will be described below. The reasons for taking this approach will now be discussed briefly. Educational researchers investigating conceptual change teaching strategies have already used a variety of quantitative methodologies to test theories. For example, Smith, Blakeslee and Anderson (1993, 115) trained teachers in the use of specific teaching strategies, then compared pre- and post-test results for what they called 'treatment' groups of pupils, with control groups. Such studies can be valuable for practitioners but should be balanced by the qualitative approach taken here, which sought to construct a grounded theory from what experienced science teachers appear to do to promote conceptual change in a messy context which models, to some extent, what happens in science

classrooms. Here it is argued that rich qualitative data from whole classrooms are best interpreted once a framework for pedagogy analysis is in place and that the method presented in this paper can provide such a foundation (see next steps below).

Research methods

Three research methods (expert microteaching, teacher verbal protocols, and teacher retrospective debriefing)[1] were used. Firstly, pupils discussed what happens to a hot cup of tea and a bowl of ice cubes. Secondly, they each did a 'living and non-living' card-sort activity (Figure 1 below).

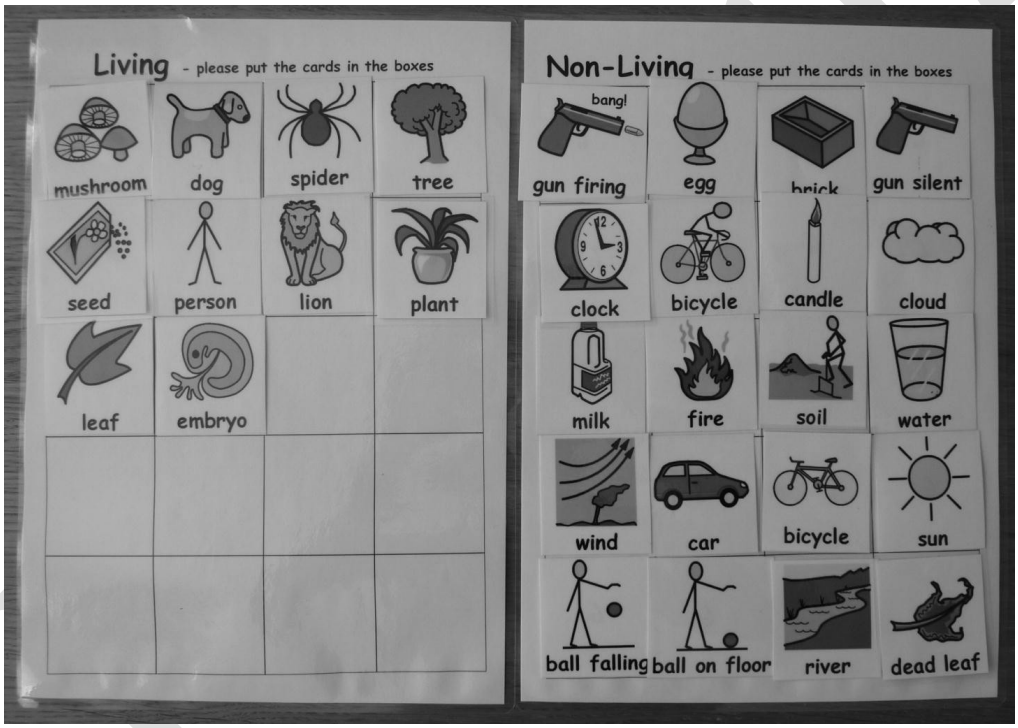

Figure 1. card-sort activity used in the EMT interview completed by me (© Widgit Software 2013 - used with permission)

Finally, a teddy bear and torch were used by participants as they discussed how you see the toy in a completely dark room. Researchers have found children have multiple misconceptions in these topics (Driver *et al*., 2015).

1 [1] Expert micro-teaching (EMT), Verbal Protocol (VP) and Retrospective Debriefing (RD)

Six groups of 11-year-old pupils participated (three girls and three boys) in each EMT interview, led by a science specialist (so six 'Advanced Skills Teachers' participated altogether). Each group interview took place around a table and was videoed from three different angles. Approximately one month later (to give time for data analysis), a thirty-minute VP (Taylor and Dionne, 2000) was video recorded where the teacher watched, and commented on, short clips from the group video. Lastly, the teacher was interviewed for thirty minutes on video (RD; Taylor and Dionne, 2000). These three types of video data were analysed using Grounded Theory Methods and managed using NVivo software. About fifteen hours of interview data in total were analysed using grounded theory methods.

Video clips for the VP interviews were selected using the following criteria: where a pupil had expressed what appeared to be a misconception; where I wished to compare my interpretation with that of a participating teacher; and/or where I was not sure how to understand an exchange during an interview. As findings emerged, these influenced the selection of clips used in subsequent VP interviews (a process called 'theoretical sampling' within grounded theory (Corbin and Strauss, 2008)). The rationale for the selection of the clips evolved during the study (another Grounded Theory Method called 'constant comparative analysis'). The methods used in this study do pre-empt each participant's own choice of which sections are important. Many things are important during lessons and this study explores only instructional strategy used during the EMT interviews. Using the selection of clips to maintain the focus of this study on the complicated interactions between participants, which occurred whilst pupils expressed misconceptions, was considered a necessary compromise. Clearly, the selection of clips represents one of many significant influences of the researcher on data collection and analysis (see the limitations section later).

Participant selection

Six teachers (two biologists, two chemists and two physicists) were involved in the study. Teachers were recruited from 211 secondary school science Advanced Skills Teachers in the UK. Those who worked closer to my home were invited first. Hence, a convenience sample was used. The sample size needed to be balanced against the depth of analysis. As the theoretical perspective is interpretive, a small sample was used so that data could be examined in considerable detail. The sample size was partly determined by reaching what grounded theorists call 'theoretical saturation' (Bloor and Wood, 2006). Sample size necessary to achieve theoretical saturation is unpredictable in grounded theory (Denscombe, 2010). Additionally, the size of the sample was influenced by practical considerations such as the time available. Six groups of 11-year-old pupils participated (three girls and three boys) in each EMT interview. The six pupils (36 pupils in total) were 11-12-year-old volunteers from each of the participating teacher's classes.

Data collection and analysis

Grounded theory methodology uses procedures for data collection and analysis from which emerges a 'grounded theory'. Grounded theory studies start with broad open questions, and research questions do not direct such work in the same way they do experiments in the natural sciences (Corbin and Strauss, 2008). The present study assumes that the indispensable techniques essential for research to be a grounded theory study are:

> [Initial] coding and categorization of data; concurrent data generation or collection and analysis; writing memos; theoretical sampling; constant comparative analysis using inductive and abductive logic; theoretical sensitivity; intermediate coding; selecting a core category; theoretical saturation; and theoretical integration. (Birks and Mills, 2011, 9).

A straightforward pragmatic approach was taken to coding (one supported by Bryant and Charmaz, 2010).

Ethics

Pupils and teachers participate in this study, so the guidelines from the British Educational Research Association (BERA, 2004) were followed. Advanced Skills Teachers were invited to participate by email or telephone. Formal permission to do this research was then requested by letter to the Head Teacher. Pupils were first informally invited to take part by the participating teacher. Those interested were given letters with reply slips for their parents or guardians. Pupils were also written to and asked to fill in a consent form, so as to ensure informed consent.

As regards confidentiality, the names of the schools were not used. Teachers and pupils were referred to using only initials. Each teacher was sent a full transcript of their interviews. General feedback was offered to each participating teacher on the results of the analysis and participants were sent findings and invited to comment.

Timing

This research started in 2009 and finished in 2014.

Results

The theme of strategy emerged during data analysis in this study. Strategy, according to a Clausewitzian understanding of this term, describes how the means each participant has at their disposal (both human and non-human; and real or imaginary) are used to try to achieve particular ends (objectives). To help understand the sort of data examined here, and how the framework presented afterwards can help, a thick description of a short section of the transcript will now be presented and analysed.

A thick description of strategy in these data

The following transcript extract (1a:129-201) illustrates enacted instructional strategies. This 'thick description' explains the behaviour of participants, and the context within which it occurs, such that the behaviours exhibited can be understood (Geertz, 1973, 5). The passage below represents part of an exchange during an EMT interview that lasted from 1a:129 until 1a:201 (a period of 10 minutes and 21 seconds).

1a:129 **TU (teacher):** OK. Right, so we've all agreed on the spider haven't we. OK, so let's turn that over then. If we all agree. What about mushroom?

1a:130 LN: Depends whether it is dead or alive.

TU: What do you [LN] mean dead or alive? Who has got it on living? [BN, CS and JK put hands up then EM and LN - JB does not put a hand up]. Everybody got it on living? Where is your [JB] mushroom?

1a:131 JB: On non-living [said quietly whilst pointing in an exaggerated way at the card which is on the non-living mat].

1a:132 **TU:** On non-living. Why have you put mushroom on non-living?

1a:133 JB: Because it doesn't live [said with feeling].

JK: Yes it does.

LN: Yes it does.

JB: It is like you said. It has got to move.

1a:134 **TU:** Mushrooms don't walk or swim or fly.

1a:135 Everyone except LN and JK: [unclear]

1a:136 **TU:** [To EM] Let him [JB] have his say and then you can argue with him. Like good scientists, we have to also listen to the other person's point of view.

1a:137 JB: A mushroom can't move. It can't move at all because it doesn't have roots and the actual person has to feed it to make it grow. It can't feed itself.

TU: [putting finger to lips to stop BN interrupting] Let him have his say. That's not fair, is it? Go on. [to JB]

1a:138 JB: Yes. That is what I wanted to say... and just like [LN] said a dog can feed itself.

1a:139 LN: Yes, but a fish can't and they're a living thing?

EM: Exactly.

1a:140 JB: No they don't. If it is on the side of the tank they can just

1a:141 LN: You'd have to put the food into the tank.

1a:142 JK: But that's not [unclear]

1a:143 **TU:** Shall we not think about pets. Shall we think about them in the wild? […]

The teacher (**TU**) above asks whether mushrooms are living or non-living (1a:129), an issue recognised in the literature as problematic (Tamir *et al.*, 1981) and chosen for the sorting activity for this reason. A pupil (LN) counters by suggesting it depends whether the mushroom is alive or dead (1a:130). Some non-living things are dead (i.e. they were living) but many were never living, a distinction many children find difficult (Carey, 1985). **TU** considers exploring 'alive and dead', but quickly returns the discussion to the issue of whether mushrooms are living or non-living by assessing where pupils have placed their mushroom card (1a:130). Avoiding the problematic issue of the difference between 'dead' and 'non-living' can be considered a type of strategy (a tactical withdrawal).

All pupils but one (JB) have placed mushroom on living, and JB does not raise his hand when **TU** asks who put this card on their living mat. From the video, it appears that **TU** has seen both that JB's mushroom card is on non-living and that he has not raised his hand with the others (putting a hand up is understood in the framework below as a type of strategic behaviour called an 'action'). Hence, 'Where is your [JB] mushroom?' may be interpreted as the start of the conceptual conflict. This line is not innocent, and JB's reaction in 1a:131 (his unusually quiet tone and exaggerated pointing at his card) indicates that he may not wish to be singled out as disagreeing with other pupils. **TU** summarises JB's point and asks him for clarification (1a:132). JB asserts more loudly (in contrast to 1a:131), and with feeling, the 'truth' that mushrooms do not live. Two other students then flatly refute this claim (1a:133). The interactions here are clearly oppositional. JB counters by calling on the authority of **TU** ('it is like you [**TU**]

said') and using an enthymeme: all living things move, mushrooms do not move, therefore mushrooms are non-living. An enthymeme according to Aristotle (Kennedy, 1980) is a loose type of syllogism, used in speaking to an audience rather than in a dialogue, where one of the premises is often suppressed. **TU**'s summary of this enthymeme in 1a:134 is far from neutral. She stokes conceptual conflict, humorously inventing a fake reality of mushrooms walking, swimming or flying. **TU** is a biology specialist who knows well that mushrooms are living and that they move, yet she pretends to side with JB's misconception. In effect, she invites the others to take JB's point seriously, and counter his argument with something stronger than the refutation used in 1a:133. The teacher imitating a person who thinks that a mushroom is non-living is an example of deception (i.e. presenting disinformation). As a result, pandemonium breaks out for a moment, with everyone talking at once (1a:135). **TU**, like a referee, informs EM that JB will speak first and that she (EM) can then argue with him (the tactic 'instruct'). **TU** then makes a point about 'good scientists' listening to each other (1a:136).

JB then makes three further arguments. Firstly, living things move, mushrooms cannot move because they do not have roots, therefore mushrooms are non-living. The idea that roots might have something to do with movement appears to be a misconception (plant roots move, but plants do not use their roots to move themselves – JB might be considering roots as similar to animal legs). Secondly, JB argues that living things feed themselves, mushrooms need to be fed (a misconception), and therefore mushrooms are non-living. **TU** manages the behaviour of a pupil (BN), who is attempting to interrupt JB, by suggesting this is not fair (i.e. referring to shared information). Finally, JB claims that one of his adversaries (LN) has already argued (it is unclear where) that living things can feed themselves, dogs can feed themselves, and

therefore dogs are living (1a:138). LN counters that there exists a living thing (a fish) that cannot feed itself (another misconception). In this way, LN attacks JB's first premise. JB disputes this, claiming that just because an owner puts food in a fish tank, it does not follow that the fish is not feeding itself (1a:140). LN presses her point by repeating it in 1a:141, and JB appears to be struggling (1a:142). The teacher (**TU**) appears to make another strategic decision, directing the conversation away from pets, perhaps because pupils may understand that wild fish must be capable of feeding themselves (being able to absorb nutrition is one characteristic of living things).

The VP and RD interviews sometimes corroborated the interpretations summarised in the framework below. For example, in the VP interview (1b:32-37) the teacher (**TU**) watched the video of a short section of the conceptual conflict described above (1a:130-137). **TU** noted the tension between JB using a theory (for example that living things move) and the other students being intuitively aware that mushrooms are living (1b:33). **TU** interprets the misconception that plants cannot feed themselves, as emanating from the experiences of farming and gardening. She is proud of JB's determination, whilst acknowledging that he is wrong (1a:34). **TU** speaks of other means she could use:

1b:34 **TU** (teacher): […] I think that is something I'd really like to think about later. How we get round that. The plant one is easier. Because even in their own experiences they can talk about leaves moving and flowers and sunflowers - and you can even show them an animation of a sunflower moving round through the day. And I suppose one of the other things I would do, if he persisted in that opinion, is I'd probably go away and I'd look for evidence and video clips of mushrooms and the hyphae, that kind of thing. Searching out the minerals. In the same way that a root does.

So **TU** acknowledges that the means she uses to help children accept that plants move (which could involve reminding children that some flowers close at night and open

again in the morning) may not be adequate for achieving the same aim where mushrooms (a fungi) are concerned. She suggests a different means which she might try (a new video). This is one example of how video-analysis of one type of data (here a VP) has been used to help understand a different data source (a EMT interview).

This conceptual conflict extract, in reality, lasted 1 minute 46 seconds. This particular conflict continued for a further 8 minutes and 35 seconds in as much detail as has been described so far, and about fifteen hours of video data were analysed in total. This passage was selected because it is particularly rich and was discussed by the teacher during a VP interview (1b:32-37), but in many ways, it resembles the other six and a half hours of EMT video data. The noise and bustle of a school classroom, where many talk simultaneously, is removed from this sanitised version. These complicated interactions between participants illustrate the context within which conceptual change occurs, often because of strategic behaviours by participants. Misconception, scientific concept and conceptual change were coded many times in these data (see Table 1 below).

Table 1: Number of times misconception, scientific concept and conceptual change were coded in these data

Type of interview	**Misconceptions**	**Scientific concepts**	**Conceptual change**
Expert Micro-teaching (EMT)	436	620	127
Verbal Protocol (VP)	117	23	21
Retrospective Debriefing (RD)	49	3	9
Total (All interviews)	602	646	157

A framework for video-based pedagogy analysis

The following framework for pedagogy analysis emerged from the analysis of these data and is summarised in Figure 2 below. A version of this framework designed

for use by teachers, student teachers and mentors during pedagogy analysis is available in the appendix. Strategy is how means (both human and non-human) are used to try and achieve ends. Non-human means include all the things participants use in the classroom, and the built and natural environment itself. Means can be both real and imaginary. Human means includes the changing information, misinformation and disinformation of participants (Stahl, 2006). Information is a disputed concept (Shannon, 1993). So in this paper data is understood to be any non-uniformity (i.e. the diaphoric definition of data), and information is data that are 'well-formed' (i.e. following the syntax/rules of the system) and meaningful (Floridi, 2017). Misinformation is information that is incorrect where the cause is accidental. There are many types of misinformation (see for example Clement, 2013). Disinformation is information that is incorrect where the cause is deliberate. Communicating disinformation, and hiding information, are examples of deception, which can be defined as a deliberate 'distortion of perceived reality' (Whaley, 1982, 182). The information, misinformation and disinformation available to each participant are limited (similar to the Clausewitzian concept of 'fog'), and change during interactions.

Strategy can be understood as a spectrum concept ranging from a micro-scale consisting of simple actions (for example, raising a hand to get attention), through a tactical scale (a sequence of actions, for example, summarizing what another participant has said), to a macro-strategic scale (how each participant uses their localised understanding of the entire system to try and achieve change). Macro-strategy involves the interactions of participants (usually pupils, and their teacher and teaching assistants), so cannot generally be identified as discrete types. In general the analysis of macro-strategic behaviours requires a thick description in order to identify the elements of the framework in play for each participant. Strategic interactions between participants can

be both cooperative (Meyer and Woodruff, 1997) and oppositional (including both offensive and/or defensive acts).

Ends can be personal, political or logistical. Personal ends can involve cognitive, affective, conative (i.e. motivational) and social outcomes. Political ends are activities associated with the governance of the classroom. These can be internal to the classroom (for example, negotiations about tasks) or external (for example, involving the Senior Leadership Team, school council, government education policy, etc.). Logistical ends involve how participants ensure means (both human and non-human) are available when and where required.

Everything can and does go wrong sporadically for these very experienced teachers and for pupils. Participants (for example, pupils or teachers) often initiated or took advantage of these 'accidents'. This is similar to the Clausewitzian concept of 'strategic friction'.

> Everything is very simple in war, but the simplest thing is difficult. These difficulties accumulate and produce a friction, which no man can imagine exactly who has not seen war. (Clausewitz, 1832)

This framework is now illustrated below. The appendix is a version of this framework designed for use by teachers, student teachers and mentors.

A framework for pedagogy analysis:

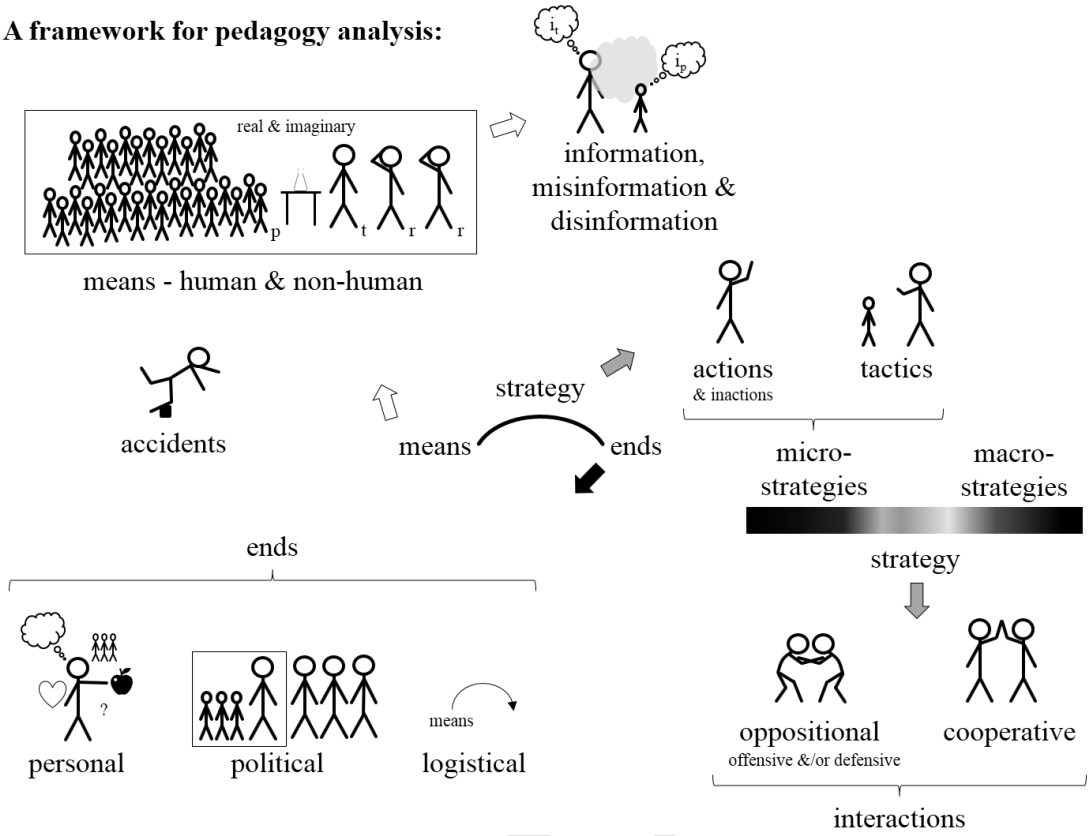

Figure 2. a framework for pedagogy analysis

Trustworthiness

What can be considered evidence is a function of the researcher's methodological position (Pearson, 2004), so what constitutes reliable evidence can be contentious. Some argue that only conclusions from traditional scientific methodologies provide evidence for practitioners (Watson, 2003). That would proclaim a hierarchy of evidence, where the 'gold standard' becomes the systematic review of randomized control trials. This implicitly undermines interpretative studies as evidence for practice, irrespective of the quality of the work. In contrast, this present research contends,

> epistemologically, daily practice is much closer to the interpretive or postmodern paradigms and … the validity and value of evidence ought to be considered by the criteria of these paradigms. (Mantzoukas, 2008, 219)

Appropriate criteria for evaluating the grounded theory emerging from this present study were defined by Lincoln and Guba (1985).

> The four terms 'credibility', 'transferability', 'dependability' and 'confirmability' are… the naturalist's equivalents for the conventional terms 'internal validity', 'external validity', 'reliability' and 'objectivity'. (*ibid*., 300)

The following 'operational techniques' (Lincoln and Guba, 1985, 219), were used to establish credibility, transferability, dependability and confirmability:

Table 2. Summary of techniques for establishing trustworthiness from Lincoln and Guba (1985, 328)

Criterion area		Technique
Credibility		Activities in the field that increase the probability of high credibility: prolonged engagement

		persistent observation triangulation (sources, methods, and investigators)
		peer debriefing
		negative case analysis
		referential adequacy
		member checks (in process and terminal)
Transferability		thick description
Dependability		the dependability audit, including the audit trail
Confirmability		the confirmability audit, including the audit trail
All the above		the reflexive journal

I acknowledge the ongoing debate about reliability in qualitative research (Morse *et al.*, 2002), but argue that the techniques of Lincoln and Guba (1985) used alongside grounded theory methods, can give trustworthy evidence. A thick description of tactical and strategic behaviour by participants in this study is given in the findings above (Geertz, 1973).

> [T]he naturalist cannot specify the external validity of an inquiry; he or she can provide only the thick description necessary to enable someone interested in making a transfer to reach a conclusion about whether transfer can be contemplated as a possibility. (Lincoln and Guba, 1985, 316)

Significance

This research is significant because the framework for interpreting classroom pedagogy, which has emerged, could help dialogue between conceptual change researchers and teachers, could help experienced practitioners understand their own practice better (Rich and Hannafin, 2009; Tripp and Rich, 2012), and could be useful in initial teacher education, particularly for video-supported reflection (Rosaen *et al.*, 2008).

Originality

Firstly, a grounded theory study of conceptual change pedagogy in school science from an interpretivist theoretical perspective (symbolic interactionism), and using a constructionist epistemology (social constructionism), would appear from my investigations to be unique. Secondly, EMT was developed as a research method for this present study. In addition, Taylor and Dionne (2000) claim that combining VPs and RD interview data is 'uncommon' in the research literature. Therefore the research method of combined EMT with VPs and RD constitutes an original approach. Thirdly the framework which emerged from this research does not support the idea that instructional strategy is merely a plan for a teacher to implement. That view of strategy is prevalent in conceptual change literature. Finally, the 'gap' (Duit *et al.*, 2013, 629) between theory and practice is a recurrent issue in the literature (for example Driver and Erickson, 1983; Scott, Asoko and Driver, 1991; Sinatra, 2005). This research contributes a new framework for pedagogy analysis to this debate, which emerged through collaboration between pupils, a group of experienced science teachers, and myself.

Discussion

(1) The framework presented draws on insights from military strategy and may help teachers, student teachers, mentors, teacher educators and educational researchers develop a shared vocabulary and avoid talking at cross purposes. This framework could contribute to the strategic education of student teachers. There are no simple answers to the question of how to promote conceptual change in school science lessons, but it is important to help experienced teachers to develop their pedagogy further and to support student teachers as they enter the challenging, complex social context of the classroom. What works in one

lesson or with one pupil will not necessarily work in another or with a different pupil, and it will not always be possible to predict what will prove to be effective during the enacted curriculum in advance.

(2) Strategy is not simply the plan of one of the participants in a lesson, for example, a teacher (though the intentions of the teacher prior to the lesson are undoubtedly important). Instructional strategy is here understood to be a spectrum concept ranging from simple actions, through tactical behaviours to sophisticated macro-strategies involving understandings of the system and of participants within that system. In education as in war:

> everything is uncertain and variable, intertwined with psychological forces and effects, and the product of a continuous interaction of opposites. (Clausewitz, 1832, 127-147)

(1) The enacted curriculum rarely corresponds to that intended (Gehrke, Knapp and Sirotnik, 1992, 55), so strategy must be dynamic; responding to the strategies of other participants and circumstance (for example, the evolving means available during a lesson, or the mutating ends, whether achieved or not).

(2) The method presented allows teachers to help the researcher understand incidents in video-data that are not evident to any external observer. Describing strategic behaviour in classrooms will always be difficult, as evidence for interpretations often arises from multiple data sources (for example a teacher explaining during a VP interview how they understood an exchange during an EMT interview).

(3) Teachers and conceptual change researchers collaborating may more successfully address the gap between research and practice in this field (Duit *et al*., 2013, 629) than either working on their own.

(4) No suggestion is made that participants themselves would consciously separate out what they do using the framework as they teach, even if they had time. However, the framework may provide a conceptual framework for practitioners that might influence what they do.

Limitations

This study had many limitations, so the conclusions can only be tentative.

(1) This study did not explore a naturalistic context. The small groups allowed in-depth analysis of interactions between pupils and teachers, but may not reflect what occurs in a real lesson.

(2) Combining EMT with VP and RD interviews provides some insight into the way participants understand their own practice, but obviously cannot tell us what someone is actually thinking.

(3) VP and RD interviews were not conducted with pupils because of practical time constraints. This represents a significant limitation as interpretations of pupil talk could not be triangulated in the same way as the teacher talk.

(4) The time delay between the interviews may have had an influence on the data and interpretation of events.

(5) It is not possible to know that the interpretation of any event during such complicated social interactions is precise, accurate and complete.

(6) Deception by participants necessarily has implications for the credibility of the findings of this, or any other, study of conceptual change pedagogy.

(7) All researchers influence their data, but it might be possible to have less impact.

(8) Grounded theory methods were used carefully, but with applying 21,612 individual codes to about fifteen hours of video, I acknowledge that some mistakes in coding are likely.

(9) This paper can only illustrate how the video-data supports the findings using one page of transcript. The full transcript is 252 pages long (see the data availability statement below).

(10) Similarities between some elements of the framework and the findings of other studies are acknowledged (for example, Wilson, Smith, and Ross, 2003; or Latour, 2005).

(11) The pedagogical aim investigated in this research is conceptual change, but teachers and pupils had many other aims which they expressed on occasion, or which were interpreted as underpinning their behaviour.

Next steps

(1) My current research explores video-based pedagogy analysis in normal school lessons to further develop the framework in a naturalistic context. This new study also incorporates pupil VPs in addition to teacher VPs, and the teacher watches the whole lesson back rather than using video clips from the EMT interviews. In addition the teacher and two educational researchers are coding the data so that interpretations can be compared and contrasted. Thus several of the limitations of the present study are being addressed.

(2) Future work could investigate how this framework might be used by teachers, student teachers, mentors and teacher educators. Such a study could investigate how this framework might help teachers promote conceptual change.

(3) This research design could be used to investigate pedagogy in different school subjects, with younger or older pupils, and in different types of educational setting (for example, in special school lessons or in Higher Education).

(4) A longitudinal study could use this research design and the framework to investigate how the pedagogy of novice teachers evolves during their careers.

(5) Teachers implement interventions suggested by conceptual change researchers into the complex social context of real lessons, during which the intervention is but one of the strategies enacted. Examining the enacted strategies during real lessons may help researchers and teachers understand what happens when findings from conceptual change research are implemented in actual classrooms.

(6) One way in which military personnel learn to cope with the complexity and unpredictability of war is by studying exemplars from history. There is potential for student teachers to learn in a similar way from video of real lessons, with corresponding VP data from the teacher and pupils. Inevitably, for novice teachers both the interpretation and the description of the subtlety of strategic behaviours by both teacher and pupils will need the collaboration of teachers, pupils and educational researchers.

Disclosure statement

No potential conflict of interest.

Data availability statement

Removed for review.

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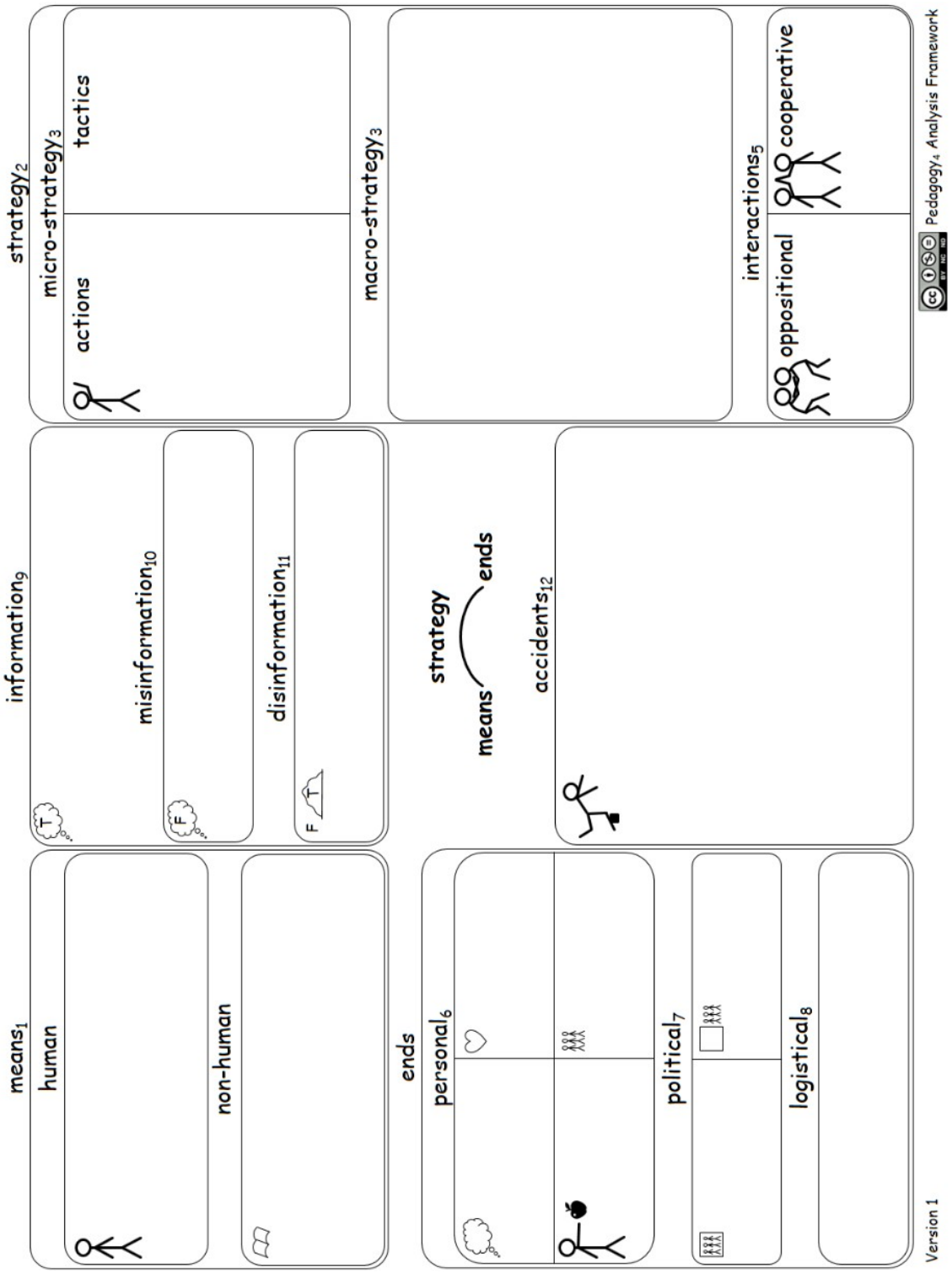
Appendix


means1
human
non-human
information9
misinformation10
disinformation11
strategy2
micro-strategy3
actions
tactics
macro-strategy3
ends
personal6
political7
logistical8
strategy
means
ends
accidents12
interactions5
oppositional
cooperative
Version 1
Pedagogy4 Analysis Framework

1. means Means are either the human resources in the classroom (pupils, teaching assistants, teacher…), or non-human resources (any objects, including those of which the learning environment consists). Means can be real or imaginary.	2. strategy The word 'strategy', as used by teachers and educational researchers, can signify different things. For example, some understand this to be 'a plan' (Scott, Asoko and Driver, 1991), whereas others see this as a particular action like 'grouping' (Forsyth, Jolliffe and Stevens, 1999). Strategy can be understood as how means are used to achieve ends (the 'bridge' between means and ends; Clausewitz, 1832; Lykke, 2001). The strategic spectrum varies from the micro scale (how a means is used to achieve an end) to a macro scale (see 3). Each participant's means, strategies & ends are continuously adjusted and/or abandoned as the information available to them changes, cooperative and oppositional interactions occur, and as accidents (see 12) are addressed.	3. micro-strategy & macro-strategy Micro-strategy can be analysed from two perspectives: actions (what a participant does) and tactics (a sequence of actions). For example, a pupil raising their hand is an action (designed to attract attention). In contrast, 'think-pair-share' (Lyman, 1981) is a tactic involving individual thinking time followed by collaborative work. A tactic is therefore a sequence of actions that can be practiced, so can be done with varying degrees of expertise. Macro-strategy is how each participant uses their localised understanding of the entire system to try and achieve change (Riordan, 2014). Macro-strategy involves the interactions of participants. Participants may or may not be aware of their own strategic behaviours (called meta-strategic knowledge).	4. pedagogy Pedagogy is a contested term (Watkins and Mortimore, 1999), uncommon in older UK educational literature (Simon, 1981). The focus of pedagogy can be on the teacher (Alexander, 2008) or can be understood as social in essence (the latter is used in this framework). This social perspective may be defined as follows: "[Pedagogy involves] those factors affecting the processes of teaching and learning and the inter-relationships between them" (Hallam and Ireson, 1999, p. 78).
5. interactions Participants can cooperate, oppose each other, or do both (for example, when factions form in the classroom). Opposition involves both 'attack' (usually non-violent) and defence.	6. ends (personal) Personal ends can involve cognitive, affective, conative (i.e. motivational) and social outcomes.	7. ends (political) Political ends are activities associated with governance of the classroom. These can be internal to the classroom (for example, negotiations about tasks) or external (for example, involving SLT, school council, government education policy, etc.).	8. ends (logistical) Logistical ends involve how participants ensure means (both human and non-human) are available when and where required.
9. information Information is a disputed concept (Shannon, 1993). Data is any non-uniformity (i.e. the diaphoric definition of data). Information is data that are 'well-formed' (i.e. following the syntax/rules of the system) and meaningful (Floridi, 2017).	10. misinformation Misinformation is information that is incorrect where the cause is accidental. There are many types of misinformation (see for example Clement, 2008). Three 'traditional' areas of research into conceptual change were identified by Sinatra (2005, p. 108): the exploration of cognitive factors which included the attempt to list children's 'misconceptions' (Driver et al., 2015); a developmental perspective which examined the origins of children's naïve thinking; and the exploration of conceptual change pedagogy. There are many different causes of misinformation (for example, misremembering, misunderstanding, mis-reasoning, miscommunication…).	11. disinformation Disinformation is information that is incorrect where the cause is deliberate. The use of disinformation is deception, which can be defined as a deliberate "distortion of perceived reality" (Whaley, 1982, p. 182). Classroom teachers, like magicians and soldiers, appear to use six different types of deception (Riordan, 2015). These are: Dissimulation (hiding the real) D1 masking (make invisible) D2 repackaging (disguise) D3 dazzling (to cause someone to lose clear vision) Simulation (showing the false) D4 mimicking (through imitation) D5 inventing (displaying a different reality) D6 decoying (diverting attention)	12. accidents Everything can and does go wrong sporadically in real classrooms even for very experienced teachers (Riordan, 2014). Participants (for example, pupils or teachers) often initiate or take advantage of these 'accidents'. This is similar to the Clauswitzian concept of 'strategic friction'. "Everything is very simple in war, but the simplest thing is difficult. These difficulties accumulate and produce a friction, which no man can imagine exactly who has not seen war." Clausewitz (1832) Book 1, Chapter 7
Version 1			Pedagogy$_4$ Analysis Framework