Writing geology: Key communication competencies for geoscience

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Abstract

Science is fundamentally about communication. Un-communicated science in essence does not exist. This study analysed both expert and undergraduate writing in geology to explore key weaknesses in students' writing. Skills found lacking included use of the academic register, in the writing process and in the structure, referencing and 'argumentation' of work. Action research seminars have identified possible strategies for dealing with these.

Introduction

What does it mean to become a geologist? What are the aptitudes and competencies needed by a good geologist? When I ask this question of friends, geosciences students and practising geologists the responses are quite predictable: an aptitude for outdoors work; an interest in the environment; an aptitude for logical analytical thought; competencies in field and lab work; competencies in physical, chemical and structural analyses etc. What are often left off the list (except by a few) are aptitudes and competencies in communication.

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Yet science is fundamentally about communication. Un-communicated science in essence does not exist. The processes and products of science communication – the conference posters and papers, the peer-reviewed articles, the text books, even the popular science books and TV programmes – provide the life blood of science. For many scientists the competencies needed for conducting communication are learnt 'on the job'. Though many curricula include opportunities to write or to engage in verbal and visual presentations of information, detailed training in the required competencies is scarce. This lack of specialist training and reliance upon 'on the job' training is not specific to science nor to geology; the same situation holds for most technical and engineering disciplines.

The issue is perhaps of special importance to geology, as geology is a heavily representational science. Key products of geological practice include verbal and visual representations of data: maps, logs, sketches, notes in notebooks, stereonets, graphs, etc. In fact, many analytical techniques require the manipulation of visual representations of data. Geology also tends to be historical and descriptive and less mathematical than other sciences (e.g. physics). On a practical level many students making direct use of their geological training at postgraduate level or in employment will quickly be required to produce a large volume of verbal and written reports.

The study described here developed out of my personal awareness of this issue – being an academic trained in communication studies, working on science communication, and also having undertaken a degree in geology. From this advantageous position it was possible to see the extent to which many of the limitations encountered by students were not their understandings of the geology – though they did have such problems – but in their ability to engage with the communication of geology. In particular, what struck me most was their expressed view that communicating their findings and understandings were a chore to be done after the 'geology' and not seen as part of 'doing geology'. This study specifically explored the 'writing' of geology. What are the key student weaknesses when writing up geology? How do we improve their writing and communication competencies?

The study

A short study funded by the GEES Subject Centre was undertaken to analyse the key weaknesses in geology students' writing at undergraduate and postgraduate levels. The study consisted of:

- analyses of student writing – both an expert evaluation of their writing and a quantitative comparison of key linguistic features between student and expert writing; and
- a small set of action research training seminars designed to bring out the areas of weakness and identify possible strategies for dealing with them.

Some theory

Before looking at the specifics of the study this paper will explore some of the socio-linguistic arguments for the centrality of communication, especially writing, in science practice.

Writing science requires that students learn the 'genres' – the styles and formats – of scientific communication (Swales 1990). Halliday (1993) has noted that what defines something as 'scientific English' is not just the use of 'terminology' but the combination of 'features' that cluster together in consistent relationships. We can identify a general 'register' of scientific writing – an impersonal, objective and descriptive style of writing. We can also identify specific genres of science writing – combinations of style, argument structure, presentation and topic – that are specific to certain contexts and disciplines. These genres are a "class of communicative events, the members of which share some set of communicative purposes" (Swales 1990, p.58). Examples include such things as lab or field reports, field and lab notes, exam questions and dissertations. It is, in part, through learning to write within the conventions of existing science genres that students become members of scientific "discourse communities" - they learn to "communicate in the language of science and act as a member of the community of people who do so" (Lemke 1990, p.1). Much of this learning tends to be informal or implicitly part of other activities - such as submitting lab reports, taking field or lesson notes, answering exam questions etc.

Though it is possible to attempt to analyse weaknesses in science students' writing and to provide support for 'science writing' in general, there is evidence that topic-specific training is required. Students are likely to understand the reasoning behind genres of writing better in the context of their own subject and it is likely that genres of writing vary between sciences (Horowitz 1986; Braine 1989). Much of the recent research on literacy has indicated that learning 'how' to write on a topic is bound up with understandings of it. Specific acts of writing in a discourse community are "integral to the participants' interactions and their interpretative process and strategies" (Heath 1986, p.98). Also literacies are not just about knowing how to write but also about appropriate conceptions and behaviours in relation to reading and writing (Street 1993, p.12) - for example the behaviours and understandings required in order to use a field notebook

effectively. What we have tried to do in this study is to identify the key weaknesses in geology students' writings at the levels of both the scientific register and in relation to the specific genre of geological report writing.

Basic method

The project used the following methods:

First, an expert analysis of writing produced by undergraduate and postgraduate geology students. The experts consisted of an expert in writing and English language (Dr. Noel Williams), an expert in science communication with knowledge of geology (Dr. Simeon Yates) and an expert in technical communication (Ms. Ann Florence Dujardin). The experts also discussed with geology teaching staff the key weaknesses they had identified in student writing.

Second, a linguistic comparison between undergraduate and postgraduate geological writing and 'expert' geoscience writing.

Third, the running of action research seminars in which undergraduate and postgraduate students engaged in possible intervention tasks and educational/training activities.

Data were collected from one UK university geosciences department. The majority of the data came from geology students with some from physical-geography students and geophysics students taking courses combined with geology. The sample of student writing consisted of 49 undergraduate and postgraduate dissertations. The dissertations were provided in MS Word format and converted to RTF and ANSI text formats for analysis. The comparison sample of 'expert' writings consisted of a random sample of papers from *The Journal of the Geological Society*. Using random numbers generated by SPSS, a set of 49 articles were selected from those currently available online in electronic (PDF) format. These papers were then also converted into RTF and ANSI text format for analysis. Extensive notes were taken during the expert analysis and in the observations of the intervention activities.

Findings

Expert analysis

It would be churlish to imply 'nothing' surprised the three experts who examined the student writing. It was the case that the key weaknesses in the students' writing mirrored those found in most writing by scientific and technical writers with limited formal training – with some twists specific to geology. It is important to note that the weaknesses identified are real and important but they are not unusual, exceptional or excessive in comparison to those found in other disciplines. It is important to bear in mind that not all reports exhibited all weaknesses, nor were all examples of weaknesses exhibited to their fullest extent. The key weaknesses identified are clustered around four issues.

Register

In many of the reports it was evident that students seem uncomfortable generating an academic register. They often used slightly uneven tones, slightly inappropriate sentence and clause constructions and inappropriate vocabulary. The problems with vocabulary included poor choice of geological terminology as well as the selection of inappropriate 'big words' (low frequency items in the English lexicon – e.g. using 'insinuate' to mean 'integrate'). Many texts contained unnecessary redundancy through repeating identical phrases in close proximity generating confusing sentence structures: For example:

"As these beds are curved around curve of the pluton emplacement a knock on effect is caused where the beds next to the curved beds are forced to curve also and so on."

What we were not able to fully explore in the project was the depth of students' understandings of accepted writing practices. We were only able to gain general evidence of the use of active and passive forms, the use of the personal and impersonal and, most importantly for geology, the use of the present and past tense. It is clear from the evidence we have that, whatever the claims of students, actual understanding of the relationship of these aspects of register and genre to science and geological practice and underlying epistemological positions is limited.

Writing process

In many of the reports it was clear that students may not be making the best use of iterations (i.e. feedback on drafts), either submitting drafts late or not at all. This suggests a case for better time management - though time management skills were beyond the scope of this project. In the weakest cases there was a lack of awareness of the manner in which writing can be broken down into a set of smaller, easily defined tasks, and that writing is an iterative process of sectioning writing, combining, editing, proofing, rewriting and so on. Many texts clearly needed further proof reading to ensure consistency of capitalisation, use of terminology and overall presentation and layout. Editing and proofreading are tasks which students and inexperienced writers often ignore or assign limited time to. Once again it is the issue of poor writing practices possibly obscuring or undermining good geology.

Structure

One of the most notable weaknesses was that of weak cross-referencing. Very often reports simply gestured in the right direction without being precise. The classic case is the use of as discussed above/below' where the referenced text is many pages prior to or after the current text. Another case, in relation to maps and figures, is where the reader is provided rather open tasks to perform. For example the use of: 'as can be seen on the map'; where the reader has to work out where, and decode what is encoded on the map with no further guidance. Similarly, references to figures may be made which are one or more pages away from the reference and relevant text. There are two problems at work here. First, there is a lack of knowledge of good section referencing practices, and also of how tools (e.g. MS Word) can support good practice. Second, there is a lack of understanding of the role of sectioning and cross referencing to the construction of both local and overall arguments.

Referencing

The major bugbear of all academic writing, namely poor referencing, was also present in the reports examined. Some students failed to cite properly and did not seem to know how and where to appropriately cite or reference. This is a common problem in all disciplines at undergraduate level. Once again it is a key skill required in science writing and students need to understand that referencing is more than a means of preventing accusations of plagiarism. Importantly the weakest reports contained referencing forms, styles and placement that implied thinking along the lines of 'I know I need a reference but I'm not quite sure why'. We chose not to address referencing in our action research activity, though we do recommend a two part approach to the teaching of referencing. First, students need an explicit explanation of: how referencing functions to bind together science writing; how it functions to allow readers to see how work relates to other work; and how it can be used to help evaluate work. Second, students need to be taught at least one formal referencing method.

Geological practice

Students were observed to confuse observation with interpretation in the reports we analysed. This was an issue raised by all the teaching staff we spoke to. Some students also appeared to have difficulty in developing an overall argument in their writing – even though the information and data needed for the argument might be present and often well presented. Both of these weaknesses implied a lack of understanding of the relationship between geological practice and the method by which this is written up.

Linguistic analysis

The key findings from the linguistic analysis are presented in Table 1. The table indicates those key linguistic variables that were examined and where distinct differences (indicated by significant t-tests) were found between the 'student' and 'expert' tests.

From the analyses in Table 1 we can identify the following specific points:

- Overall 'expert' geologists writing has a higher lexical density – a higher information density – than student writing, though the lexical density of student writing, with a value of about 55%, is also high compared to general writing which scores around 50%.

Table 1: Key linguistic findings

Measure	*Text type*	*Mean*	*Std. Deviation*	*t-test p<*
Lexical density				
	Student texts	54.9731	2.93388	0.017
	GSL Paper	56.3588	2.69260	
Lexicals per sentence				
	Student texts	9.0314	1.62026	0.000
	GSL Paper	5.7088	1.47970	
Pronoun use				
	Student texts	13.5698	5.31389	0.281
	GSL Paper	12.2220	6.88094	
High frequency words				
	Student texts	69.1310	10.37232	0.000
	GSL Paper	56.9761	8.40960	
Modals				
	Student texts	8.9103	3.31593	0.000
	GSL Paper	4.9256	2.18749	
% of long words				
	Student texts	28.4155	3.46661	0.001
	GSL Paper	32.8582	3.32220	
Letters per word				
	Student texts	5.0304	.22413	0.001
	GSL Paper	5.1941	.23053	
Sentence length				
	Student texts	16.4855	3.10608	0.000
	GSL Paper	10.1555	2.72128	

- Students' sentences are on average longer than experts' and as a consequence often contain more content (lexical) words and more high frequency words (such as grammatical words and connectives).
- Students make almost twice as much use of modals – words that indicate conditional states or 'distance' the writer (e.g. could, might, should, would etc.)
- Students and experts do not differ in their levels of pronoun use which are low in both cases compared to writing in general.
- Experts are more likely to use longer words – possibly terminology – than students.

Overall we can see that students' writing differs considerably on some key points from expert writing. Importantly, the overall picture is one of students applying some of the features of a scientific register such as: higher lexical density, lack of pronoun use, use of terminology etc. Having said this, student writing lacks precise sentence and clause structuring – as evidenced by the longer sentences. Student writing also lacks confident definitive statements – as evidenced by the higher use of modals.

Action research seminars

From the seminars a number of general background issues were identified:

- Despite the findings in the analyses above, many students felt they already knew 'how to write' – in many cases they articulated knowledge of structures, features and styles needed in geological writing but were not able to fully articulate the reasons for these.
- Students who were keen for help and support had only come to see the importance of this as a reaction to either poor

marks or to the imminent need to produce a long piece of writing (e.g. dissertation). None of the students appeared to view the writing or communication of geology as part of geological practice itself.

- Students had no 'deep' knowledge of the relationship between the forms of argument in geology and the structures and forms of geological writing.

Specific findings from the intervention activities were:

- Students could identify key differences in register, format and layout when presented with the same science but in three different generic forms. What appeared missing was an understanding of how these differences function in relation to the audiences for these items and how writing form, function and style vary with audience.
- Students could reasonably re-construct the structure of an actual geology dissertation from a set of contents list entries. What they found difficult was articulating the reasoning as to *why* the sections needed to be in a specific order. They were able to provide some argument for alternative arrangements within the 'rules' as they viewed them but could not fully explain the reasoning for these rules. For example, they could all identify the need for descriptions of formations to come before the reporting of structural features in a mapping report.
- Students could identify statements taken from an overall description of a formation and reasonably align these with 'observation, process, interpretation and environment'. Though they all knew this was the required order, the evidence from the expert analysis was that this was not always done in actual dissertations. It was also evident from student comments that many had not understood the process of 'observation, note-taking, write-up' as an integrated one in which each step organises, codifies, and formalises the previous step.
- Students were unaware of the relationship between types of argument and the structuring of a text at all levels. As noted above, students could identify the structure 'observation, process, interpretation, environment' but they did not understand this as an inductive argument. Importantly they were unaware of the overall inductive form of geological argument. Often students mixed inductive and deductive forms of argument. For example:

  "... as the formation is silicaceous limestone the fossil is likely a bivalve ..." as compared to "... given these features the fossils were most likely bi-valves, providing further evidence of the shallow marine environment of deposition..."

  This included the building up of larger inductive arguments from individual cases such as the description of formations or of structures. The students could not fully articulate how the building up of a set of arguments into a section, and using the concluding points of sections to build an overall argument in a meticulous manner, essentially provides the basis for overall report structure.
- Students were aware of the need to break down the work into specific writing tasks and sections. Some were also aware that an optimal writing strategy was to start with major content sections, followed by interpretative or concluding sections, and finally introductory sections. Even so, many admitted to not doing this. It was also clear that students conducted a limited amount of revision and proofreading once the first draft was complete.

Approaches to making an argument in geology

General to particular

This is described within rhetoric as the deductive approach to an argument. You start from generic principles, such as a theory in geophysics (e.g. mantle plumes), and show how particular detailed consequences follow from it (e.g. the geology of Hawaii)

Particular to general

This is described within rhetoric as the inductive approach to an argument. It is what Sherlock Holmes does (though confusingly Conan Doyle who wrote the books has Sherlock Holmes call it deduction!). You start from particular observed details, such as observations or data, and show how a general truth follows from them. This approach is the corner stone of geology field work! You gather lots of specific bits of information from observations and build these into an account, a history, of the geology you have observed.

Spatial

Your document follows the same structure as the geography or spatial layout of the area under discussion. This is obviously most useful when, for example, describing a place but also where you need to summarize and explain the relations across a mapped space. For example providing an overview of the main types of geology in a region.

Historical or narrative

Whilst 'history' and 'story' are not quite the same thing, the basic idea is the same, as far as geology report writing goes. Detail what happened in the order it happened. Be careful, however, not to choose this approach simply because it is easiest. Be careful not to describe observations and data as a story of 'what you did'. Observation and interpretation require an inductive approach. You use an historical argument where you have causal explanation of some kind. So your narrative will need to answer the question why something happened, as well as merely reporting what happened.

When to use the methods to structure your writing

- When testing theory (i.e. confirming a geophysics of seismic model) – use a *deductive argument*
- When describing and interpreting rock units, facies and sequences from field data – use an *inductive argument*
- When describing location context and spatial relations – use a *spatial argument*
- When describing geological histories and sequential geological processes – use an *historical argument.*

Methods for intervention

The points made above might make gloomy reading, but some important caveats need to be made. First, the analyses above have focused on the weaknesses of the students' writing. There were many examples of very good practice, with the clear implication that good writing formed a key point of distinction between the highest grades and those slightly below. It was rarely the case that good writing accompanied bad geology, but good geology badly written up did occur. Second, all of these weaknesses are found in the work of scientific and technical writers with a limited writing experience. So how might we go about improving writing competencies?

It is the case that teaching good scientific and technical writing competencies is a major task in its own right. The TCEurope project has identified 11 core and 13 specialist competencies needed by professional scientific and technical writers. A competency is defined as:

"... what one needs to achieve a determined result in a specific situation. A competency comprises four essential components:

- The knowledge of relevant theories, concepts, methods and procedures.
- The capability of applying this knowledge to achieve a particular goal.
- The capability to determine which skills have to be used in which situation
- The attitude and motivation necessary to achieve a particular result." (Dujardin, et al., 2005)

To deliver all of the competencies identified by TCEurope requires specific specialist education or training and it is not possible to do this in the context of teaching the substantive science content of a course in geology. The students first need some geology to write about! It is also the case that such training tends to be provided by communication and writing professionals and not by those with subject knowledge. Of course, developing writing competencies is also about practice as well as instruction. The following are some suggestions for activities that should provide students with understandings of the key underlying issues and principles. We would strongly recommend that such activities are given a decent amount of time, and that the importance of them is stressed to the students, either through argument or through some more direct method such as assessment.

Activity 1: Geology writing is peculiar!

Look at the questions below. In groups discuss and write a few sentences in answer to each of the questions

- Why do you not use personal pronouns (e.g. I observed that the rock was basalt) in geology reports?
- Why do you use the present tense when describing observations of rocks (e.g. the unit is pink in colour and contains well rounded and sorted clasts; the bed dips at 20 degrees) in geology reports?
- Where and how often should you use 'attenuated assertions' (it might be, it could be, a possible interpretation is) in a geology report?

teaching good scientific and technical writing competencies is a major task in its own right

Teaching genre and register

Students need to appreciate that the style of writing needs to reflect the communicative goals of the writing task (see Activity 1). This involves doing several things:

Text analysis - What should my text look like? What do other texts that do this job look like?

Audience analysis - What is my audience like? What can they understand? What are they used to reading?

A good way to get students to engage with both of these is to provide them with a set of texts to analyse. In our case we used the following 3 texts:

Extracts from the 'great plumes debate' on the Geological Society of London web site

Foulger, G.R., Du, Z., Julian, B.R., 2003, Icelandic-type crust, *Geophysical Journal International*, 155(2): 567-590

Jones, N., 2003, Volcanic bombshell, *New Scientist*, March 8th, Issue 2385

Students can then be given the task of exploring and identifying the features of each text. This can be done in a very open manner, getting students to read texts and eliciting ideas to be noted down and fed back to the group. Alternatively, a more didactic approach asks students to find, identify and count features of texts (use of pronouns, use of terminology, sentence length etc.). Once a reasonable set of features are identified, or a good set of data has been generated, the students need to be challenged on why they think these differences exist. Doing this should bring up issues about conventions within the scientific discipline (discourse community) as well as thoughts about the nature of the audience. In our case we used papers covering the same topic designed for three different audiences: a scientific, a geo-science aware and a 'lay' general science aware. These contrasts provided a strong foundation for talking about audience. More generally, competencies with the register of science writing and the specific genres of geology only come with exposure to examples of writing and practice at writing. The inclusion of opportunities to engage with primary sources and to engage in substantive realistic writing tasks at all stages of undergraduate and postgraduate training are therefore the key to developing this set of core competencies.

Teaching argumentation

This is an area of weakness in nearly all forms of HE provision. But given the centrality of inductive reasoning to geology, there is an opportunity to overtly teach students about its importance - to both the science and how the science is written up. For the purposes of our training we asked students to unpack a description of a formation into observations, processes, interpretations and environment. A set of cards with sentences taken from a description were provided and students worked in groups to place these on a large sheet with columns headed 'observations' etc. Students were then asked to articulate why they had placed the items as they had and then to reconstruct the overall description. Some sentences were deliberately 'difficult' in that they included both statements of interpretation and 'induced' processes. The main goal of this activity is make clear to students how arguments build at various levels – within sentences and among sentences, and how paragraphs function to contain overall arguments. In this way students can learn that building arguments is not something one does 'intuitively' but something that can be done through good but simple planning. If the nature of inductive argument is also explained as a core aspect of geological practice then students can make the connection between the nature of the science and how the science is 'written up' – how it is represented. The final aspect of argument is, of course, how paragraphs and sections build up to an overall argument, or set of arguments; one follow-up activity required students to construct the description of the formation as it would appear written up.

Activity 2

In your groups:

- Sketch out what sections need to go in a geology report
- Put these in what you think is the 'correct order'

For each section write down two sentences that explain:

- Why the section is needed
- Why you placed at that point in the order

Teaching structure

There are four aspects to teaching structure. First, and most obviously, there is teaching what are the appropriate sections and structures in reports, papers, essays and any documents they need to produce. Second, there are the writing practices needed to make sectioning work - such as cross-referencing. Third, there is teaching the reasoning for these sections and structures. Fourth, there is teaching how sections of a document embody the largest elements of the overall argument. In our action research seminars we gave the students the task of reconstructing a report from the elements of a detailed sectioned contents list (with, of course, the section numbers removed).

Teaching of writing and communications skills needs to be built into an overall education from initial undergraduate to final postgraduate work.

Students were asked to discuss and make comments on the reasons for the order they came up with. The more complex issues around the reasons for structure and the fine detail of how to cross-reference are best taught through specific examples or activities. These can include demonstrating good structure within paragraph, between paragraph and between section, referencing, and how sections are reliant upon each other. Teaching argument structure is best done by showing how the sections of a report embody the appropriate elements of one of the major overall argument forms in geology - inductive, deductive, historical (narrative) or spatial arguments.

Chopping up the task

Throughout the activities we tried to demonstrate the mundane, somewhat tedious and practical nature of writing. For many students, not just in the sciences, writing is perceived as a somewhat mystical activity – the fiction of the author simply imagining words onto the page. All writing, and especially scientific and technical writing, is a practical task. By teaching students to break up the task into specific 'chunks' defined by specific activities, such as describing a formation, or by elements of argument or structure, makes the task seem both 'do-able' and practical. A key element of this is teaching an appropriate order in which to conduct the work – leaving introductions to last, writing elements of arguments in the order of the development of the argument etc. Simply getting students to move towards this more rigorous approach to writing can radically improve the quality of their writing.

Conclusions

Teaching students the overall set of competencies needed for very good expert scientific and technical communication is in fact beyond any single undergraduate or postgraduate degree – and it is therefore beyond any one module within such degrees. Teaching of writing and communications skills needs to be built into an overall education from initial undergraduate to final postgraduate work. There needs to be two strands to this education. First, ever-present opportunities and requirements to engage with geological texts and to write up or about geology. Second, overt teaching of writing skills and competencies. As noted above, learning to write science well is not simply about good communication, it is also about being a good scientist.

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The full report and activities used in the study can be accessed via: gees.ac.uk/projectheme/smallfund/2003