Stretch and challenge: Building expertise in Chemistry

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INTRODUCTION

This research project started while I sat in a meeting thinking about the new syllabus. Introduced in 2008, the new ‘A’ level syllabus for Chemistry from OCR has a specific requirement for “stretch and challenge”. This is part of the QCA mandated changes to all syllabi occurring this year. This change is intended to address the need to better differentiate between the highest achieving candidates. The exams will be changed to better differentiate students not just by introducing the new higher grade A*, but also the style of exam changing, according to the OCR website:

- Including a greater variety of introductions to questions, for example 'analyse', 'evaluate', 'discuss'
- Including extended writing
- Using a wider range of question types, for example, case studies and open-ended questions, rather than just short answer questions.
- Developing improved synoptic assessments.

The exam board does not see this as a major change, “We see ‘stretch and challenge’ as being about the recognition of existing practice rather than the introduction of a new initiative.” (Chair of examiners David Swainton). It is intended to assess these skills
However I wondered if I was ready to “stretch and challenge” the whole class at once, as I certainly did not feel that my own in class differentiation had given direct preparation for this type of questions to the whole class.

In one of my classes last year, three students who had had the same GCSE teacher told me with great verve how ‘he taught us much more than we needed’ and ‘the exam didn’t have half the stuff we knew’. All commented on how much this helped them start their AS Chemistry. Though formally they had done OCR Gateway Science, they arrived with the knowledge expected of a student who had completed the much more demanding IGCSE Chemistry course, which covered much material that was also in the first January module. Clearly, this teacher had ‘stretched and challenged’ their students, with the result that they were much better prepared for their ‘A’ level courses. They were able to ask useful and probing questions in class, and demonstrated a much clearer mental model of the principles of basic Chemistry.

At the time, I also had some very able, motivated A2 students who intended to study Chemistry at university, and I felt that I was not stretching or challenging them enough in the classroom. I decided to try to find out if whole class ‘stretch and challenge’ was possible, and how.

What is “Stretch and Challenge”?

“Bloom's Taxonomy”, published in 1956 by Bloom *et. al.,* was designed to give a hierarchy of cognitive skills to aid educators in classifying different educational objectives. Evaluation and synthesis of knowledge are placed at the top, i.e. considered to be the most demanding of cognitive skills. This should mean they are also the most highly valued skills, and should be rewarded by a higher weighting in grading schemes.

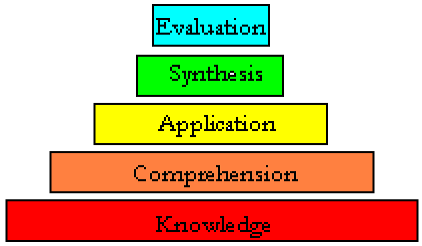

Fig. 1 Bloom's Taxonomy

Anderson and Kraftwohl in 2001 made some modifications to this hierarchy, placing evaluating and creating at the top, as the most demanding skills.

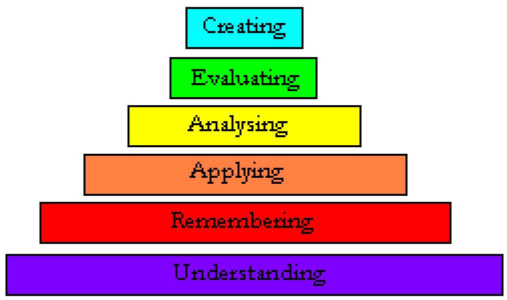

Fig. 2 Revised cognitive taxonomy

Though Bloom's taxonomy and related work may be very widely known, in fact it appears that Gagne's taxonomy of intellectual skills from his "Conditions of learning and theory of instruction" (1965) which although being less general, fits with teaching activities much better, and has been used more widely in the development of school curricula internationally. A part summary is shown below:

Intellectual skills:

Discriminations-

1. Point out distinctive features.

Concrete concepts-

2. Remember facts using short term memory.
3. Use a previously learned skill.

Defined concepts-

4. Using a principle to other problems of the same class.

Rules-

5. Applying rule to different types of problems

Higher order rules-

6. Combining and adapting rules for other problems

The intent of the exam board to include terms such as 'analyse', 'evaluate', 'discuss' in the new exams appears to directly reference Bloom’s taxonomy, so if these skills are recognised in the mark scheme, then students will need to have experience of analysing, evaluating and discussing Chemistry in the classroom. In my own everyday teaching, I do not feel that I directly teach all students in my class these skills, or provide enough opportunity for them to be developed.

What are we doing at the moment?

At Farnborough, 'stretch and challenge' appears to be addressed most fully in the ‘Farnborough Extended Project’, where students are able to take a project of their choice, research around the area and evaluate what they have found out, perhaps creating their own opinions and ideas as well.
In Chemistry, and a selection of other subjects under the old syllabus, a separate ‘stretch and challenge’ qualification called the ‘Advanced Extension Award’ (AEA) could be taken. As this award had timetabled lessons, only a very select few of the ‘gifted and talented’ cohort were offered it.
Now, the AEA has been discontinued, and the challenging nature of the exam has been partly subsumed in to the mainstream ‘A’ level due to the introduction of the A*. Only the 'gifted and talented' students, as labelled by average GCSE score are invited to participate in the 'Farnborough Extended Project'.
Naturally, there is also the classroom based differentiation that all teachers do in a very wide variety of different ways.

The three methods of differentiation normally referred to are differentiation by:

- **Task**
  Selecting different tasks for different students, based on an assessment of their ability to complete the task.

- **Outcome**
  Giving a more open ended task to students, and allowing them to push themselves as far as they can go. The Farnborough Extended Project is an excellent example.

- **Time**
  Can be allowing some students more time to complete a task than others, or having supplimentary challenging tasks available for those who complete the core requirements of a lesson or part lesson early.

Personally, my differentiation in-class is usually limited to an extension exercise on hand to keep the brighter students busy while I help the weaker students get up to an acceptable level of understanding. This means that most of the differentiation at the present undertaken my students in Chemistry is by task, and selection is by speed and exam results, neither of which is a total indication of ability in Chemistry.

Project aims

- Provide stretch and challenge to all students
- Avoid demotivating weaker students

To provide stretch and challenge to all students is not easy. Going beyond the syllabus with the whole class has potential risks, as well as possible benefits. The main and most obvious risk is that of demotivating weaker students. This method does however avoid the possibility of demotivating weaker students when they are not selected for stretch and challenge activities.

- Reduce misconceptions

By introducing S&C activities to the whole class arena, I also hope to reduce misconceptions. When students learn about a new facet of a previously learned principle, they must adjust their concept of this principle (their conceptual framework) to allow it to fit. For students using ‘alternative conceptions’, i.e. those that have inaccurate or incomplete mental models of what happens at the particulate level, it may become more obvious to them themselves that these frameworks are insufficient.
This then requires good scaffolding to help reconstruct sound foundations of knowledge, thus supporting extension work much better. Chemistry requires an understanding of how the theory of particles affects the concrete reality of the world around us, things we can see and measure. One of the main difficulties in teaching Chemistry is getting students to relate what happens to particles too small to see, to the reality that they can see and measure around them.

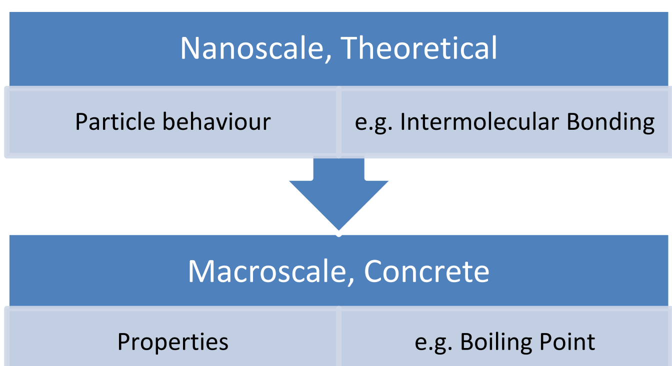

Fig. 3. Progression from the theoretical and abstract to the concrete

Students have been constructing their own ideas of how the world works without intervention for most of their lives, much of what we teach tends to be seen by the students as only applicable to the laboratory, overlaying their instinctive understanding of the everyday behaviour of things. Especially with something as abstract as an organic mechanism, relating the detail of how a the steps though which a reaction actually occurs to the products isolated from the reaction is not trivial.

Further possible aims are:

- Pupils should become more confident with unfamiliar material

By exposing all students to ‘stretch and challenge’ materials in the classroom, where even the weaker students can be supported to achieve some success if they try, should hopefully allow these students to be more confident when tackling such questions in an exam situation, and further on at university.

- Better preparation for university

As all students will face the same exam, all students need to be prepared for these questions, so it makes sense to show all students ways to take apart and to at least partly solve these questions.
Being more confident with unfamiliar material and problems requiring more than one or two steps to solve should also be better preparation for university.

What do universities want?

From talking to David Read (former teacher fellow now admissions tutor) at Southampton University Chemistry department, and Martyn Coles (senior lecturer in Chemistry) at Sussex, it seems universities want more independent learners.

> “Students ask what page of the text book to look at- have they not heard of an index?”
> “Students are less willing to tackle tasks that look harder, and expect much more help.”
> “Many misconceptions remain at university level, as students are not used to linking different parts of the syllabus, so not realising how interlinked the subject is.”
> “Students learn for the modular exam, then wipe their brain clean ready to be taught the new material here.”
> “When they enter university, they assume they will be taught everything they need, not understanding that previous knowledge and understanding will be assumed by the lecturers that they do not necessarily have.”
> “Our two weakest students in Year 2 both have 4 ‘A’s at ‘A’ level.

Students who go to university to study your subject may well have not faced any real challenge to their abilities. At GCSE they are told ‘if you don’t work, you won’t succeed’ and then they succeed. At ‘A’ level, the vast majority of students must work to succeed, however a minority, some of whom will be going on to study your subject or a related area at university will sometimes succeed with a minimum of input. When they get to university, they don’t pay any more attention than they did before, and find out often too late that they must study, and have not.

So my intervention should include enough challenging material to help brighter students realise that they must work hard to learn too. It should also help students to link in their basic chemical understanding with the more complex principles they must learn, and so use these principles to extend further beyond the syllabus.

METHOD

My approach is based on an ‘Aufbau’ approach, a building up of expertise from basic principles. Aufbau is a German word meaning ‘build up’ it is used in Chemistry when examining how electrons fill orbitals from the lowest level up.

Starting with the top, a principle or process, working out what tools are needed to understand it is very hard, as when we as teachers solve a problem, we use principles and knowledge acquired over a lifetime in our subject.

Breaking a problem down into its constituent parts, in order to show students how to solve it is part of general teaching, as everyone does it. Personally, however, I don’t think I’ve been as rigorous as I could have done in the past, and to bring stretch and challenge questions to the whole class, a very careful break down is needed to support weaker students with harder problems.

Using an ‘Aufbau’, building up of basic chemical principles (covered at GCSE and before) to better anchor learning at ‘A’ level, and then to progress beyond the syllabus using these principles is the philosophy of my project.

I had hoped I would be the first person to use the word ‘Aufbau’ in this manner, however Keith Taber, senior lecturer in Education at Cambridge University used this self-same term in a paper on misconceptions in Chemistry (2002). However, I can find no other use of the ‘Aufbau’ principle in the production or delivery of ‘stretch and challenge’ material, so this seems to be partly at least a novel philosophy.

For example, electrophilic substitution:

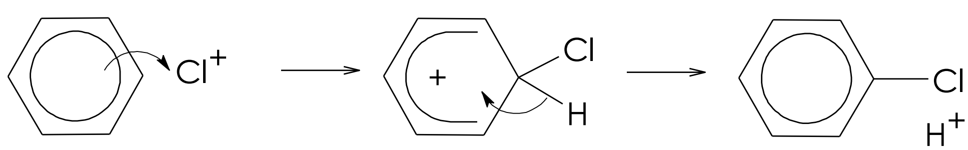

Fig. 4. Electrophilic substitution to form chlorobenzene

This is a mechanism that many find difficult at ‘A’ level, Common mistakes made by students include showing the electrons moving the wrong way, i.e. from the electrophile to the electron rich aromatic ring. Supporting students to understand better what an electrophile is by constructing ‘dot-cross’ diagrams of the reacting species should help more students avoid these mistakes, and have a better more 'grounded' idea of why the electrons move the way they do. Students learn the ‘octet rule’ at GCSE, that atoms generally need 8 electrons in their outer shell to be stable. For example, the Cl+ electrophile shown below can accept a pair of electrons to form a new bond.

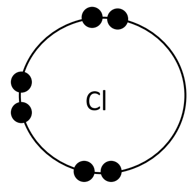

Fig. 5. 'Dot-cross' diagram of Cl+, showing space available for electron pair for a new bond to form

To understand electrophilic substitution you first need to know what an electrophile is, (an electron pair acceptor) so therefore understand that it must be able to make a space in its outer shell for a pair of electrons to go, and so make a bond. The simplest example of this on the syllabus is Cl^{+}, produced after use of a halogen carrier. This links in with what covalent bonds are (a shared pair of electrons), and to the AS level concept of 'dative' covelant bonds (a shared pair of electrons where both electrons come from the same atom).

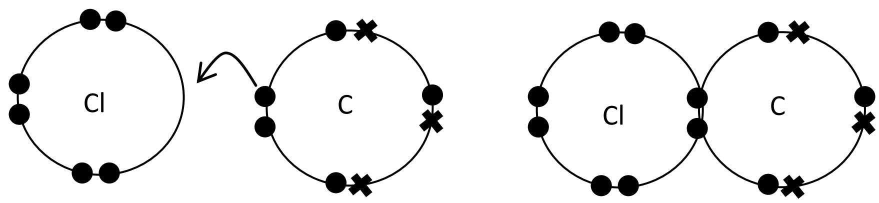

Fig. 6. Showing how the Cl+ can accept a pair of electrons to form a covalent bond.

The concept of aromaticity is also required, not something most students struggle to describe but struggle to apply to this mechanism (according to the OCR examiners report 2009), to see an aromatic ring as an electron pair donor (nucleophile) is not easy. The idea of a carbon-carbon double bond acting as a nucleophile is first visited in AS Chemistry, looking at electrophilic addition. Explaining why substitution occurs and not addition when the first step is the same, requires a good idea of aromatic structure, and its inherent stability.

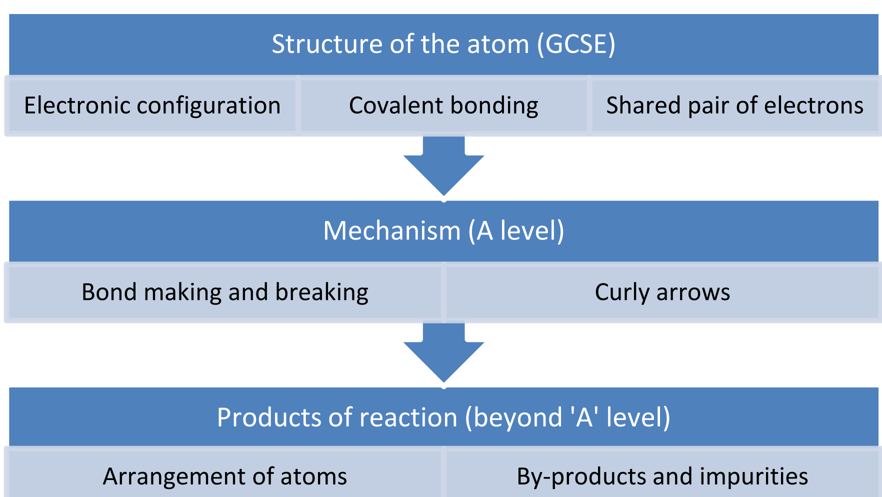

Fig. 7. Progression from abstract ideas of atomic structure and bonding to the concrete, i.e. products made by reactions

We can use basic chemical principles to get as far as the learning outcomes from the syllabus, but the same principles can be used to go further.

Any electrophile can be used in this mechanism, NO_2^+ can be used as an electrophile (after the reaction of nitric acid and sulphuric acid) so undergo the same mechanism, this is also on the syllabus.

As of 2008, Friedel-Crafts (alkylating the benzene ring) is no longer on the OCR A Chemistry syllabus. However, as it involves making a carbocation intermediate, dot-cross diagrams can show that it has a space for a pair of electrons, so can undergo the exact same mechanism. The high pressure substituition of CO_2 is a classic example used in exam questions to test knowledge of this mechanism, 'dot-cross' diagrams can show that one of the carbon - oxygen bonds will break, so allowing it to behave as an electrophile. Sulphonation requires use of the electrophile SO_3, which although was on the 'A' level syllabus more generally before 2000, does require the idea of sulphur expanding its octet, which makes it much more difficult to explain its electrophilicity, and according to more up to date research is a very poor model to use (Gillespie and Silvi, 2002)

Placing more learning on top of their basic Chemistry also can make students realise sooner when there is a problem, as cognitive dissonance can pinpoint a problem with an 'alternative' i.e. wrong model though further learning faster than a simple test could indicate an 'alternative' model was in use by the student to allow remedial teaching.

This also can act as revision for weaker students, as it is the same mechanism following the same pattern for each electrophile.

My Intervention:

What?:

I decided to use worksheets, so that the students could progress at their own pace, with less support from me. For a wide range of abilities to tackle material as challenging as this was, I needed to have time to support the students individually.

The sheets were graded in difficulty, with the basic concept building up (Aufbau) at the beginning, and building on that framework the more advanced challenging material further though. This allowed the more able to progress faster and find the challenge later on in the sheet, and the weaker students to make step by step progression though the less challenging earlier parts of the sheet.

Writing a worksheet also allows me to think very clearly about how I am going to break the task down, so guidance for each step can be provided. In order to write these sheets, I needed to go back to my text books and relearn, sometimes learn for the first time a very large amount of Chemistry. I have a PhD in the subject, and was shocked to find out just how little I knew about how the different topics in 'A' level Chemistry fit together. It strikes me that we expect students to make links between different topics and complain when they do not, but perhaps we need to make those connections first ourselves.

Using a worksheet aslo frees me from direct teaching to provide assistance to individual students, especially weaker students, who needed more guidance than can be provided on a sheet, and also stronger students, who were prompted to ask more probing questions, going further than I had planned.

Who?:

I decided to use the worksheets on both my groups (18 students each), not to keep a control group, as the students do know each other, and as I had informed both about my research project, It would be demotivating for them not to be included. They could be compared to the rest of the A2 year group (9 groups in total, 171 students).

When?:

The organic Chemistry unit 'Rings Polymers and Analysis' OCR Chemistry A, is taught from the summer after the exams up to Christmas. The first materials were trialled on the groups I taught in the summer for the first unit, then used as revision material when this unit was revised in January. Extension work sheets were prepared for each topic of this unit. 'Arenes', 'Spectroscopy and analysis' 'Carbonyls', 'Carboxylic acids', 'Amines', 'Amino acids', 'Polymers', 'Synthesis' were the topics covered.

RESULTS

Data was collected in the form of comments made by students thoughout the course, a diary I kept thoughout the intervention, a questionnaire at the end of the course and comparing examination data.

Exam Results, based on the January mock examination:

Comparing data from the mock exam taken in January by the whole year group under examination conditions, taking the average score for my students on question 5 which was the 'A*' question, as it contained unfamiliar material and asked the question in an unfamiliar way.

There were no statistically different (>5%) results between my groups, and the rest of the year, so this cannot be considered as successful with respect to examination grades. However, as other teachers did use some of the materials in their lessons, few conclusions can be drawn from this.

Student verbal feedback:

- 'I can remember it better when I understand it better' VG
- 'It makes more sense now' MN
- 'It is like revision, I can see the pattern' SL
- 'We should just stick to the syllabus' AF

Much discussion was prompted by some of the sheets, e.g. comparing the basicity of amines (no longer on OCR Chemistry A syllabus as of 2008) was widely discussed thoughout the classroom. One student in particular (KD) was much more involved than usual by her neighbour (LG) in these discussions.

One topic, looking at nucleophilic substitution in detail (Sn1 and Sn2, no longer on ‘A’ level syllabus as of 2000) comparing different types of nucleophilic substitution was not as well done by the students, it had needed better preparation from me. However, LG commented ‘Why don’t we do this any more, it makes the Chemistry make much more sense’ Another student, MN commented ‘They seem to have taken off all the interesting stuff’.

Student questionnaire feedback:

- Students initially worried about stretch and challenge questions (*ca.* 75% worried, by comments made in discussion of the research project in class)
- Improves to 51% students saying they are confident in tackling the new “stretch and challenge” questions
- 60% students want to learn more than the syllabus
- 70% students believe that going beyond the syllabus will help them after 'A' levels

The questionnaire was given at the end of the course in May, unfortunately I did not do a similar questionnaire at the beginning of the course which would have given a clearer indication of trends thoughout the year. The questionnaire and its results are in appendix 1 and 2 respectively.
Many students felt the January examination to be hard, which was not surprising. However I was pleasantly surprised by the number who valued ‘going beyond the syllabus’ and felt it would help them after ‘A’ levels. This is with only one student (who did not participate in the questionnaire) intending to study pure Chemistry at university.

CONCLUSIONS:

- No improvement in exam performance
- Some very good general verbal feedback
- Has encouraged students to ask more probing questions
- One able 'B' student has blossomed
- More work needed.

In summary, although it seems the aim of improving confidence was achieved, any secondary bonus feeding though to examination results is yet to appear. This may change with the summer examination results.

Reflections on results:

- Success of different activities depended on painstaking preparation
- Definitely worthwhile, success with some weaker students as well as with traditional G&T students
- Not useful for exam performance, but for student growth and motivation
- With further work could benefit examination performance too

With further bedding down of the new syllabus and examination question style, I believe this type of approach could really benefit student attainment too, however this will require a much more sustained long term intervention than the remit of this study.

Reflections on professional development:

- I had to learn much Chemistry to prepare the worksheets
- I now appreciate the difficulties of what we demand from the students.
- I am more conscious of steps necessary to understand Chemistry
- More work needed, this is now an ongoing effort for me, extended to both A2 and AS Chemistry

It was very much worth while, for me as a teacher, and for my students. To see mid-range ability students asking difficult probing questions and pushing themselves further was reward enough for me, however with the added benefits for me professionally of taking a much more scientific approach to my teaching, in terms of material and delivery, it has been eye-opening.

APPENDIX 1: Questionnaire

The questionnaire was originally written as an online survey, on 'survey monkey' however due to low take up, I printed it out and gave it to the students in the last week of teaching A2 Chemistry.

1. How confident do you feel about tackling the new 'stretch and challenge' questions in the A2 exams?

	Very confident	Confident	Unsure	Really worried
Confidence	○	○	○	○

Any further comment

[ ]

2. I am retaking the January exam

○ Yes

◉ No

3. How did you feel about the January exam?

	Agree strongly	Agree	Disagree	Disagree strongly
I had enough time	○	○	○	○
I had been taught all the material	○	○	○	○
I revised well	○	○	○	○
I could work out the harder questions	○	○	○	○
You just had to remember the facts	○	○	○	○
The questions were easy	○	○	○	○
You had to understand the facts	○	○	○	○
You could work out the answers	○	○	○	○
The exam was fair	○	○	○	○

Any further comment

[ ]

4. How did you feel your grade represented your ability?

	Agree strongly	Agree	Disagree	Disagree strongly
I got a fair grade	○	○	○	○
I got a lower grade than I deserved	○	○	○	○
I got a higher grade than I deserved	○	○	○	○
I worked hard enough	○	○	○	○
I am happy with my grade	○	○	○	○

Any further comments

5. How do you feel about 'stretch and challenge' in the classroom?

	Agree strongly	Agree	Disagree	Disagree strongly
We should just stick to the syllabus	○	○	○	○
I am never bored in lessons	○	○	○	○
It is interesting to learn more	○	○	○	○
We need to work more out for ourselves	○	○	○	○
Lessons are too easy	○	○	○	○
Lessons are hard enough	○	○	○	○
Going beyond the syllabus will help me after ‘A’ levels	○	○	○	○

Any further comments

6. How do you feel about the June exam?

	Agree strongly	Agree	Disagree	Disagree strongly
I feel confident	○	○	○	○
I have learned from the January exam	○	○	○	○
I am better prepared this time	○	○	○	○
My teacher has prepared me well	○	○	○	○
I can improve my grade	○	○	○	○

7. Is there anything else you would like to add?

APPENDIX 2: Questionnaire results

Question	**Very confident 1**	**Confident 2**	**Worried 3**	**Very worried 4**	**Number of responses**	**average**
1	1	13	11	2	27	2.52

Question	**yes**	**no**	**Number of responses**
2	15	12	27

Question	Very confident 1	Confident 2	Worried 3	Very worried 4	Number of responses	Average
3a	3	12	9	3	27	2.44
b	12	13	2	0	27	1.63
c	6	13	8	0	27	2.07
d	8	11	8	0	27	2.00
e	3	5	18	1	27	2.63
f	1	6	17	3	27	2.81
g	12	14	1	0	27	1.59
h	5	15	7	0	27	2.07
i	4	14	9	0	27	2.19

Question 4	Very confident 1	Confident 2	Worried 3	Very worried 4	Number of responses	Average
a	5	12	8	2	27	2.26
b	6	6	10	5	27	2.52
c	2	2	17	6	27	3.00
d	8	10	8	1	27	2.07
e	7	5	10	5	27	2.48

Question 5	**Very confident 1**	**Confident 2**	**Worried 3**	**Very worried 4**	**Number of responses**	**Average**

a	4	7	15	1	27	2.48
b	2	10	13	2	27	2.56
c	3	13	5	1	22	1.78
d	1	12	13	1	27	2.52
e	0	1	24	2	27	3.04
f	1	24	2	0	27	2.04
g	2	17	5	3	27	2.33

Question 6	**Very confident 1**	**Confident 2**	**Worried 3**	**Very worried 4**	**Number of responses**	**Average**
a	2	18	7	0	27	2.19
b	4	22	1	0	27	1.89
c	4	14	9	0	27	2.19
d	9	18	0	0	27	1.67
e	7	16	4	0	27	1.89

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