nature of scientific inquiry in Year 11 science

What do our New Zealand students experience in school science as they learn about scientific inquiry? This article is based on two classroom-based case studies in 2005, as *Anne Hume*, Waikato University explains:

Context for the Case Studies

In the context of a national science curriculum (Ministry of Education, 1993) that sought to promote students' engagement in authentic inquiry, my case studies involved Year 11 science classes where students (15–16 year olds) were learning how to perform investigations for Science Achievement Standard 1.1 *Carrying out a practical investigation with direction* (SAS 1.1) towards their National Certificate of Educational Achievement (NCEA). The Year 11 context was chosen because for many of our students this is their last opportunity for formal schooling in science, and likely to be a time when they form lasting impressions of the nature of scientific inquiry. These ideas and beliefs could have implications for their scientific literacy as future citizens, in terms of the extent to which they understand and appreciate the ways scientists work to produce scientific evidence, solve problems and build knowledge.

My case studies were set in two large New Zealand secondary schools, River Valley Boys' High School and Mountain View High School (pseudonyms). Both school populations were similar in that they were predominantly of New Zealand European ethnicity (77% and 68% respectively) and each had 12% Maori. Mountain View also had a significant proportion of Asian students (15%). Each case study involved a female teacher, and four to five Year 11 students (15-16 year olds) who were studying SAS 1.1 towards their NCEA qualification. The students at each school were in classes representing a very broad band of mid-range of abilities – approximately 80% of the whole Year 11 cohort. The remaining 20% were streamed into two classes of high and low ability respectively. At River Valley, Jenny (pseudonym) the teacher held a Master's Degree in genetics and was in her eighth year of teaching. At Mountain View, the teacher Kathy (pseudonym) had begun her teaching career three years earlier after completing a conjoint Bachelor's Degree in science and teaching.

My three research questions were:

- *What* science are New Zealand science students learning in NCEA classroom programmes for SAS 1.1?
- *Why* and *how* are New Zealand science students learning the science they learn in NCEA classroom programmes for SAS 1.1?
- *What* match is there between the intended curricula (i.e. those of the SiNZC and the teacher) and the operational science curricula (i.e. those experienced by New Zealand science students)?

Classroom sessions: an overview

At both schools many decisions to do with classroom practice were not made by the individual teachers, but were made collectively at departmental level in the form of departmental guidelines. These guidelines were based on recommendations, including exemplary materials, from the New Zealand Qualifications Authority (NZQA) which departments and classroom teachers were obligated to follow under school accreditation requirements. Thus, at both schools the content of departmental guidelines was very similar, and both case study teachers adhered closely to departmental guidelines in their teaching and learning programmes.

At River Valley, the teaching and learning took place during twelve one-hour lessons over a three-week period, late in term one of a four-term year. In contrast, students at Mountain View experienced a staggered teaching and learning programme, eleven hours in total. Their teaching started with five one-hour lessons late in the first term, followed by a three-week break before another four consecutive lessons early in the second term. Two weeks later, Mountain View students attended a single timetabled session (two hours) within the school's mid-year internal exam programme where they underwent the formal assessment for SAS 1.1. Despite the variation in the overall timing and duration of the teaching and learning sessions at the two schools, the sequence of lessons in both schools showed strong parallels. Each sequence could be divided into three distinct phases: the preparatory phase (instructional sessions); the practice phase (called the 'Formative Assessment' by the teachers in these studies) and the formal assessment phase (the summative assessment).

Preparatory phase

In this first phase, students in both classrooms were introduced to the requirements of SAS 1.1 and key concepts and skills associated with investigating relationships between two variables. Lesson content in these largely instructional sessions focused on: terms, definitions and procedures to do with fair testing: specific skills such as making observations and measuring, tabulation and averaging of data, plotting graphs and the planning and reporting of fair tests using templates and how to meet the assessment requirements of SAS 1.1 as depicted in assessment schedule exemplars. Less time was devoted to the first phase at River Valley (three lessons, compared to five at Mountain View), and Jenny also revised specific science concepts that featured in the investigation her students were to perform in phase two (rates of chemical reaction and preparation of solutions of given concentration by dilution).

Practice phase

In the second phase, students at both schools participated in a mock assessment known as the 'formative assessment,' designed to give students practice at performing a whole investigation under test-like conditions. Again, there were many commonalities between the two case studies:

- the mock assessment took place over four lessons, with each lesson covering in turn: the planning; data collecting; reporting; and feedback stages of the investigation
- the science context for the investigations was the same (both teachers used the same exemplar materials for investigating the effect of factors such as temperature or concentration on the rate of reaction between magnesium metal and hydrochloric acid)
- students worked in teams of four for planning and data gathering, but as individuals for the reporting
- the format, timing and reporting requirements of the mock assessment activity closely matched those of

Table 1. The teachers' intended learning at River Valley and Mountain High

Concepts	Skills	Procedural Knowledge
Fair tests Purpose of an investigation as an aim, testable question, hypothesis or prediction Variables - key, dependent and independent Primary and secondary data, qualitative and quantitative data, reliability of data Tables as a systematic format for recording data Graph types (bar and line); graph components such as title, x (independent variable) and y (dependent variable) axes, units and values for axes, plotted points, and lines of best fit Sources of error and systematic errors Equipment names, types and purpose Background/contextual science concepts to the investigation e.g., factors affecting rate of reaction and behaviour of pendulums.	Designing, evaluating, modifying and carrying out a systematic plan for a fair test Determining the purpose of a fair test investigation Identifying, controlling, changing, observing and measuring variables Choosing and using equipment appropriately Determining appropriate range of values for variables Repeating experiments Recording and processing data – tabulating, averaging, graphing Interpreting data, and recognising trends and patterns Discussing findings, linking findings to existing science ideas and drawing conclusions in a written report Evaluating the investigation in the written report (sources of error, improvements).	Knowing how to plan a workable, fair test Knowing that planning requires trialing, evaluating and modifying Knowing why reliable data is needed and how to obtain consistent data Knowing that the findings should be linked to science ideas Knowing how to work as a team Knowing how to interpret the template and assessment schedule requirements of tasks for the internal Science A.S. 1.1 at achievement, merit, and excellence levels.
*At River Valley Jenny added 'Good science' (the science that real scientists do), and 'school science' (the portrayal or simulation of science experienced by students in school); systematic errors; and the concept of controls *At Mountain High Kathy provided an experimental plan which included an aim, list of equipment and an experimental method, a format for scientific reports and coverage of the relationship between two quantities when change in one causes change in the other.	*At River Valley Jenny also included some trialing of plans	*At River Valley Jenny also dealt with how to recognise and account for errors in measurement; and recognising that the planning and carrying out of investigations required for Science A.S. 1.1 more closely resembles 'good science', than most 'school science' *At Mountain High Kathy added knowing that the findings should be linked to the science behind the investigation; and knowing when assumptions can be made and the limitations of those assumptions

the summative assessment in phase three

- teacher direction was highly evident, including extensive and targeted feedback for students related to the assessment schedules for the task.

In addition, at River Valley students initially peer assessed each other's reports using a common assessment schedule and provided verbal feedback to one another before the teacher provided global feedback to the class.

Formal assessment phase

In the third phase for their formal assessment, known as the 'summative assessment,' students again performed fair test investigations in groups along similar lines to the practice investigation in the second phase. They initially planned as individuals, then collaborated as a group to produce a single plan and obtain data, and finally wrote up the reports individually.

The planning and reporting templates were virtually identical in the two schools, however, the science contexts for the investigations were different. Students at Mountain View performed their investigation in the context of reaction rates again, this time the relationship between surface area and the rate of reaction, while students at River Valley performed their investigation in the context of pendulums which they had no prior experience of in the course. Students at Mountain View planned and executed their investigation with relative ease, whereas my study group at River Valley experienced difficulties carrying out their plan investigating the relationship between the length of a pendulum and its period, that is, the time taken to complete a full swing. They were unable to operate the pendulum successfully, and consequently could not record sufficient data. However, they were very savvy of assessment techniques, and showed adeptness at 'playing the system' as the following excerpt shows:

Within the closing stage of the practical session the group scrambled to complete and record sufficient runs for their data processing and interpreting phase. The four group members frequently interchanged roles as they each took it in turn to record their own copy of the results (which they needed for the write-up in the following session). All other groups had finished their data collection and were listening as Jenny covered points for the write-up. Martyn, Peter, Mitchell and Eddie continued operating their pendulum and consequently missed hearing what Jenny was saying during her briefing. In their rush to finish, confusion set in, "Is this the third or fourth one?" asked Mathew who was recording and calculating. When the pendulum continued to collide with the support arm, Peter commented, "You'll have to estimate," while Eddie was convinced they should "make up the rest." Mitchell agreed, "Let's make up the rest, and take sixteen seconds as the average," and Martyn confirmed, "It will still give us our results." Each group member had a complete set of written data by the end of the practical. Jenny allowed the class to view the background science notes (a set of notes explaining the science concepts and terms related to the pendulum) prior

Table 2. Key influences on *Why* and *How* students learned

The Content of the Teachers' Intended Curricula	The Pedagogical Approaches, Strategies and Capabilities of their Teachers	The Learning Strategies that Students Employed
Teachers delivered content in the teaching and learning programmes specifically targeted at fair testing and the assessment requirements of SAS 1.1 Teachers' decisions about lesson content were governed by their respective school departmental guidelines for delivering the SAS 1.1 - all teachers in the departments were obliged to follow these guidelines. Departmental guidelines were similar in each school since each school looked to materials provided by government agencies to support learning programmes for the SAS 1.1 i.e., planning templates, and exemplar assessment tasks and schedules. * The exposure of students at River Valley to the notions of 'good science' as opposed to 'school science' in their learning, probably stemmed from their teacher's own knowledge base and beliefs about the nature of scientific investigation and her personal experience of scientific research.	Departmental guidelines produced many commonalities in the pedagogical strategies teachers employed - they effectively decided the: manner in which the teaching and learning programmes were to be delivered and assessed; timing of the programme delivery and; adoption of the planning template and exemplar assessment tasks and schedules. As a result teachers' pedagogical approaches were predominantly didactic in nature. Students identified particular common teaching strategies that helped their learning, including: provision of the opportunity to do practice investigations and write-ups for assessments in groups: direct instruction from knowledgeable teachers; provision of a planning template and assessment schedules and; feedback they received from teachers and fellow students after assessments. Convergent formative assessment practice underpinned why and how students were succeeding in many aspects of their learning. Explicit sharing of learning goals, success criteria and learning progress with students was achieved via the use of exemplars. The timing of the teaching and assessment early in the school year appeared to limit students' opportunities to consolidate and improve their learning in a wide range of contexts, and to develop the tacit, intuitive knowledge required for effective investigating in science. The teaching decision to set both the formative and summative investigations in the same familiar science context possibly gave students at Mountain View the opportunity to make meaningful links with their new experiences more readily than students at River Valley, where the background science in the summative assessment was unfamiliar to students and they had had little exposure to the phenomenon being investigated.	Students often played a mediating role in their learning, at times consciously choosing when and how to engage from a range of personally preferred learning strategies. Learning choices were often related to perceptions students had about what was valuable or important to learn and who was best suited to assist their learning at given times, and feelings of self-esteem and self-confidence: - NCEA was an important personal goal for most students, and they were prepared to learn what was required of them in order to demonstrate achievement of the standard at particular levels of attainment. - high value was placed on being able to work and collaborate with peers – students appreciated the convenience and ease of sharing knowledge and expertise to problem solve, and to clarify misconceptions and/or confirm understanding in the relatively safe forum of pairs/small groups of students. They realised some interactions between peers could also be detrimental to learning, and lack of effective teamwork was seen to compromise intended learning work on at least one occasion. - students were ambivalent about the value of peer assessment in promoting and facilitating their learning, generally because they questioned the credibility and capability of their peers to assess as accurately as their teachers. While it was difficult to judge individual students' capabilities on the basis of negotiated group plans, the collaborative planning process tended to give more group members the potential to secure relevant and reliable data, and in turn the chance to process and interpret data, draw conclusions and evaluate their findings.

to the end of the period; but before collecting in all papers to retain overnight.

At the last minute, the students resorted to recording their remaining results from non-existent data, and then used these fabricated results to complete the reporting section of the assessment.

Another significant difference between the case studies is that, unlike the students at River Valley, the five students in the Mountain View study did not work in the same groups for the summative investigation. Kathy purposefully decided groupings for the summative assessment at Mountain High on the basis of results from the formative assessment, so that each group intentionally had at least one student who had demonstrated advanced investigative capabilities.

What were students learning about scientific inquiry?

Findings from both case studies indicated that the learning students were achieving closely matched that which their teachers intended them to learn. The content of the teachers' intended curricula is summarised in Table 1, and represent a synthesis drawn from data collected during teacher interviews, observation of classroom lessons, departmental guidelines and notes, and student workbook and text (Refer Cooper, Hume & Abbott, 2002; Hannay et al., 2002).

Why and how were students learning?

Interviewing the students and their teachers, observing them interact in class, and examining support materials and student records revealed why and how students learned about fair testing and the assessment requirements of the SAS 1.1 were direct consequences of three influences: the content of their teachers' intended curricula; the pedagogical approaches and techniques that their teachers used; and the learning strategies that students employed. The key findings are summarised in Table 2.

Conclusions and implications

This study sought to gain some insights about the possible nature of the student-experienced curriculum as our Year 11 students learn about scientific inquiry from the perspectives of some actual teachers and students in the classroom. By examining what these students were learning about science investigations, my research found that in both case studies their learning appeared to be focused on a narrow view of scientific inquiry, that is, fair testing, and on mastering assessment techniques. Why and how this learning occurred stemmed largely from the strong influence the national qualification NCEA, and its interpretation of the science curriculum, was having on decisions affecting the two classroom programmes. This study supports the observations of Black (2001, 2003) that qualifications are considered high stakes by schools and teachers, and that assessment for qualifications is driving the senior school and classroom programmes in New Zealand. Decisions were made in this study at school and departmental levels, which reflected the importance the two school communities, and professional staff placed on their students achieving success in this qualification, and these decisions directly impacted on the content of classroom curricula and the methods teachers used to deliver that content.

The NCEA interpretation of the science curriculum (in the form of SAS 1.1 and supporting materials) and departmental decisions determining time allocation and timing of the science investigation programme in classes influenced the instructional approaches teachers chose to use and the strategies used by students to learn. The structure of the qualification, especially the standards-based mode of assessment, promoted some aspects of formative assessment practice with teachers employing strategies such as explicit learning goals, exemplars and feedback. However, relatively short teaching and learning programmes before summative decisions were made restricted students' ability to act on formative assessment information to improve their learning. Consequently, student learning tended to focus on procedures and there was little evidence of the higher order thinking skills linked to creativity, evaluating and self-monitoring of learning.

However, in the intervening period since the collection of data for this study, NZQA has made some modifications to SAS 1.1 Carrying out a practical investigation with direction and introduced more flexibility into the standard and support materials.

In October 2005, the standard was re-registered with a number of changes, which seem to introduce more recognition of the complexity of scientific investigation into the standard, and give more latitude for teachers to offer students some variety in their approaches to scientific investigation. The revised standard also provides more specific detail about what constitutes 'quality' in a scientific investigation.

The achievement criteria are more generic than those in the previous form of the standard, and some former aspects of the accompanying explanatory notes have been given increased emphasis, while some have been dropped and new features introduced. For example:

- greater specificity is provided about what constitutes a directed investigation.
- the terms practical investigation and quality practical investigation are introduced and defined in detail, reflecting the content of the modified achievement criteria. The terms workable and feasible to describe plans are dropped.
- the terms sample and collection of data are introduced, alongside the terms independent and independent variable respectively in the definition of a practical investigation, and sampling and bias as possible factors to consider in data gathering in the description of a quality practical investigation. The inclusion of these terms potentially enables students to use approaches to investigation other than fair testing, but because sampling and bias can have close connotations with fair testing it is possible that fair testing may still prevail in classroom practice unless appropriate exemplary support materials and text are accessible to professional development providers, teachers and students.
- validity of method, reliability of data and science ideas are specified as requirements to consider where relevant when evaluating the investigation.

These changes signal more acknowledgement of the nature of scientific inquiry in NCEA assessment procedures for SAS 1.1, and possibly greater opportunity for students to experience authentic scientific investigations (that is, the 'doing of science' in a manner that mirrors the actual practice of scientific communities. Atkin & Black, 2003) and develop higher order thinking skills. This move should give teachers greater autonomy in designing teaching and learning programmes to meet students' learning needs and interests. An overview of exemplary material now present on the Ministry of Education (MoE) website for Achievement Standard 1.1 reveals one assessment task linked to the new version of the standard. This assessment resource is based on a pattern-seeking investigation. The resource includes a planning and reporting template and assessment schedule similar in format to the fair testing versions, but with terms relevant to pattern-seeking and the new requirements of the standard.

Awareness that school-based decisions that focus too much on meeting administrative, logistical and moderation requirements of high stakes qualifications can have detrimental effects on pedagogy and student learning may hopefully prompt schools to re-evaluate the wisdom of these decisions. Finally, the views and insights that students have given in this study, about the teaching and learning they experienced, and the role they play in these processes, should provide useful information for teachers to reflect on as they evaluate the effectiveness of their teaching and assessment strategies in helping students to achieve quality learning in scientific inquiry.

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Author's note: For a more detailed account of the study refer to 'Student Experiences of Carrying out a Practical Science Investigation Under Direction' by A Hume and R Coll for the *International Journal of Science Education* DOI: 10.1080/09500690701445052.

References

Black, P. (2001). Dreams, strategies and systems: Portraits of assessment past, present and future. *Assessment in Education*, 8(1), 65-85.

Black, P. (2003). *Report to the Qualifications Development Group Ministry of Education, New Zealand on the proposals for development of the National Certificate of Educational Achievement*. Retrieved March 14, 2003 from http://www.minedu.govt.nz/index.cfm?layout=document&documentid=5591&data=l

Cooper, B., Hume, A., & Abbott, G. (2002). *Year 11 science. NCEA level 1 workbook*. Hamilton, New Zealand: ABA Books.

Hannay, B., Howison, P., & Sayes, M. (2002). *Year 11 Science. Study guide*. NCEA Level 1 edition. Auckland: ESA Publications.

Ministry of Education. (1993). *Science in the New Zealand curriculum*. Wellington, New Zealand: Learning Media.