ASSESSMENT AND DEVELOPMENT OF SCIENTIFIC LITERACY AT SECOND LEVEL

Ruth Chadwick, Eilish McLoughlin & Odilla Finlayson

CASTeL, Dublin City University

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List of acronyms and abbreviations

1. CfE: Curriculum for Excellence
2. OECD: Organisation for Economic Co-operation and Development
3. PISA: Programme for International Student Assessment
4. SSI: Science in Society Investigation
5. STS: Science, Technology, Society

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Introduction

Scientific literacy is a widely used term that relates to how an individual uses their scientific skills and knowledge to participate in society. PISA describes the competencies and knowledge required for scientific literacy in students (OECD 2013). Socio-scientific Issues (SSI) are scientific issues that contain elements of ethical or moral concern and tasks based on SSI can be used to assess the competencies of scientific literacy (Zeidler & Nichols 2009). SSI tasks have been included in the curriculum of Scotland and Ireland, e.g. the Curriculum for Excellence National 5 Biology Assignment and the Junior Cycle Science in Society Investigation.

This research comprises of a case study of the implementation of the National 5 biology Assignment in one Scottish school and aims to answer the following research questions: What are the teacher and student experiences of carrying out the National 5 Assignment in Biology? To what extent does the National 5 Assignment in Biology assess the PISA competencies of scientific literacy in students? The case study uses observation of lessons, teacher post-lesson reflections and interviews, student post-lesson evaluations and document analysis; and thematic analysis of data gathered. From this the student and teacher experience of the National 5 Assignment was investigated.

Background to research

Scientific literacy is a widely used term, particularly in relation to a desired outcome of education. There is no universally accepted definition but it usually includes reference to the skills and knowledge required for a person to participate successfully in a society (DeBoer 2000, Laugksch 2000).

The PISA 2015 Framework for Scientific Literacy defines scientific literacy as:

> "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology." (OECD 2013 p7)

By the time students leave compulsory science education they should have developed the ability to perform the following scientific competencies:

- Explain phenomena scientifically
- Evaluate and design scientific enquiry
- Interpret data and evidence scientifically (OECD 2013)

These competencies are each divided into five sub-competencies, which can be seen in tables 1 to 3 below.

Table 1: Explain phenomena scientifically (OECD 2013 p15)

1. Explain Phenomena Scientifically
Recognise, offer and evaluate explanations for a range of natural and technological phenomena demonstrating the ability to: A. Recall and apply appropriate scientific knowledge; B. Identify, use and generate explanatory models and representations; C. Make and justify appropriate predictions; D. Offer explanatory hypotheses; E. Explain the potential implications of scientific knowledge for society.

Table 2: Evaluate and design scientific enquiry (OECD 2013 p15)

2. Evaluate and Design Scientific Enquiry
Describe and appraise scientific investigations and propose ways of addressing questions scientifically demonstrating the ability to: A. Identify the question explored in a given scientific study; B. Distinguish questions that are possible to investigate scientifically;

C. Propose a way of exploring a given question scientifically; D. Evaluate ways of exploring a given question scientifically; E. Describe and evaluate a range of ways that scientists use to ensure the reliability of data and the objectivity and generalisability of explanations.

Table 3: Interpret data and evidence scientifically (OECD 2013 p16)

3. Interpret Data and Evidence Scientifically
Analyse and evaluate scientific data, claims and arguments in a variety of representations and draw appropriate conclusions demonstrating the ability to: A. Transform data from one representation to another; B. Analyse and interpret data and draw appropriate conclusions; C. Identify the assumptions, evidence and reasoning in science-related texts; D. Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations; E. Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals).

These three competencies are underpinned by three types of scientific knowledge:

- Content Knowledge *of* science – previously known as knowledge *of* science
- Procedural Knowledge *about* science
- Epistemic Knowledge *about* science

} previously known as knowledge *about* science

(OECD 2013, OECD 2006)

Socio-scientific issues (SSI) are scientific topics that contain elements of moral and ethical concern. These can be used as the basis for classroom tasks and assessments (Zeidler & Nichols 2009). SSI connect the learning of the content of science with its real-life application and implications to society and tend to be more meaningful and engaging to students due to their focus on contemporary social issues (Zeidler & Nichols 2009).

SSI based tasks can be used to develop and assess scientific literacy when students are given the opportunity to use relevant socio-scientific topics to evaluate information, make decisions and take part in debate and discussion (Zeidler & Nichols 2009). Student-led SSI research tasks have been included in the curricula of Scotland and Ireland, e.g. Scottish Curriculum for Excellence (CfE) National 5 biology, chemistry and physics Assignment and Irish Junior Cycle Science in Society Investigation (SSI). When carrying out the CfE National 5 Assignment, students: devise an appropriate aim; describe an application of biology and its effect on the environment/ society; select relevant sources; select relevant information from sources; process and present data/information; draw a valid conclusion; apply knowledge and understanding of biology; and write a structured report (SQA 2014).

Research focus and aims

This research is a case study of the implementation of the National 5 biology Assignment in one Scottish school. The study aims to investigate the following:

1. What are the teacher and student experiences of carrying out the National 5 Assignment in Biology?
2. To what extent does the National 5 Assignment in Biology assess the PISA competencies of scientific literacy in students?

Research methodology

This research is a case-study of the implementation of the CfE National 5 Biology Assignment in one Scottish school. The participating school is a large, mixed gender, non-denominational school, which has been rated “excellent” in all aspects.

The following methods of data collection were used:

1. Observation of lessons;
2. Teacher post-lesson reflections and individual interviews with 6 participating teachers;
3. Student post-lesson evaluations with approximately 150 students;
4. Document analysis (e.g. lesson plans, teacher notes, quality assurance documentation).

The post lesson reflections and evaluations consisted of a two part questionnaire. In the first part, open questions gathered information about the student and teacher experience. In the second part, students and teachers were asked to indicate which competencies they/their students used during the Assignment. This questionnaire can be seen in Appendix A.

Thematic analysis was carried out on all teacher and student responses, using the software NVIVO. The method used was based on Braun & Clarke (2006): familiarisation with the data; generate initial codes; search for themes; review themes; define and name themes; produce the report (Braun & Clarke 2006 p87). The themes were dictated fully by the student and teacher responses and to ensure consistency, each reference to a topic or key word was consistently coded into the same working theme. Extracts could be coded into as many themes as were appropriate. If codes appeared more frequently, i.e. had a higher number of coded references (see tables 4 and 5), they were deemed as more important.

Discussion and recommendations/ outcomes

Results: Thematic Analysis of Student and Teacher Lesson Reflections

Thematic analysis of the student and teacher post-lesson reflections/ evaluations revealed a number of themes relating to the student and teacher experience of carrying out the National 5 Assignment. These can be seen in tables 4 and 5, and figure 1.

Tables 4 and 5 show the overall themes and associated sub-themes, along with relevant quotes that demonstrate the way that the students and teachers discussed their experience in relation to that theme.

Student lesson evaluations revealed 5 main themes: personal experience; ways of working and learning; recall and apply scientific knowledge; working with sources, information and data; and Assignment as an assessment.

Table 4: Student experience of the National 5 Assignment showing themes, sub-themes and relevant quotes from students

Themes	Sub themes	Number of references	Quotes
Personal experience	positive	15	"To be confident in yourself", "I really liked them and it was easy to follow through"
	negative	22	"I didn't like that no guide lines were given and didn't understand the content", "it was over complicated, kinda in a big rush to do it all"
ways of learning & working	independent	4	"Conduct an independent research task"
	Planning	12	"A good, pre-planned assessment", "I would plan what I was going to write"
	research	21	"Develop research skills and write-up skills"
	experiment	5	"Carry out an experiment and plan a write up"
	resources	5	"The guide booklet was a great help able to take information from the guide booklet and put it in our assignment"
Recall and apply scientific knowledge	content knowledge	17	"To recall and apply appropriate scientific knowledge"
	Terminology	3	"Meaning of terms such as "processed" data", "phenotypes, genotypes, plants, neurones"
	Impact on society & the environment	14	"To learn how science can affect our environment and society in many different ways"

Working with sources, information & data	Identifying and selecting sources	6	"How to find reliable sources", "source evaluation"
	Identifying and selecting information	15	"Gathering information about enzymes"
	Selecting, analysing and presenting data	15	"To practice processing data, to analyse data", "To interpret results"
	Presenting information	52	"Present info in a report that explains any conclusions you have reached and how you reached them"
Assignment as an assessment		8	"To get a good mark", "Experience an SQA assessment and a chance to achieving an A in our end of year biology exam"

Teachers discussed their experience of teaching the National 5 Assignment with their classes in very similar terms to the students themselves. Teachers talked mainly about the student experience, including the students' personal experience, the students' ways of working and learning, the students' recall and application of scientific knowledge and how the students worked with sources of information and data. When talking about their own experience, teachers talked about their own actions and pedagogy, in which they discussed using a mixture of facilitating and direct teaching and how time pressures and time management had an effect on their ability to carry out the Assignment. Teachers talked little about the National 5 Assignment as an assessment.

Table 5: Teacher experience of the National 5 Assignment showing themes, sub-themes and relevant quotes from teachers

Themes	Sub-themes	Sub-sub theme	Number of references	Quotes from teachers
Student experience	Students' personal experience	positive	11	"Students were very focused" "Pupils had to be self motivated and confident to complete the task."
		negative	7	"Overall the complexity of the flow/structure of the report was very challenging for pupils at this level. Some sections /words could not be accessed, especially for the less able pupils"
	Ways of learning and working	Independent	8	"Independent research: selecting information and constructing this information in their own words"
		Planning	5	"Working individually on planning and writing up the assignment."
		Research	12	"Research skills - appropriate use of text from a variety of sources, finding reliable data and information."
		Experimental	4	"Students were able to plan and carry out an experiment."
	Recall and apply scientific	Terminology	11	"I would spend slightly more time on each section to ensure understanding of terminology."
		Impact on	3	"the application of theory they have learnt in class

	knowledge	society & the environment		in the real world and the impact on society"
	working with sources, information and data	Identifying and selecting sources	4	"They learned how to choose references that were relevant and reliable"
		Identifying and selecting information	6	"Pupils developed their research skills and became quite adept at identifying appropriate information that they required for the assignment."
		Selecting, analysing and presenting data	7	"Finding suitable, relevant and reliable data", "Developing skills in processing data from one format to another"
		Presenting information	16	"Pupils learned to communicate the findings of their research on a relevant biological topic.", "Overall the complexity of the flow/structure of the report was very challenging for pupils at this level."
Teacher experience	teacher actions/ pedagogy	Facililitating	5	"Pupils were directed to read the success criteria for the report and marks allocation for the different sections."
		Direct teaching	7	"Lessons 1 - 3: In depth explanation of what is required for the assignment."
		Time management	5	"Allow more time for planning stage." "Perhaps allow more time for student feedback"
	Resources		15	"Using logbooks"
Assignment as an assessment			6	"Pupils completed their assignment under exam conditions."

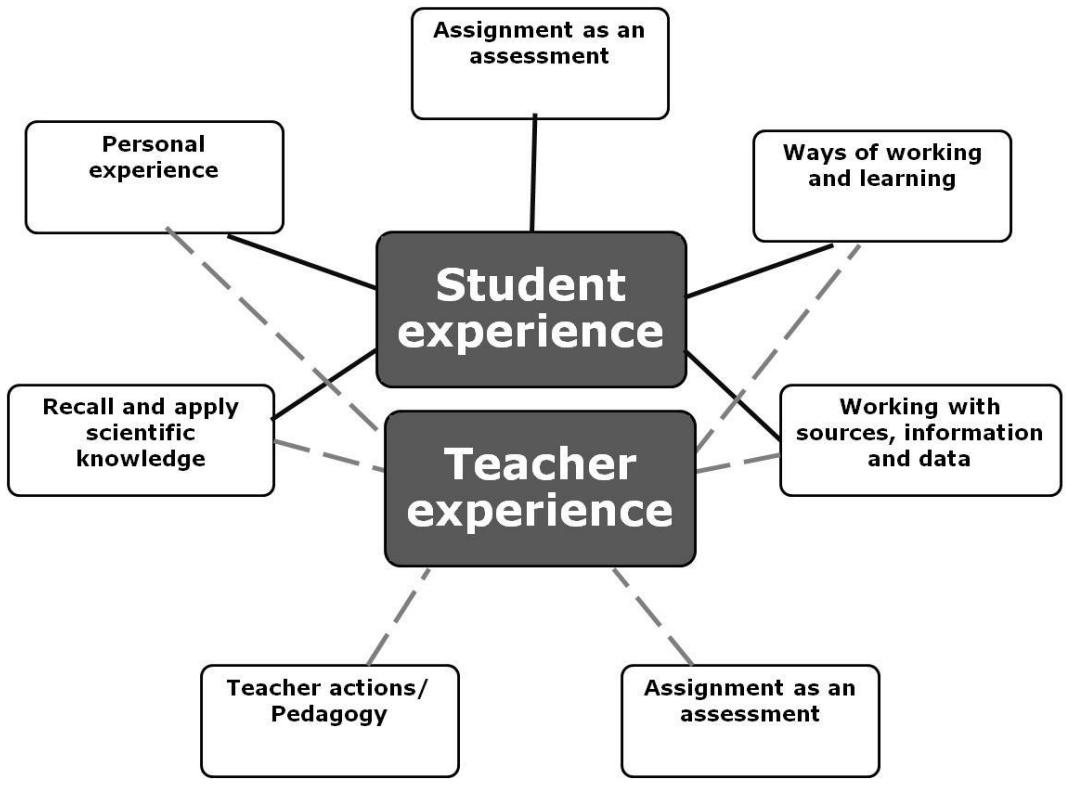

Figure 1: Student and teacher experience of the National 5 Biology Assignment

Teachers and students agreed on the student experience, although the teachers were slightly more positive than the students, i.e. there is a higher number of positive references than negative from the teachers. Both teachers and students referred to *independent research* with little evidence of student collaboration. This is somewhat at odds with the aims of the Assignment which states that "groupwork approaches are acceptable as part of the research stage" (SQA 2014 p3).

Thematic analysis of the student and teacher lesson reflections/evaluations indicates student engagement with the PISA competencies of scientific literacy when carrying out the National 5 Assignment. The student and teacher experience of the National 5 Assignment can be considered in light of the PISA Framework for Scientific Literacy. Themes within the student experience, both teacher and student view, align with the PISA competencies of scientific literacy (see figure 2).

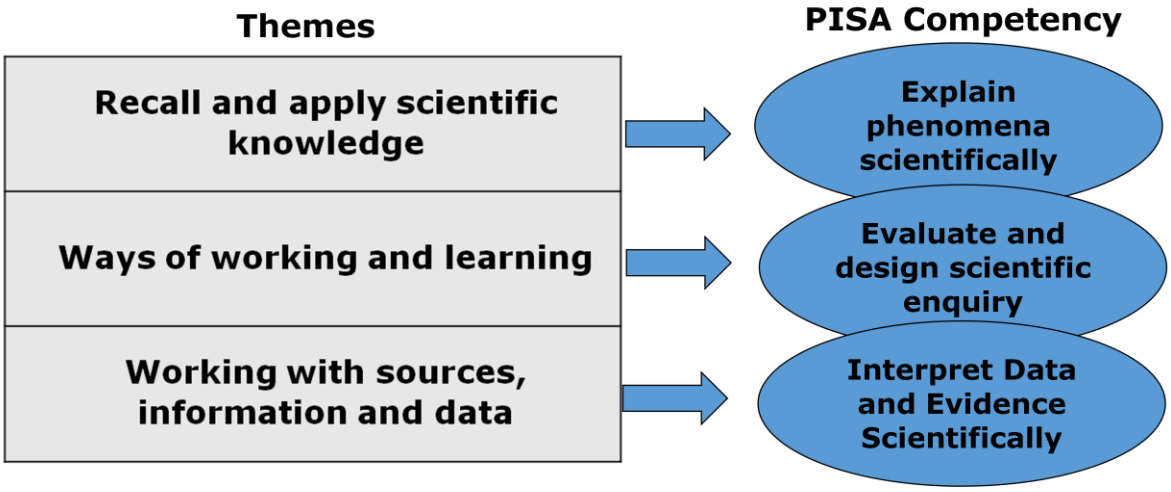

Figure 2: Themes vs. PISA competencies

The theme from the student and teacher experience, recall and apply scientific knowledge, is aligned with the PISA competency *explain phenomena scientifically*. The theme ways of working and learning, from the student and teacher lesson reflections/evaluations aligns with the PISA competency *evaluate and design scientific enquiry.* Finally, the theme working with sources, information and data is aligned with the PISA competency *interpret data and evidence scientifically.*

Results: PISA Competencies of Scientific Literacy and National 5 Assignment

Teachers and students were asked to identify the PISA competencies used when carrying out the Assignment. The questionnaire used can be seen in Appendix A. Results are shown in figures 3 -5.

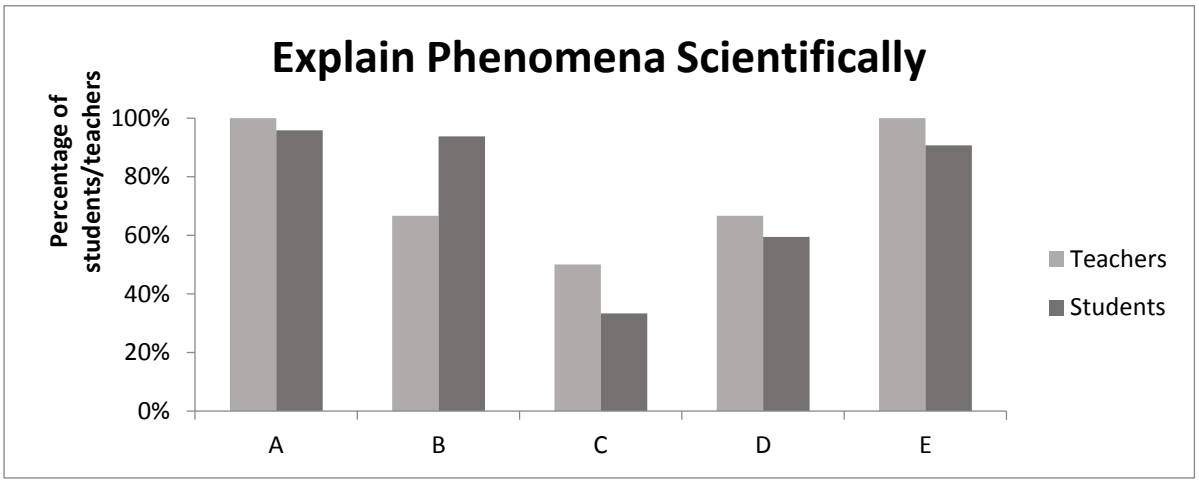

Figure 3: Percentage of students using competency *explain phenomena scientifically*

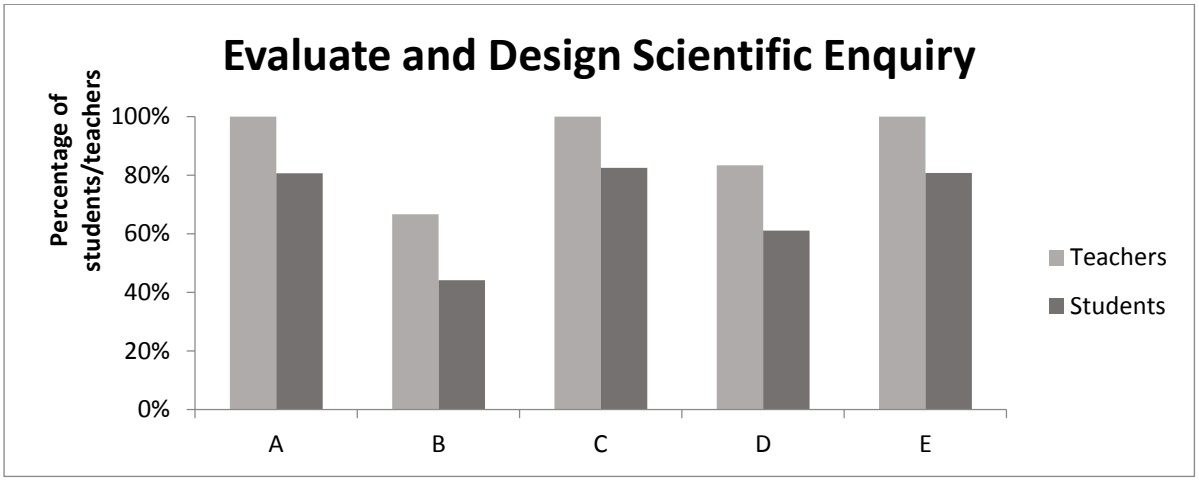

Figure 4: Percentage of students using competency *evaluate and design scientific enquiry*

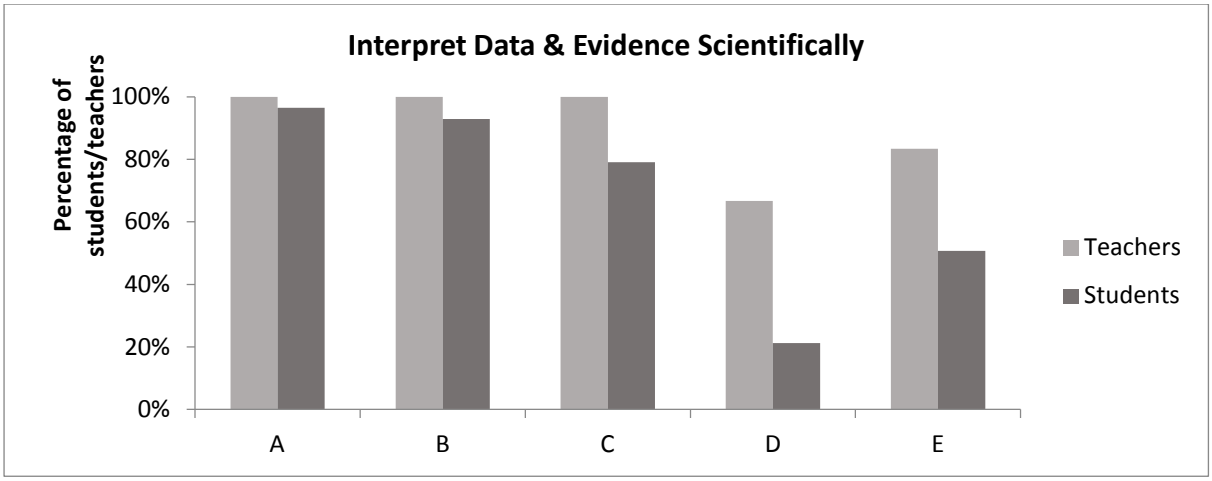

Figure 5: Percentage of students using competency *interpret data and evidence scientifically*

Overall, students and teachers felt that they/their students had used all the PISA competencies of scientific literacy when carrying out the Assignment. There was strong agreement between teachers and students as to which competencies were used, across all three competencies.

The competencies most used, according to the teachers and students, were competency one *explain phenomena scientifically* A *recall and apply appropriate scientific knowledge* and D *explain the potential implications of scientific knowledge for society*; competency two *evaluate and design scientific inquiry* A *identify the question explored in a given scientific study*, C *propose a way of exploring a given question scientifically* and E *describe and evaluate a range of ways that scientists use to ensure the reliability of data and objectivity and generalisability of explanations*; and competency three *interpret data and evidence scientifically* A *transform data from one representation to another*, B *analyse and interpret data and draw evidence based conclusions* and C *identify the assumptions, evidence and reasoning in science related texts*.

Teachers were more likely to consider a competency used, with the exception of competency 1B *Identify, use and generate explanatory models and representations.* This may be due to a different understanding of this competency between teacher and student. The teachers may have a deeper understanding of what constitutes a scientific model and representation and are therefore may be less likely to consider this competency to have been demonstrated by the students.

The least used competencies, according to both teachers and students, were 1C *make and justify predictions,* 2B *Distinguish questions that are possible to investigate scientifically* and 3D *Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations*. It is interesting to note the contrast between 2A *identify the question explored in a given scientific study,* being one of the competencies most used by students and 2B *Distinguish*

questions that are possible to investigate scientifically, which is one of the least used. These two competencies are similar but students and teachers clearly differentiated between them. Students and teacher felt they had identified the question in their study, in fact they had been asked to "devise an appropriate aim for an investigation" (SQA 2014 p8) but they were not asked explicitly to choose between questions as competency 2B implies. Although, one might argue that in devising their aim or question they had distinguished between scientific questions. It is also interesting to note that competency 3D was considered to be used the least by both teachers and students but that teachers felt that it was used considerably more than the students, 67% of teachers and 21% of students. The nature of the Assignment would lend itself to competency 3D as students would generally distinguish between scientific arguments and non-scientific arguments as part of their research. It is possible that many of the teachers recognised this while the students did not.

Conclusions and Implications

The results presented to date are based on a case study from one school and focussed on self-reported data. The study showed that teachers are aware of how the students experience the National 5 Assignment and that the students and teachers agree with the competencies of scientific literacy used. However, the following questions may be considered:

1. *How will document analysis, of student work and teacher quality assurance materials, compare to the self-reported findings of the study so far?*
2. *How were the Scottish teachers in this study prepared for the Assignment and what are the implications for the preparation of Irish teachers?*
3. *How were the Scottish students in this study prepared for the Assignment and what are the implications for preparation of Irish students?*

This research will be extended to carry out further studies, including case studies from chemistry and physics teachers and their students within the same Scottish school, as well as further data collection from the current biology teacher participants and their next cohort of classes. Research will be carried out in Irish secondary schools to investigate how teachers plan to develop scientific literacy and socio-scientific issued based research skills in their students in years one to three of Junior Cycle science. This will involve observation of teachers teaching Junior Cycle classes in year one and two and examining lessons for evidence of engagement with the PISA competencies of scientific literacy and the skills relating to socio-scientific issues based tasks. Teacher interviews will be carried out on these teachers asking their experience of using socio-scientific issues based tasks

in the classroom. Analysis of materials generated through these lessons, e.g. lesson plans and student work, will be carried out.

References

BRAUN, V. & CLARKE, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* **3**(3), pp. 77--101.

DEBOER, G. 2000. Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching,* **37**(6), pp.582-601.

GALVAO, C. & SERRA, P., 2014. *Draft Specification for Junior Cycle Science Review and Critique.* Lisbon, Portugal: Institute of Education, University of Lisbon / National Council for Curriculum and Assessment.

LAUGKSCH, R.C., 2000. Scientific Literacy: A Conceptual Overview. *Science Educaton,* **84**(1), pp. 71-94.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD), 2013. *PISA 2015 Draft Science Framework.* France: OECD.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD), 2006. *Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006.* Organisation for Economic Co-operation and Development (OECD).

SCOTTISH QUALIFICATIONS AUTHORITY (SQA), 2014. *Biology Assignment General Assessment Information.* Scotland: Scottish Qualifications Authority.

ZEIDLER, D.L. and NICHOLS, B.H., 2009. Socioscientific issues: Theory and practice. *Journal of Elementary Science Education,* **21**(2), pp. 49-58.

Appendix A: Teacher and student lesson reflections and evaluations

Teacher Questionnaire: National 5 Assignment

1. Provide a brief description of lesson activities, learning intentions and success criteria. Please also include an extract from your planner or other material as relevant.

2. What do you think the students learnt from this lesson/series of lessons for this stage of the assignment? Please give examples and include any evidence as relevant.

3. What about this lesson/series of lessons was successful in terms of student experience? Please give examples and include any evidence as relevant.

4. What about this lesson/series of lessons was particularly challenging for the students? Please give examples and include any evidence as relevant.

5. If you were to repeat this lesson, what changes, if any, would you make? You may wish to think about timing/pace, skills development, ethos, student interactions, feedback, questioning, materials/equipment etc.

The file names of any attachments you have chosen to include should be listed below.

Which of the following skills do you think your students used in this lesson?

National 5 Assignment Scientific Literacy Answer Grid

	Competency or Knowledge type	Skill used (✓/X)	Give examples of when/how this was used or demonstrated by students during the lesson/series of lessons.
a	Recall and apply appropriate scientific knowledge;		
b	Identify, use and generate explanatory models and representations		
c	Make and justify appropriate predictions		
d	Offer explanatory hypotheses		
e	Explain the potential implications of scientific knowledge for society		
a	Identify the question explored in a given scientific study;		
b	Distinguish questions that are possible to investigate scientifically;		
c	Propose a way of exploring a given question scientifically		
d	Evaluate ways of exploring a given question scientifically		
e	Describe and evaluate a range of ways that scientists use to ensure the reliability of data and the objectivity and generalisability of explanations		
a	Transform data from one representation to another		
b	Analyse and interpret data and draw appropriate conclusions		
c	Identify the assumptions, evidence and reasoning in science-related texts		
d	Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations		
e	Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals)		

Student Questionnaire for National 5 Assignment

Class:

Teacher:

Think about your experience of the National 5 Assignment as a whole from the introduction to the research to the report-writing stage. The following questions ask you to talk about your own experiences and how you felt the National 5 Assignment went for you. This includes the skills and knowledge you feel you personally developed through carrying out the Assignment.

START OF QUESTIONS

1. From your experience of carrying out the National 5 Assignment, list the top 3 things you learnt? This may be knowledge or skills or something else. Give an example for each.

2. What about the National 5 Assignment went particularly well for you? Give examples.

3. What about the National 5 Assignment was particularly challenging for you? Give examples.

4. If you had the chance to complete the Assignment again, what changes, if any, would you make to how you carried out your assignment?

5. When carrying out the Assignment, did you give scientific explanations? Yes/No
   Describe when or how.

6. When carrying out the Assignment, did you evaluate or design scientific investigations? Yes/No
   Describe when or how.

7. When carrying out the Assignment, did you explain scientific data and information? Yes/No
   Describe when or how.

Please complete the following table individually.

Which of the following skills do you think you used in the National 5 Assignment?

National 5 Assignment Scientific Literacy Answer Grid

	Competency or Knowledge type	Skill used (✓ if used)	If skill was used, give examples of when or how you used this skill during the Assignment
a	Recall and apply scientific knowledge		
b	Identify, use and make models, diagrams, graphs etc.		
c	Make predictions		
d	Use your science knowledge to **explain why** or **how** something happens		
e	Explain how science impacts society (personally, nationally or globally)		
a	Identify what question the investigation aims to find out		
b	Choose between questions that can be investigated through science and those that can't		
c	Plan an investigation to explore a scientific question		
d	Evaluate investigations		
e	Describe and evaluate how scientists make investigations and data fair, reliable, objective and fit into a wider context.		
a	Transform data from one representation to another e.g. table to graph		
b	Analyse and interpret data and draw conclusions		
c	Identify the assumptions, evidence and reasoning in scientific reports, articles etc.		
d	Choose between arguments which are based on science and those which are not		
e	Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals)		