Assessment of scientific enquiry: a comparative study of two high achieving countries (Korea and England)

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Along with TIMSS (Third International Mathematics and Science Study), this study shows both commonalities and differences in the National Curricula, assessment and teachers' perceptions, in depth. Teachers in both Korea and England indicate that assessment dominates their teaching. They show similarities in the way they say they would prepare their pupils for specific assessment items.

Through the documentary analysis, Korean students show consistently higher achievement than their English counterparts in international comparison tables. However, content and assessment in England more fully reflect the aims of the curriculum. In Korea there is less consistency between the aims and content of the curriculum and assessment. In addition, the standardized assessments in England assess a more varied range of a student's abilities. For example, the English KS3 tests show a wider spectrum using Klopfer's specifications whilst Korean tests reflect a narrower spectrum. Using Bloom's taxonomy, Korean tests are shown to contain higher cognitive ability questions.

The results of surveying teachers in both countries, reflects the documentary analysis. The Korean teachers express dissatisfaction about the Korean National Curriculum and assessment as well as being less-confident in teaching scientific enquiry although the Korean students showed better performance in the TIMSS-2003. The opinion of perceptions of teachers from both countries are more similar than findings from documentary analysis of their National Curriculum and assessment tests would suggest.

Objectives of the study

Students in Korea and England have been consistently high performers in international comparisons of student achievement in scientific literacy, with Korea at or near the top of comparison tables (TIMSS (Third International Mathematics and Science Study) 1995, 1999 and 2003; PISA (Programme for International Student Achievement) 2000). Science is a universal subject being taught with similar content and with more or less the same amount of time at grades 6-8 in both countries.

The National Curriculum in Korea (KNSC) was implemented in 1945 with a rigid structure. It has developed and been revised to give more flexibility, diversity and autonomy to individual schools and teachers. The National Curriculum in England (ENSC) was implemented in 1989, being defined as 'the minimum education entitlement for pupils of compulsory school age' (QCA 2003). It encompasses common requirements, programmes of study and standard achievements. Later on, target attainments and standard achievement have been imposed on each year and schools have been required to set targets for the percentage of pupils achieving more than level 5 in science at the end of Key Stage 3 (grades 6-8). This approach entails performance norms and the setting of individual performances against themselves (QCA,2003, Brooks, 2002). Therefore, the English Curriculum has added more structures in order to maintain the standard of achievement having a greater emphasis on examinations than there has been ever before (Brooks, 2002).

However, although the curricula in the two countries stem from different backgrounds in terms of different cultural and historical value systems, both are heading towards similar goals by fostering 21st century citizenship for young people and by putting the emphasis on the quality of education by incorporating more scientific enquiry in the science classroom. Yet eighth grade students in the two countries experience different teaching and, particularly, different national assessment of their achievements.

This study set out to compare assessment of the nature of science and its modes of enquiry which becomes a core of scientific literacy in the two countries and to explore teachers' perceptions of the impact of assessment on their teaching of scientific enquiry. This paper reports on the first of these aims. However, scientific enquiry cannot be separate from its content and context just as assessment cannot be thought of as being separate from the curriculum content. Thus, this paper also includes a general analysis of the differences in aims, content and assessment in the National Curricula in England and Korea in general.

Significance

A comparison between two different curricular systems may highlight commonalities and differences with respect to the quality of science education. In particular, it is expected that the comparison will enable common issues relating to teaching and assessment of scientific enquiry to be identified, with the findings offering recommendations for future curriculum and assessment policy in the two countries and with worldwide implications.

Theoretical underpinnings

This study has its basis in assessment theory and practice and perceptions of what constitutes scientific enquiry. Despite differences at the level of detail, there is growing evidence of international consensus of what should be taught about the nature of science and its practice and processes as scientific enquiry (e.g. McComas & Olson, 1998; Osborne et al, 2003).

As scientific enquiry refers to *'the methods and activities that lead to the development of scientific knowledge'* in the contemporary view, scientific enquiry can vary as much as the methods of scientific enquiry themselves. (NRC,1996,p23; Schwartz, et al, 2004, p3). By its very nature, scientific enquiry is known to be difficult to assess not only in the area of empirical work and the actual execution of routine procedures of scientific enquiry but also in the areas of theorizing, analysing and solving problems which refer to cognitive performance (Zuzovsky & Tamir, 1999). Thus valid and reliable pen-and-paper assessment of scientific enquiry is the subject of much research (e.g. Lederman et al, 1998; Osborne & Ratcliffe, 2002). It is also known that the nature of science and the scientific enquiry process is difficult to transform into pencil and paper mode and to identify an appropriate assessment context (McComas, 1998). Thus, it means that pencil and paper tests have limitations in assessing not only scientific process skills but also the more complex ability of solving problems (Zuzovsky & Tamir, 1999). Thus, along with performance assessment, assessing the elements of scientific enquiry have been identified as the most difficult and time consuming areas by science teachers in both countries (Roberts&Gott,2004, Sung & Kim 2004)

Despite the difficulties in constructing assessment items, their use has a profound backwash effect on teaching. Black (2000) argues that high-stakes testing can dictate how curriculum content is taught. Teachers have become used to summative approaches, which they perpetuate in the classroom. Thus, some teachers may emphasise goals for learning and use teaching techniques that are aligned with a student's ability to earn high grades. This has a direct effect on the development of other school based exams. It is thus important to examine the nature of high-stakes assessment items in Korea and England and teachers' perceptions of the impact on their practice.

Design and procedures

Documentary analysis was used to compare the content of the science curricula in Korea and England for grades 6-8. In both countries, high stakes pen-and-paper tests form a major part of assessment in grade 8. Although there are various assessments, which could be used for the purpose of this research, external summative assessments seem to be most appropriate. These examination papers are different in purposes and type. The English test papers assess pupils' achievement using criterion referencing. However, the Korean examinations are on a selective basis with a norm reference. Nevertheless because of their application to classroom practice, as well as the fact that they comprise of a whole range of the programme of study they have validity for international comparison.

Grade 8 tests for 2003 and 2004 were compared using Bloom's (1956) taxonomy and Klopfer's (1971) specifications to gauge the general and science-specific demand of the questions. The TIMSS 2003 paper was also included in the analysis.

Bloom's taxonomy is useful in distinguishing, at a general level, between questions demanding higher and lower order cognitive skills. Klopfer's specifications are known as a comprehensive attempt to classify the learning and assessment expectations of science education including reference to the details of the processes of scientific enquiry, attitudes and interests as well as knowledge and comprehension. Analysis was undertaken by the first author, with discussion with the second author in cases open to multiple interpretation in order to resolve classification into jointly agreed categories.

In the second part of the study questionnaires for grade 8 teachers combined with focus groups for in-depth discussion are being used to probe perceptions of the impact of the assessment of scientific enquiry on teaching and views of important similarities and differences in assessment emerging from documentary analysis. In particular, teachers were given scientific enquiry questions from English test papers, Korean test papers and TIMSS-2003 papers. Data was collected from questionnaires completed by 90 English science teachers and 100 Korean science teachers. Data was also collected from 4 focus group interviews in England and 3 focus group interviews in Korea. The distribution of respondents to the questionnaires is nationwide in both countries. The participants for the focus group interviews were from local schools in the Southwest of England and from the Kyungki and Junnam areas during in service science training courses in Korea.

Collected data were analysed quantitatively and qualitatively using appropriate software programmes, with SPSS used to support statistical analysis. Categorisation of teachers' responses in focus groups was aided by the use of NVivo software, with categories being determined iteratively using a grounded theory approach in seeking comparison of focus groups for common and differentiated themes.

Findings from documentary analysis

Although both curricula place great emphasis on scientific enquiry, there are different interpretations.

The English National Science Curriculum (ENSC) describes scientific enquiry as 'SC1' as a part of the programme of study recommending the teaching of science as a process of enquiry(QCA,1999). It also specifies 'scientific investigation' and 'ideas and evidence' in the same way as it identifies other key concepts of science. The elements of scientific enquiry are described as 'ideas and evidence' 'planning' 'obtaining' and 'presenting evidence' 'considering evidence' and 'evaluating'. In addition, there is an exemplar scientific investigation unit provided for grade 8 which is expected to take 7-12 hours (DfES,2002) The ENSC has an emphasis on students' understanding and conduct of discrete investigations and describes what pupils should be taught in some detail (e.g. that is important to test explanations by using them to make predications and by seeing if evidence matches the prediction; make sufficient relevant observations and measurements to reduce error and obtain reliable evidence) (QCA, 1999).
Therefore, the inclusion of scientific enquiry as a separate strand in the National Curriculum has raised its profile and importance in the National Curriculum in spite of the gap between policy and practice (Bartholomew, Osborne, Ratcliffe,2002)

On the other hand The Korean National Science Curriculum (KNSC) does not mention scientific enquiry specifically in its content. Instead, it says that *' scientific enquiry areas are integrated into every science lesson'* even though no practical work or experiments are involved (MOE, 2001). Thus, KNSC seems to be putting its emphasis on teaching

science content with enquiry rather than on scientific enquiry itself. Basic enquiry is expressed as observation, classification, measurement, prediction and reasoning. Integrated enquiry is expressed as: finding problems, setting a hypothesis up, transformation of information, interpretation of information, controlling factors, drawing conclusions and generalization (MOE, 2001). Enquiry activities are categorised as investigation, discussion, research, presentation and field trips. Scientific investigation is recommended once a year at least but not as part of a programme of study.
Although more than 65% of the science content is common to the assessment systems in the two countries the difference in detail between the curricula is reflected in the assessment.

There is a distinct difference in style between the sets of papers. Korean questions are all multiple-choice whereas English test papers use a range of question styles including multiple choice, short answer or explanation. Questions in English test papers include diverse question types, various contexts and a higher proportion of scientific enquiry, broadening the role of scientific investigations, introducing aspects of the nature of science and the ways in which scientists work and included open-ended questions having no wrong or right answers.

Both sets of national tests and TIMSS-2003 have a similar proportion of questions focused on scientific enquiry at around 21%, although the English papers for 2004 show a higher proportion (28%). However, there are important differences. Although the KNSC emphasizes the importance of scientific enquiry, Korean examination papers hardly ever include a full process of scientific investigation. The English test paper can ask for an interpretation, generalization and the transformation of data within one complete question. On the other hand, in the Korean examination papers, pupils are asked to answer the questions by making simple observations or interpretations which are designed to test their understanding of scientific knowledge. English examination papers include much more experimental based questions than the Korean ones.

According to Klopfer's specification, the area of scientific enquiry can be divided into *'Observing and measuring'* (b1-b5)' *'Seeing a problem and seeking ways to solve it'* (c1-c4) *'Interpreting data and formulating generalisations'* (d1-d6) and *'Building, testing and revising a theoretical model'*(e1-e6). In addition it also comprises *'Knowledge and comprehension'* (a1-a11) *'Application of scientific knowledge and method'* (f1-f2) *'Manual skills'*(g1-g2) *'Attitude and interest'*(h1-h5) and *'Orientation'* (i1-i6)

Korean test papers show a narrower distribution of scientific enquiry sub-categories in Klopfer's specifications than English test papers. In practice, scientific enquiry questions in Korean test papers are only found in four categories of Klopfer's specifications which are '*Observing and Measuring'* (b1-b5) '*Interpreting Data and Formulating Generalisations'*(d1-d6), and '*Manual Skills'*(g11-g2) being particularly skewed towards the area of 'd'(Interpreting data and formulating generalisations).

English test papers show a wider distribution than the Korean ones. In practice, the category *'Seeing a problem and seeking ways to solve it'* (c1-c4) mainly cover discrete scientific investigative questions. English test papers have increased their proportion of scientific enquiry questions and have had a greater variety in sub-categories in 2004.

The following graphs show the distributions of Klopfer's specifications

Figure 1 Each category of Klopfer's specifications in 2003 test papers(%)

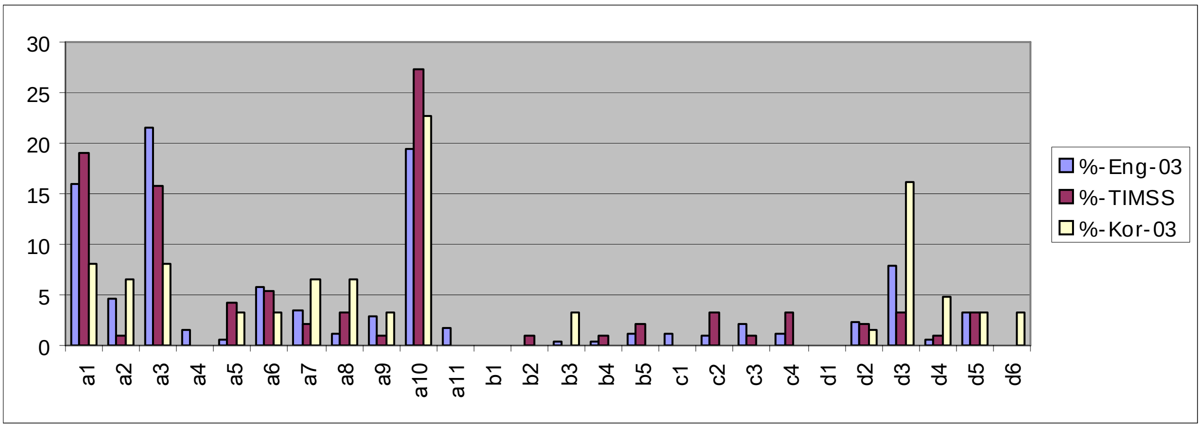
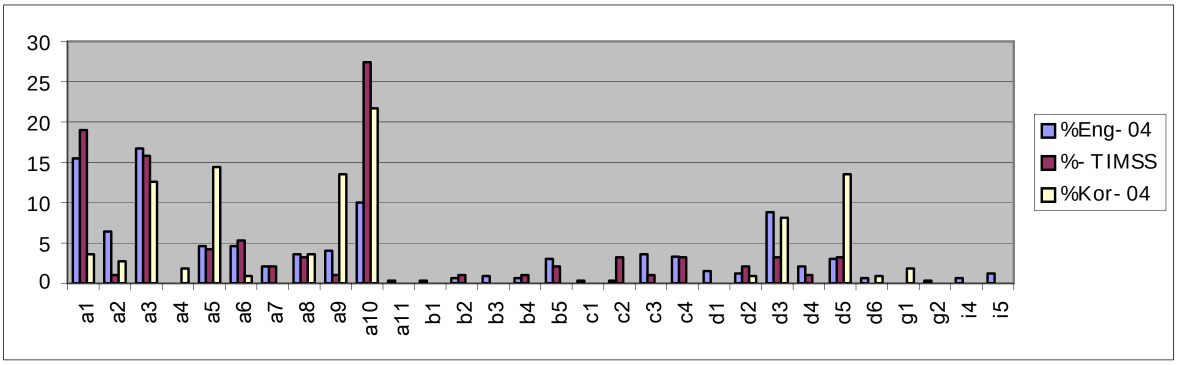
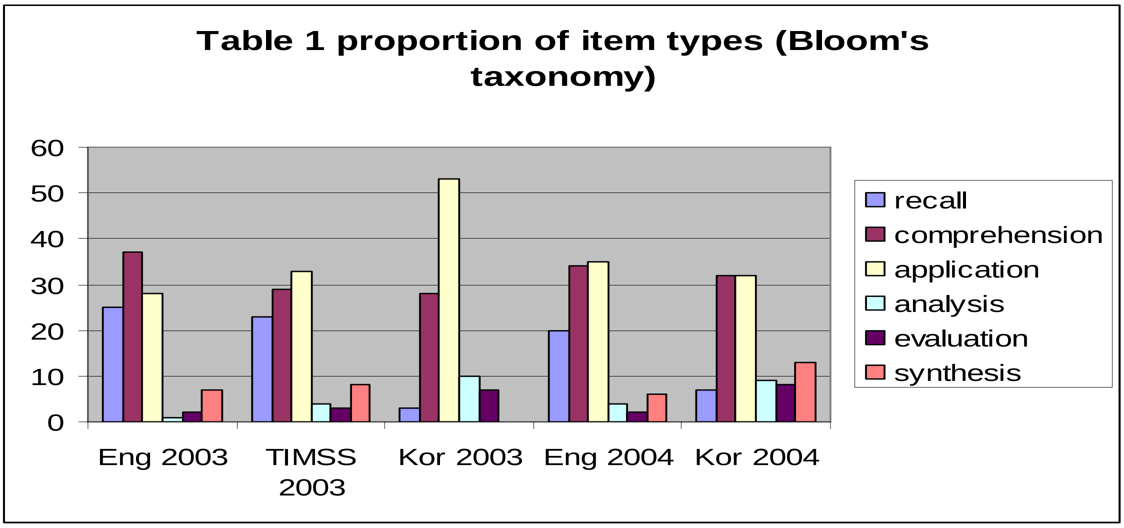


Figure 2 Each category of Klopfer's specifications in 2004 test papers(%)



According to Bloom's taxonomy, each question can be classified into six domains : '*Recall*' '*Comprehension*' '*Application*' '*Analysis*' '*Evaluation*' and '*Synthesis*'

Korean test papers appear to have more higher level cognitive domains in Bloom's taxonomy than English test papers. In practice, English test papers appear to fall into mainly comprehension and recall domains with a relatively lower level of application domain whilst Korean test papers appear to have more questions falling into the application domain and less in the comprehension domain. They also show more in the analysis, evaluation and synthesis domains than that of English test papers. The results reflect that Korean test papers contain questions demanding a higher cognitive level.



Korean students have consistently achieved higher marks in TIMSS assessments in science than English students have. In particular, TIMSS 2003 results reveal that Korean students were ranked in 3rd place with a score of 566, whilst English students achieved 5th place with a score of 533 when compared with 46 OECD countries. Interestingly, TIMSS-2003 test papers in the scientific enquiry area show similar features to English test papers in terms of proportion, distribution and nature of questions. However, TIMSS-2003 test papers contain more multiple-choice format and less discrete scientific investigative questions than English test papers. TIMSS-2003 test papers contain '*Seeing a Problem and Seeking Ways to Solve it'* (c1-c4) and other elements of contemporary science, including the view of the nature of science although the proportion of scientific enquiry is more or less similar to the Korean ones.

Nevertheless, concerns still remain in the scientific enquiry area in Korean test papers, which narrows the range of content in tests in consistency between the aims and content of the curriculum and assessment. Despite having the highest achievement in science literacy as well as showing the smallest range between highest achievement and lowest achievement, Korean students showed the least interest and motivation in science subjects (Kim et al, 2003)

Findings from the research survey of teachers' perceptions

The findings from the teachers' research survey reflect the findings from the documentary analysis There are more commonalities in teachers' perceptions and opinions about each set of scientific enquiry questions from English, Korean and TIMSS-2003 test papers than the results of documentary analysis would show. There is also a disparity between their perceptions and their practices in the classroom.

Teachers in both countries recognise the importance of scientific enquiry, indicating that scientific investigations and scientific enquiry activities help students perform better in science overall. They generally agree that English questions are better for enhancing students' scientific enquiry ability but TIMSS-2003 questions were favoured by both groups of teachers because they include less-reading, are simple but with a core of scientific enquiry. By contrast, teachers in both countries indicate that the most frequent teaching methods they use for teaching scientific enquiry are teachers' talking and explaining, experimentation, and teacher demonstration in England whilst in Korea, teachers talking and explaining and teacher demonstration were favoured as well as working from worksheets (experimentations omitted from most frequent teaching method). This common emphasis on talking and explaining may reflect that teachers in both countries are not engaging in teaching methods, which they acknowledge are a help to scientific enquiry.

Teachers in both countries regarded the same items to the aims of teaching science but they indicated different teaching methods, which were employed most frequently in the classrooms. They indicated the most important aims of teaching science are to motivate students and to provide a good understanding of scientific concepts. However, the English teachers do more practical work indicating that more than 50% of lessons involving practical work with 64%. Whereas the majority of the Korean teachers indicate that they only do practical work in 10-50% of their lessons.

In teachers' perceptions about the aims of teaching science, by doing practical work and teaching scientific enquiry, the English teachers are more concerned the about empirical nature of science such as manipulative skills, investigative skills and so on as whilst the Korean teachers are less concerned about skills but more concerned about conceptual enquiry such as problem solving, logical thinking and critical thinking. However, both groups of teacher put their emphasis on understanding the content of a topic but the Korean teachers give more weight to this item.

The English teachers show their confidence in teaching scientific enquiry. They also have less pressure concerning assessment. Although the scientific enquiry questions from English test papers were relatively new to them, only being employed since 2003, most of them agree that the English questions are better for enhancing students' scientific enquiry ability.

By contrast, there was great dissatisfaction and conflict between policy and practice amongst the Korean teachers. The majority of the Korean teachers indicate their confidence in teaching scientific enquiry as 'Neither high nor low' or 'High' whilst the majority of the English teachers rated it as 'High' or 'Very high'. In terms of pressure to reach the attainment targets set by schools, the Korean teachers feel under more pressure than the English teachers.

Although the Korean teachers indicate that the scientific enquiry questions from English test papers were better for enhancing pupils' scientific enquiry ability, they do not agree with the idea of doing more investigative work. The apparent reason given by the Korean teachers was assessment driven school curricula. If the examinations do not incorporate scientific investigations, it would hardly be worth teaching scientific enquiry by doing more practical or investigative work.

Another underlying reason was the Korean teachers' perceptions. The Korean teachers put much emphasis on students' cognitive enquiry and conceptual understanding about the basic theory or principles. According to the Korean teachers' description of how they prepare students to answer the Korean scientific enquiry questions was that they would explain explicitly the elements of scientific enquiry including terms, scientific concepts, the nature of the questions and the related skills. Then they would demonstrate the process of solving problems including mathematically calculating ways to get the right answers.

They show their commitment to students' rote learning by mentioning they would do this over and over again until the students got used to the process.

The Korean teachers agree that pupils do not understand hard questions rather they are getting used to the process of understanding to solve the problems and ways of thinking in order to get the right answers through much repetitive practice. Later on they would understand more and more about the content. They show a strong belief in the importance of laying foundation by learning scientific principles and theories in order to go on to further study in science. Other reasons for not changing their teaching methods were large classes and lack of facilities.

Teachers in both countries indicated that they would prepare their pupils in similar ways to be able to answer each set of questions from the English test papers, the Korean test papers and TIMSS-2003. The Korean teachers described how they would do more practical work concerning indication of variables and do more open-investigations in order to help their pupils answer the English scientific enquiry questions. For the Korean scientific enquiry questions, the English teachers said that they would familiarize the children with the questions by using worksheets or previous exam papers and that they would give more explanations about the related science concept. Teachers from both groups suggested that to prepare students for the TIMSS-2003 questions they would use the same methods of preparation as for the English scientific enquiry questions.

The English teachers indicated that their grade 8 students would do 'Very well' in TIMSS-2003 questions, 'Well' in the English questions but 'Not very well' in the Korean questions. On the other hand, the Korean teachers indicated that their grade 8 students would do 'Well' in TIMSS-2003 questions and in the Korean questions but would not be able to answer the English questions. This may reflect that the Korean teachers have a lack of confidence in teaching scientific enquiry.
However the teachers in both countries agree that they can train their students up to answer each set of questions.

Conclusion

Both countries place an emphasis on scientific enquiry, but there is a difference in the content of scientific enquiry in their test papers. In particular, Korean test papers show a narrower range of distribution in this area, which reflects a different interpretation of scientific enquiry in the 7th National Curriculum to that of the English National Curriculum. These different interpretations may also affect not only the content of the tests but may cause the curriculum to have a fragmented structure without scientific enquiry being properly integrated and without the nature of science as a value system being brought in to the content of the science curriculum.

The Korean test papers contain more questions demanding a higher order of cognitive ability. This being combined with teachers' perceptions and their actual teaching in practice results in apparent conflicts between policy and practice in Korea. Underlying the conflict, were the teachers' dissatisfactions about inconsistency between the content and assessment of the National Curriculum plus their lack of confidence in teaching scientific enquiry.

An assessment driven school curriculum was the apparent stumbling block inhibiting the integration of more scientific enquiry into the classroom in Korea. Unless scientific investigations are incorporated within the assessment content, scientific enquiry is not considered to be a way to teach science.

Therefore, implementing scientific enquiry seems to be a complex process involving assessment driven school curricula, teachers' perceptions, the content of the National Curriculum and other factors. In addition, it would appear to be harder to persuade or mould a teacher or to revise the curriculum in Korea than in England.

However, teachers in both countries indicated that they would teach in a similar manner in order to prepare their students to answer each specific set of questions. TIMSS-2003 questions were familiar to them and were favoured by both groups of teachers. TIMSS-2003 papers impact on both groups of teachers.

These findings are being used to compare Korean and English teachers' views on the impact of assessment of scientific enquiry on their teaching. In particular their responses concerning the preparation of students for three different types of scientific enquiry questions (a distinctive Korean question, a distinctive English question; a TIMSS question) are being explored. So far commonalities between the teachers in the two countries in their stated approaches to preparing students for particular assessments outweigh differences.

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