REASONS BEHIND THE FINNISH SUCCESS IN SCIENCE AND MATHEMATICS IN PISA TESTS

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Abstract

Finnish teacher educators with the research background joined in a common enterprise to gather information from the Finnish education system and used practices in teaching science and mathematics to explain the Finnish students' success in the international PISA (Program for International Student Assessment) assessment. The items dealt with were the following: the Finnish school system and teacher education, learning environments, gender issues, influential factors outside the school, and teaching science and mathematics at the comprehensive school. From the articles by 40 authors the book "How Finns Learn Mathematics and Science?" was produced. The explanations for Finnish success based on the authors' conceptions can be classified into three groups: Teacher and teacher education, school and curriculum, and the national developmental projects. Most probably a true explanation will be a combination of several factors as no single clear explanation was found, although research-based teacher education seems to be a rather influencing factor.
Key words: *explanations for Finnish success, PISA program, teacher education.*

The aims and the framework of the PISA program

PISA (Program for International Student Assessment) is an OECD program to inform the partners how their school politics has succeeded. The PISA program aims at assessing 15-year-olds' skills, knowledge and competencies from the perspective of future learning demands in three main domains: reading literacy, mathematical literacy and scientific literacy. Also the factors, that influence student achievement like student background, school characteristics, and organisation of teaching, are looked for. PISA program produces three kinds of indicators:

1. Basic indicators give a profile of knowledge and skills among 15-year-olds;
2. Contextual indicators tell the connection between pupils' knowledge and skills to the demographic, economic and didactic factors both in macro- and micro- level.
3. Trend indicators tell about the changes both in national and international school organizations. The PISA 2006 survey, for the first time, sought information on students' attitudes to science by including questions on attitudes within the test itself, rather than only through a complementary questionnaire (OECD 2006.)

The PISA program involves surveys to be conducted every three years with alternating prime domains. In 2000 this prime domain was reading literacy, in 2003 mathematics, and in 2006 science. The proportion of the items in the prime domain is about 70% of all tasks. The PISA 2000 survey involved 32 participating countries. In 2003 the number of participating countries had grown to

41, and in 2006 it was 57. To ensure representative data from each country the minimum sampling requirement in PISA has been a random sample of 150 schools and 4500 students. In PISA, for calculating the PISA scores, a special technique, Item Response Theory (IRT), have been used for determining the PISA scale and calculating national PISA scores. Through this data transfer the mean of the whole OECD *Scientific literacy data* is 500 and respectively the standard deviation is 100. PISA student scores are classified into six proficiency levels. In making comparisons, it is useful to recognize that a difference of 74.7 scores points represents one proficiency level on the PISA science scale. This means a comparatively large difference in student performance. For example in science, level 3 requires students to select facts and knowledge to explain phenomena and apply simple models or inquiry strategies, whereas at level 2 they are only required to engage in direct reasoning and make literal interpretations.

Scientific literacy

According to PISA 2006 framework (OECD, 2006), the PISA assessment emphasizes science competencies, defined in terms of an individual's scientific knowledge and use of that knowledge to identify scientific issues, to explain scientific phenomena and, to draw evidence-based conclusions. Moreover, the framework emphasizes understanding of the characteristic features of science as a form of human knowledge and enquiry and, moreover, awareness of how science and technology shape people's material, intellectual and cultural environments. These competencies are tested in PISA by a large proportion of complex open-ended tasks.

In PISA 2006 (OECD, 2006), scientific literacy encompasses both knowledge of science (knowledge of the different scientific disciplines and the natural world) and knowledge about science as a form of human enquiry. The former includes understanding fundamental scientific concepts and theories; the latter includes understanding the nature of science. The four content areas in PISA 2006 for the knowledge of science domain are *Physical system*s, *Living systems*, *Earth and space systems*, and *Technology systems*. These four content areas are presumed to represent important knowledge that is required by adults for understanding the natural world and for making sense of experiences in the personal, social and global contexts. PISA identifies two categories of knowledge about nature of science: the first is "scientific enquiry", which centers on enquiry as the central process of science and the various components of this process, and the second category contains "scientific explanations", which result from "scientific enquiry". Previously mentioned two broad knowledge areas are presented in various contexts. In PISA 2006 140 science questions were framed within a wide variety of life situations involving science and technology, namely: "Health", "Natural resources", "Environmental quality", "Hazards" and "Frontiers of science and technology". These situations were related to three major contexts: personal (the self, family and peer groups), social (community) and global (life across the world). The contexts used for questions were chosen in the light of relevance to students' interests and lives, representing science-related situations that adults encounter.

Mathematical literacy

In PISA *mathematical literacy* refers to students' ability to analyse, explain, and communicate their thoughts effectively when defining, formulating, solving and interpreting mathematical problems in various situations. Mathematical literacy is defined as *an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgements and to engage in mathematics, in ways that meet the needs of that individual's current and future life as a constructive, concerned and reflective citizen* (OECD 2003, p. 24).

PISA puts emphasis on the application of mathematical knowledge in different contexts that call for understanding, reflection and argumentation. This requires, of course, also basic mathematical competence with reference to mathematical facts, terminology, and concepts as well as computational and problem solving methods. The definition of mathematical literacy includes thus both the narrower functional use of mathematics and preparedness for further studies, and also the aesthetic and entertaining elements of mathematics.

The design of the mathematics items accounted for three conceptual elements: *mathematical* *content*, *mathematical processes* and the *situations* in which mathematics is applied. In 2003 the content was defined by means of four broad areas, which are *quantity*, *space and shape, change and relationships* as well as *uncertainty.* Mathematical processes were defined in terms of eight mathematical competencies (cf. OECD 2006, 97): *thinking and reasoning, argumentation, communication, modeling, problem posing and solving, representation, using symbolic, formal and technical language and operations, use of aids and tools*.

These competencies were divided further into three broad categories: *Reproduction* (knowledge and basic operations), *Connections* (combining and interpreting information), and *Reflection* (explanation and generalisation). Furthermore, the test items were embedded in various mathematical situations pertaining to young people's life. In 2003 there were in total 85 mathematics items in the test. Two thirds were open-ended tasks while the rest were multiple-choice items. In addition, student attitudes to mathematics learning were explored from various angles.

On PISA results

In the results of the three PISA evaluations, Finnish pupils were top ranked (for the two first ones cf. Lie, Linnakylä, & Roe, 2003, Mejding & Roe, 2006). The results of the third evaluation were released just in December 2007 (cf. Arinen & Karjalainen, 2007).

Science

In scientific literacy Finnish 15 year old students' scores were significantly better than in any other country taking part in the PISA study. Finnish students got 563 PISA scores in PISA science scale with the one of the smallest standard deviation. This means that there is about one proficiency level difference to the OECD mean in student performance in Finland. Although the 140 science items are secret, they can be classified based on the information available from national PISA organizers to the following categories: Application Area, Item Focus, Competency (Explaining phenomena scientifically, Identifying scientific issues, Using scientific evidence), Knowledge of Science (Earth and space systems, Living systems, Physical systems, Technology Systems), Knowledge about Science (Scientific enquiry, Scientific explanations). Finnish students succeeded in all classified areas better than students in any other country. (OECD, 2007)

One important point of view to PISA results is the achievement of high (90% and 95% percentiles) and low (5% and 10% percentiles) performing students which can be compared from country percentile scores to the OECD average percentile scores in PISA 2006 science scale. According to PISA data, Finnish students' performance profile differs from performance profiles obtained in other countries. Finnish school system takes special care of the lower achieving and mid-range students, in particular: the performance of low performing students was in average 80 points higher than OECD average of corresponding students. The percentage of students at level 1 (or lower) was 4.1% while it was 19.3% in average in OECD countries. However, in PISA 2006 also the high performing Finnish students were better than in any other country: the performance of high performing students was in average 50 points higher than OECD average of corresponding students. In the levels 5 and 6 the percentage of students was 20.9% while it was 9% in average in OECD countries. (OECD, 2007)

Mathematics

The 2003 PISA comparison had emphasis in mathematics literacy and problem solving. Finnish 15-year-old pupils were among the best three ones within the OECD countries. In the Finnish results, there were no big differences between the high and low achieving students. Finnish pupils performed well in all four content domains of mathematics. The domain of *quantity* was the strongest one also nationally; this domain yielded significantly higher results than the other mathematical content areas. In the domains of *Change and relationships* as well as *uncertainty* the Finnish mean scores were the third highest of all countries, and in *Space and shape* the Finnish scores reached the fifth position. (For more detailed results cf. Kupari & Välijärvi, 2005).

The overall variation of mathematical literacy was quite small in Finland. The PISA 2003 framework defines Level 2 as the minimum standard the students should achieve to have sufficient mathematical skills for coping in modern information society. At this level, students are capable of simple independent mathematical reasoning and interpretation. The percentage of students reaching this level or higher was 93%, which was also the highest among all participating countries. The share of Finnish students at the lowest levels (Level 1 and below) was the smallest. The very highest level (Level 6) was achieved by 7% of Finnish students, which is well above the OECD average (4%). In the light of these results the Finnish success in PISA 2003 is based strongly on the fact that in Finland the low achievers, in national terms, performed very well internationally.

In Finland, however, the gender difference was relatively small, yet statistically significant in favour of boys. The gender differences varied according to the different mathematical content domains. The gap was the smallest in the domains of *space and shape* and *quantity* and widest in *uncertainty* and *change and relationships.*

Explanations for Finnish success

There is very little rigid research done on what really happens in mathematics and science classrooms in Finland. Research done is more generally on school teaching (e.g. Komulainen & Kansanen, 1981, Syrjäläinen, 1990, Patrikainen, 1997). Until the PISA years, there are only very few descriptions on teaching and learning mathematics and science in Finnish classrooms (e.g. Norris & al. 1996). The newer research, i.e. from the 2000's, is not referred here, since its influence on the PISA results is marginal.

The Finnish teacher educators' explanations

The Finnish students' success in the first PISA 2000 evaluation was a surprise to most of the Finns, and even people working in teacher education and educational administration had difficulties to believe that this situation would continue. Finland's second success in the next PISA 2003 comparison waked us to think seriously on possible reasons for the success. Since there was no commonly acceptable explanation to students' success, it was decided at the University of Helsinki to find it out in the form of a book "How Finns Learn Mathematics and Science?" (Pehkonen, Ahtee, & Lavonen, 2007). All Finnish teacher educators in mathematics and science were asked to co-operate in presenting their views on essential features of Finnish mathematics and science education, and implementation of the education policy. Thus, the 40 authors most of them having a doctoral degree represent all Finnish universities, especially their teacher education faculties. One leading idea was that in each chapter there are at least two authors, in order to increase discussions and reflections when writing. The authors have peer reviewed each others' chapters and, therefore, the book presents a "national view" on mathematics and science education and their teacher education. The authors were also asked to summarize their views on the reasons of the Finnish PISA success.

Lampiselkä et al. (2007) describe the development of the Finnish school system giving the emphasis on the year 1994 curriculum for the comprehensive school (NBE 1994) as it is the one that was in use during the collection of data for PISA2003. Then also the directive administration was transferred from the central level to local authorities. In practice the implementation process was carried out by the teachers who then had to go deeply to the curriculum and reflect what are the aims, contents and methods in mathematics and science teaching, learning and assessment. Also the time allocated for teaching mathematics and science (see Table I) is one of the lowest in Europe. Therefore, Lampiselkä et al. (2007) presume that Finnish teachers have to plan their teaching carefully to avoid unconstructive acts during lessons. In the 2000's, we have a new curriculum (2004), but it is not discussed here, since it has no influence on the PISA results.

Table 1. Allocation of lessons in some subjects in Finnish comprehensive school in the year 1994 curriculum. For example "mathematics 9 hours for the grades 7–9" means 3 lessons in mathematics per week on the 7th, 8th and 9th grade, respectively. School year contains 187 days i.e. 38 weeks. One lesson is 45 min.

	1–6	7–9
Mother tongue	32	8
A-language (English, Swedish, etc.)	8	8
B-language (English, Swedish, etc.)		6
Optional language	4	
Religion/Ethics	8	3
History/Social studies	3	6
Mathematics	22	9
Environmental sciences and civics	15	
Biology, Geography		7
Physics, Chemistry		6
Arts and Practicals	44	20

In order to find a more compact way the success explanations given by the different authors are grouped into three sets according to their explaining factor: teachers and teacher education, school and curriculum, other factors (especially ICT and LUMA[1]). Each of these sets is discussed briefly.

Teachers and teacher education. The Finnish citizens value education, school and teachers in general. According to our educational policy teachers have a lot of *freedom and responsibility*. Freedom and responsibility means that teachers are, for example, responsible for developing the curriculum for their courses, choosing the teaching and evaluation methods based on the national guidelines and also selecting the learning materials. There are no inspectors, no national evaluation of learning materials, nor national assessment. In other words, Finnish teachers are educated to be *autonomous and reflective academic experts*. Most Finnish teachers are devoted to their work. An additional feature of Finnish teacher education is a *research-based approach* that has been adopted in teacher education as a main organising theme, emphasizing teachers' pedagogical thinking, i.e. reflecting on their own teaching in school. One example of the use of research in teacher education is to develop teachers' pedagogical subject knowledge. Through in-service training, teachers might get new ideas how to teach in an innovative way.

School and curriculum. Kupari, Reinikainen, & Törnroos (2007) who were involved in PISA 2000 and 2003 studies conclude that the good results of Finnish pupils should be taken as recognition of the *high quality of Finnish schools*. One factor behind the good PISA results seem to be the Finnish *curriculum planners' scenario* of the future of mathematics and science teaching and learning that were given already before the beginning of the 1990s; these have been coherent with the PISA framework. The Finnish curricula (NBE 1985, 1994) contained many *novel aspects*. PISA studies asked for pupils' abilities to use their knowledge in different situations, interpret tables, graphs and other kind of scientific presentations, use the scientific language, not only quantitative knowledge e.g. equations. Application of knowledge and problem solving skills has been an essential part of Finnish comprehensive school education. The alternative teaching methods like Models from everyday life, Activity tasks, Mathematical modelling, Learning games, Problem solving, Investigations, and Project work will surely develop pupils' skills to solve such tasks as in the PISA tests. In teaching science, the approach is subject-oriented both in primary and lower secondary level; therefore, teachers may transmit more the nature of science. Also experimentation in science is an essential part of the Finnish comprehensive school curriculum. Modelling is appreciated in Finnish science classrooms, it can be considered as an important step for understanding the nature of scientific processes and knowledge that were in turn among the main objectives of PISA 2003 assessment criteria. Thus, the national curricula have strongly affected teaching methods in schools.

Other factors (ICT and LUMA[1]). One of such factors is the development of the whole country into an information society, i.e. improving all citizens' possibilities to use information and communication technology (ICT). Therefore, the use of *ICT in school has an impact* on pupils' general ability to deal with information. About ten years ago, the Finnish government launched the joint national program in mathematics and science teaching (LUMA[1], Heinonen 1996). The *LUMA program* created substantial and exhilarating climate for science and mathematics education.

Other analyses

After the first PISA testing the Finnish PISA researchers (e.g. Välijärvi & al., 2002) explained the Finnish success "with comprehensive pedagogy, students' own interests and leisure activities, the structure of the education system, teacher education, school practices, and Finnish culture". These are coherent with the explanations given after the second PISA results that were published at the end of the year 2004 (Kupari & Välijärvi, 2005). Last year a more accurate book on success explanations was published by the Jyväskylä group (Välijärvi & al., 2007). On the basis of the multilevel modeling procedure they have found that affective factors particularly students' self-concept related to mathematics were the strongest predictors of performance variation in mathematical literacy. In addition to this Pehkonen (2008) has looked at factors that have influenced mathematics teaching during the last 30 years, and on this basis he gives a holistic view on the development of mathematics teaching from the beginning of the comprehensive school to nowadays.

Some earlier officers of the National Board of Education published their views on the PISA reasons (Aho & al., 2006). They ended up with four broad conclusions: (1) Comprehensive school that offers all children the same top quality, publicly financed education. (2) Education reform has been evolutionary rather than revolutionary. (3) Success of the education system is politically, culturally and economically intertwined with other sectors. (4) In a stable political environment education reforms have based on long-term vision, hard work, good will and consensus. The similar ideas can be read also in the papers published by the Jyväskylä group (Välijärvi & al., 2002, Kupari & Välijärvi, 2005, Välijärvi & al. 2007). Lavonen (2006) emphasizes the following reasons: information society, equality in education, devolution of decision power, and responsibility to local level. Laukkanen (2008) takes up high standards in education, support for special needs, qualified teachers, and balancing decentralism and centralism.

Simola (2005) has developed an explanation for the PISA success through analyzing teaching and teacher education in a historical and sociological framework. He has introduced several general historical and political reasons for the success, such as a homogeneous society (lack of minorities), consensus developed during the Winter War (1939-40), and the rapid development from a poor agrarian state to a modern welfare democracy. According to Simola (2005) Finnish teachers are politically and pedagogically rather conservative. Furthermore, Finnish teachers believe in their traditional role and pupils accept their traditional position.

Björkqvist (2006) has paid attention to an important component. Special education is in Finland strongly involved with the ordinary education, and thus it offers learning opportunities also for low-achievers. Only 2% of Finnish pupils are in special teaching institutes (cf. Välijärvi & al., 2007). Those who are in ordinary education of the comprehensive school have carefully-tailored support that correspond pupils' needs (cf. also Vauras, 2006). The relatively small scattering of Finnish PISA results can be understood on these supports of lower-achieving pupils.

Conclusions

Final suggestions for reasons behind Finnish students' success are discussed based on the education policy and its implementation. A framework for this discussion is presented in Figure 1.

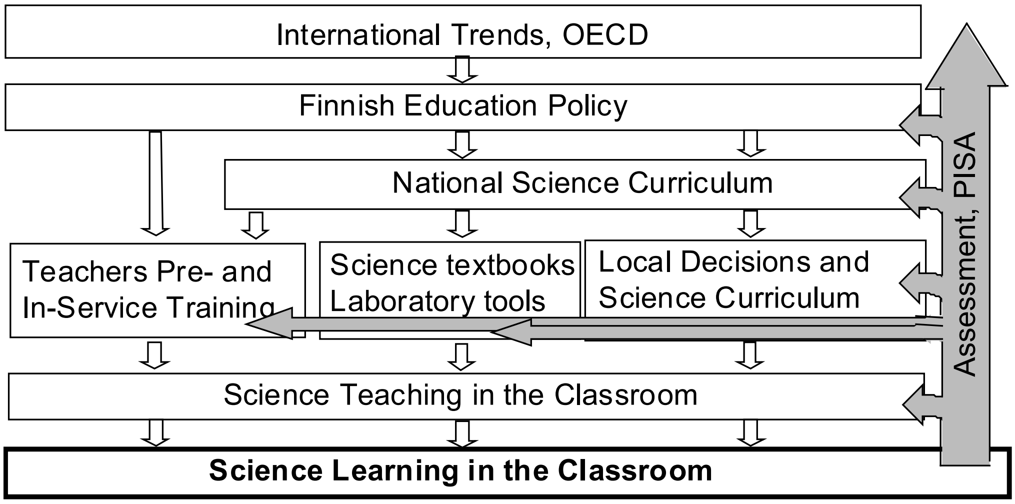

Figure 1. Finnish education policy and implementation of it through national and local level science curriculum, teacher education and science classroom practice.

There are three leading principles in the educational policy of Finland: There is commitment to a vision of a *knowledge-based-society*. This vision can be found also in the national documents published in the 70s, where implementation of common comprehensive school (Committee Report, 1970) and university level primary teacher education (KATU Project, 1978) were presented. Another long-term objective of Finnish education policy has been to raise the general standard of education and to promote *educational equality*. Basic decisions towards this direction were made during the 1970's with the other Nordic countries when a change to a comprehensive obligatory school system was decided (Committee Report, 1970). In Finland, local authorities have strong autonomy, a lot of freedom, power and responsibility. This movement was strengthening in year 1994 curriculum (NBE, 1994). Therefore, the third general education policy principle in Finland is the *devolution of decision power* and responsibility at the local level.

Summarizing, we may state that there exists no clear explanation, but the true explanation might be a combination of several factors. Nevertheless, the idea of research-based teacher education seems to be in the core of explanations (cf. Jakku-Sihvonen & Niemi, 2006). Especially heterogeneous grouping demands a highly qualified teacher (cf. Välijärvi & al., 2007). Additionally, we would like to emphasize the importance of the Finnish pupils' success in literacy, since many PISA problems are such that good understanding in reading is important.

Endnotes

1. The acronym LUMA comes from Finnish words: **Lu**onnontieteet [Science] and **Ma**tematiikka [Mathematics])

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