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A longitudinal study of science teacher change and its impact on student change in scientific creativity and socio-scientific reasoning skills

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I. **Laius, A.;** Rannikmäe, M.; Yager, R. (2008). A Paradigm shift for teachers: enhancing students' creativity and reasoning skills. In: J. Holbrook, M. Rannikmäe, P. Reiska & P. Ilsley (Eds.). *The need for a paradigm shift in Science Education for post Soviet Societies: research and practice (Estonian example)*. Germany: Peter Lang Europäischer Verlag der Wissenschaftenm, 67–85.

II. **Laius, A.;** Kask, K.; Rannikmäe, M. (2009). Comparing outcomes from two case studies on chemistry teachers' readiness to change. *Chemistry Education Research and Practice*, 10(2), 142–153.

III. Rannikmäe, **M.; Laius,** A.; Holbrook, J. (2010). Improving the learning environment: Students' creative thinking and reasoning skills through PARSEL teaching. In: I. Eilks & B. Ralle (Eds.). *Contemporary Science Education – Implications from Science Education Research about Orientations, Strategies and Assessment*, 247–252. Aachen, Germany: Shaker Verlag.

IV. **Laius, A.;** Rannikmäe, M. (2011). Impact on student change in scientific creativity and socio-scientific reasoning skills from teacher collaboration and gains from professional in-service. *Journal of Baltic Science Education*, 10 (2), 127–137.

Components where the Author is a contributor to the original publications:

	I	**II**	**III**	**IV**
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Methodology	*	*		*
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Manuscript preparation	*	*	*	*

Paper II is based on two separate studies; for study B in the paper, the major contributor was the Author. The Author did not contribute to study A.

LIST OF PUBLICATIONS CONNECTED TO STUDY

The dissertation is based on the following original publications, which are referenced in the text by their Arabic numbers.

1. **Rannikmäe, M. & Laius, A.** (2010). Enhancing students' creativity and reasoning skills. Symposium: Ways to promote essential elements of a developed scientific literacy in science education. In: G. Çakmakci & M. F. Tasar (Eds). *Contemporary Science Education Research: Scientific Literacy and Social Aspects of Science*. A collection of papers presented at ESERA 2009 Conference, Turkey, Istanbul; ESERA: A Pegem Akademi, 155–159.
2. **Laius, A. & Rannikmäe, M.** (2010). How to evaluate the effectiveness of STL teaching through students' scientific creativity in science classes. In: J. Holbrook, M. Rannikmäe, R. Soobard, B. Cavas & M. Kim (Eds). *ICASE 2010, 3rd Conference of Science and Technology Education "Innovation in Science and Technology Education: Research, Policy, Practice"*, Tartu, Estonia, June 28 – July 2nd 2010, 138–139.
3. **Laius, A. & Rannikmäe, M**. (2009). Towards a Paradigm Shift in the Teacher's Role in Science Education – Teachers' Readiness for Change. In: *NARST Annual International Conference: NARST Annual International Conference "Grand Challenges and Great Opportunities in Science Education"*, Garden Grove, CA, USA, April 17 – April 21, 2009, 7 p.
4. **Laius, A. & Rannikmäe, M.** (2007). An Exploration of Socio-Scientific Argumentation Skills in 10th Grade Science Classes. In: J. Holbrook, & M. Rannikmäe (Eds). *5th International Organization for Science and technology Education (IOSTE) Eastern and Central European Symposium: Europe Needs More Scientists – the Role of Eastern and Central European Science Educators*, Tartu University Press, 85–94.
5. **Laius, A. & Rannikmäe, M**. (2007). Development of students' creative thinking and socioscientific argumentation skills in social issue-based science classes. ESERA 2007; Malmö, Sweden; August 21st – August 25th, 2007, 1–8.
6. **Laius, A. & Rannikmäe, M**. (2005). The Influence of Social Issue-Based Science Teaching on Students' Creative Thinking. *Science Education International*, 16 (4), 281–289.
7. **Rannikmäe, M. & Laius, A.** (2004). Can we make science teaching relevant for students? *Journal of Science Education*, 5 (2), 73–77.
8. **Laius, A. & Rannikmäe, M**. (2004). The influence of STL teaching and science teachers' teamwork on change of students' creativity. *Journal of Baltic Science Education*, 2 (6), 69–75.

1. INTRODUCTION

While scientific discoveries have continued to accelerate at exponential rates, the science and the way it has been studied has become more collaborative, innovative, society-related, international and global (Wagner & Leydesdorff, 2005; Makri & Lane, 2007; Smeureanu & Isaila, 2011; Hawthorne, 2010). And there is no doubt that science and associated technology has made drastic modifications to our daily life and an enormous impact on our daily lives in the 21st century. It is not surprising therefore that reconsiderations are taking place in the both in the focus and the way science is taught in school. The magnitude of new knowledge as a part of today's society and the decisions that need to be made by all citizens have given rise to the call for a paradigm shift in the way science education is viewed, especially in post-soviet countries (Holbrook, Rannikmae, Reiska & Ilsley, 2008). This shift sees science literacy becoming an ever-increasing component of education for all in this 21st century, and a recognition that a rigorous education in mathematics, science, and technology can, with modest variations, serve vocational or liberal arts students just as well as future scientists and engineers (Lederman, 2008).

The goal of education can no longer be the acquisition of content knowledge. Education is moving from a book-based to an internet-based "New Understanding" paradigm, i.e. moving from knowing to developing capabilities or competences The emerging, new internet-based education provides powerful communication tools allowing students to pursue deep and profound learning outcomes. These learning outcomes include key competencies and dispositions which are embedded in knowledge, understanding and values, allowing learners to develop the capability to take their imagination and passion and build creative and innovative ideas (Treadwell, 2008). Without permitting the development of such a vision, it is no wonder science classes are not attractive and seem out-of-date and boring to students, neither meeting the demands of a changing society, nor for students as individuals (Sjøberg, 2002). Summarising, it seems the current education system is not sufficiently able to develop the skills, said to be necessary in the global marketplace – creativity, flexibility, initiative and leadership, combined with intellectual abilities to solve problems and make reasoned decisions (Lederman, 2008; Niaz, 2010; Baumberger-Henry, 2005; OECD, 2006).

An emergent educational skill, very much an aspect of the 21st century, is creative thinking:

> *"A creative paradigm has major implications for education and curriculum. First, the teaching-learning frame switches from a cause-effect one where learning is either a direct result of teaching or teaching is at least in a superior-inferior relationship with learning. The switch is to a mode where teaching becomes ancillary to learning, with learning dominant, due to the individual's self-organizational abilities. Further, in this mode teaching changes its modus operandi, from the didactic to the dialogic"* (Doll, 1993).

The 21st century, contemporary world of knowledge, characterized by an explosion of information and ways of communicating it, requires creativity more than ever in identifying ways to best handle scientific knowledge. It is against this backdrop that educationalists are realising that science education, especially so for the gifted, must encourage the development of creativity. But, as creativity is not something that can simply be taught, we must create the conditions for its development (Erez, 2004).

Several researchers have linked creativity to reasoning ability (Lawson, 2010; Ross, 2010; Chiu, 2008; Vartanian, Martindale & Kwiatkowski, 2003; Sternberg & O'Hara, 1999). They tend to distinguish between primary process thinking, which is analogical, and free associative, and secondary process thinking, which is abstract and goal oriented. There is evidence to suggest that creative people are more flexible in moving along the primary – secondary process thinking continuum, although creative insights are more likely to occur in a primary process mode of cognition (Martindale, 1989). Actually, deductive reasoning seems to represent the ultimate form of secondary process thinking, whereas creativity, characterized by imagination and the generation of ideas, is commonly associated with inductive reasoning (Nickerson, 1999). The characteristics of the inductive process and creative behaviour are remarkably similar. In this focus, a creative idea is characterized by its ability to offer a solution to a particular problem in an economical fashion (Sternberg & Lubart, 1999). Not surprising therefore, one would expect a creative person to exhibit superior performance on an inductive reasoning task and there is some evidence to suggest that the association between creativity and inductive reasoning may lead to a direct relationship (Vartanian *et al*., 2003).

In order to shed light on the potential relationship between creativity and reasoning ability, the last few decades have witnessed studies of the ways in which creativity is related to problem-solving ability (Nickerson, 1999) who has suggested that rather than being better at problem solving per se, creative people may excel in problem finding instead. He has also noted that the relationship between problem finding and problem solving is closely linked with the distinction between hypothesis generation and hypothesis testing in science. Hypothesis testing has garnered more attention and is better understood than hypothesis generation. And this, to understand the role of creativity in scientific discovery, one would need to compare the performance of more and less creative people on a task that requires the successful generation and testing of hypotheses (Newton, 2010).

Both problem-solving and decision-making almost certainly involve students in analysing evidence. It is therefore important for students to learn how to interpret and evaluate evidence when making decisions and to present justified arguments that support their positions. No matter from which source people obtain their information, an important skill in handling information is to know how to disentangle opinions and interpretations from factual evidence. The challenge for educators of future citizens is, therefore, to improve students' creative thinking skills so that they can analyse evidence that may be uncertain or conflicting (Maloney, 2007).

The problem facing science education today is – how to teach science successfully with its implications of sweeping changes in curriculum direction, in teaching styles, and in the recruitment, training, and professional development of teachers (Lederman, 2008). This is crucial if the development of students' skills needed for the society of the future includes the competencies (*i.e.* problem solving, decision making, creativity, reasoning, initiative, cooperation skills etc) as put forward in the new Estonian curriculum (2010). Unfortunately, there is the danger that teachers don't attempt to read the curriculum; they prefer to rely on the textbooks (Niaz, 2010). This can be coupled with the recognition that science has traditionally been taught in a very teacher-centred and convergent way, with science teachers neither developing expertise to promote students' creativity and argumentation skills nor gaining experiences in assessing these abilities. In fact there is evidence that teachers have tended to see these as time consuming, confusing and not to be considered a priority target for science learning. Holbrook (2008), basing on a European Commission concern as expressed in "Europe needs more scientists" (EC, 2004), points out in his introduction to a recent book "The Need for a Paradigm Shift in Science Education for Post Soviet Societies" (Holbrook *et al.*, 2008) that the developments alluded to earlier were not universal and in general science education had not moved forward in line with the outcomes of research.

In the Estonian situation, changes in the teaching of science subjects, at both the junior and senior secondary levels, are interlinked to major changes in curriculum orientation based on the introductions given in the new Estonian curriculum as a whole and that for science subjects in particular (Estonian Curriculum, 2010). This is further illustrated by the PISA 2006 results which showed that the Estonian school system focused mostly on memorising and did not give enough attention to reasoning and creativity (OECD, 2006; Henno, 2008). While Estonian students scored highly in the PISA test as a whole, achievement in the more reasoning and inductive items was much weaker. Teachers, however, are largely educated during the Soviet system and are still apt to practice teacher-centred methods of delivery with little attention to individual group work, nor student involvement in investigatory approaches and creative developments (Laius & Rannikmäe, 2004).

Recognising that societies in the 21st century need new approaches to science education and thus special attention to science teaching methodologies, developing in students, not facts, theories and understanding, but competencies, the current research tries to investigate the possibilities to address these shortcomings. The issue is thus clear. What approach to teacher in-service education can promote changes in the manner in which teachers focus on the science curriculum and in what ways can students' creativity and reasoning be promoted?

Findings from research have highlighted the primary importance of developing students' thinking skills, included reasoning and creative thinking, that play an important role in the stimulation of knowledge acquisition, problem-solving and in the development of expertise (Casakin, 2010; Hèlie & Sun, 2010). But still this form of thinking is not taught explicitly at school and is considered to be a side-effect of the total learning process (Molnar, 2011; Kokotsaki, 2011). In this study it was considered important to guide teachers to teach the skills of scientific creativity and socio-scientific reasoning explicitly and to evaluate the outcomes.

In addressing the issues in science education, the main goals of this research are:

1. To investigate categories of science teachers' change during in-service courses on Scientific and Technological literacy related to promoting students' creative thinking and reasoning skills (Paper II).
2. To investigate the relationship between effectiveness of the STL in-service courses and the readiness of teachers to raise the level of students' scientific creativity and socio-scientific reasoning skills (Papers II and IV).
3. To investigate the influence of classroom environment factors on promoting students' scientific creativity and socio-scientific reasoning skills and in particular the influence of teachers' integrative teamwork (Papers I and IV).
4. To examine the effectiveness of the derived STL teaching in-service model in another situation (Paper III).

Based on the above goals, the following research questions are put forward:

1. To what extent is it possible to instigate science teachers' change with respect to scientific creativity and socio-scientific reasoning where an STL in-service programme is shown to be effective?
2. How does the professional level of science teachers and the induced change, stimulated by a STL in-service provision, influence their students' scientific literacy, measured through scientific creativity and socio-scientific reasoning skills?
3. What is the impact of teachers' integrative teamwork on the increase of their students' socio-scientific reasoning and scientific creativity skills?
4. What classroom environment factors, interrelated to teachers' acquired level of change through the STL in-service provision, positively impact on the students' level of scientific creativity and socio-scientific reasoning?
5. Is the STL teaching model effective if used in another situation?

2. REVIEW OF LITERATURE

2.1. Philosophical ideas influencing science teaching

2.1.1. Science – Technology – Society teaching

Science/Technology/Society (STS) was a new movement introduced in science education, primarily in the 1980s in the United States with powerful goals to redress the ills of science education, introducing a new view of the curriculum, new teaching models, and new evaluation programmes, based on a philosophy of shifting science teaching from abstract science to linking science with both technology and the society (Yager, 1991). Students were expected to excel over those not experiencing teaching in this STS approach in terms of being better able to apply basic concepts, develop positive attitudes, better use science process skills, and gain creativity skills (Yager, 1996; Yager, 2007). The STS movement has articulated an educational policy that embeds science teaching in the everyday world of students, in a way that helps students make sense of their natural, constructed and social worlds (Solomon & Aikenhead, 1994).

However, STS education has become quite diffuse over the course of its tenure, representing approaches as disparate as isolated courses focused on particular STS issues, pedagogical strategies that highlight the connections between science and society, and ancillary text boxes in the midst of science textbooks (Pedretti & Hodson, 1995). Courses were shown to range from as little as 5 % social orientation to some that were almost social science, encompassing less that 5% towards the gaining of science conceptual ideas (Aikenhead, 1994).

Research has shown that the students who were taught with Science–Technology–Society approaches showed significant improvement in the development not only of more positive attitudes towards science, but also of their creativity skills (Lee & Erdogan, 2007). Perhaps the most considerable contribution in implementing STS was The Iowa Chautauqua Program, initiated and coordinated by Yager (1999). In the current research, the ideas for this project geared to the improving of science teaching in societal component and fostering students' creative thinking as well critical thinking skills were utilised, namely, through the Constructivist Learning Environment Survey (CLES) which was used as a validated instrument for describing the changes in the learning environment (Instrument Package…, 1997).

2.1.2. STL teaching approach

The STL philosophy is more of European origin, following on from STS and focusing on the "science" or the "literacy" aspect, accepting that literacy, wherever used, is wider than simply reading and writing (Holbrook & Rannikmäe, 2009).

Educationalists and political leaders worldwide are increasingly emphasizing the development of scientific literacy (Yuenyong & Narjaikaew, 2009). Yet, there is still a lack of consensus on what the term "scientific literacy" actually means. It has been used in the educational research literature for more than four decades, but with different meanings (Holbrook & Rannikmäe, 2009). Nevertheless there is strong recognition that scientific literacy and scientific and technological literacy – a term preferred by UNESCO (1993) – have basically the same meaning and that in the world of education technological literacy, cannot be separated from scientific literacy. This latter point does not infer of course that science and technology are the same.

There are two major points of view related to the defining of the term "scientific literacy," or "scientific and technological literacy." From one point of view, knowledge of science is given a central role (Holbrook & Rannikmäe, 2009). Scientific literacy is described as the ability to understand, analyze, and evaluate scientific data while integrating these data into a greater body of scientific knowledge (Gillen, 2006).

The other point of view is that scientific literacy enables citizens to become sufficiently aware of science-related public issues, able to make decisions and hence improve the quality of their lives (Holbrook & Rannikmäe, 2001; Laugksch, 2000). Through this viewpoint, scientific literacy is seen as being aligned with the development of life skills (Rychen & Salganik, 2003). It recognises the need for reasoning skills in a social context, not only in academic science knowledge for specialisation in science (Holbrook & Rannikmäe, 2009). It means that scientific literacy is for all, not only for citizens who want to have careers in science. Furthermore it necessitates relating scientific literacy to an appreciation of the nature of science, personal learning attributes, including attitudes, and also to the development of social values (Holbrook & Rannikmäe, 2007; Roth, 2007; Roth, 2003).

Researchers suggest that using a scientific literacy approach encompassing a socio-scientific focus, which encompasses social dilemmas with conceptual or technological links to science, improves the relevance and quality of science teaching (Holbrook & Rannikmae, 2007). The process of resolving issues arising is best characterized by informal reasoning which describes the generation and evaluation of positions in response to complex situations (Sadler, 2004). Many science educators have argued for the inclusion of a socio-scientific focus in science classrooms, citing their central role in the development of a responsible citizenry capable of applying scientific knowledge and habits of mind (Yager, 2007; Sadler & Fowler, 2006; Driver, Newton & Osborne, 2000; Kolstø, 2001).

These are the keys to STL which has seen the term scientific literacy invade science curricula today. STL teaching needs a relevant curriculum, but it also requires a curriculum made relevant by the teacher, whose ability of translating the curriculum for the students becomes of great importance. A further key component of an STL learning environment is the active participation of students (Holbrook, 1995). STL is put forward as a complete philosophy, which is driven by the needs of society.

STL teaching starts with a social issue and stipulates changing the sequence of teaching. Further, STL learning does not assume that students have mastered the concepts prior to their teaching, but rather that, the students acquire them as they are needed during the learning process (Holbrook & Rannikmäe, 2000).

A key component of enhancing scientific literacy is seen as relevance (Holbrook & Rannikmäe, 2009).

2.1.3. Context-based teaching

Worldwide, there is visible tendency for secondary science curricula to promote context-based education. Context-based approaches stem from STL approaches which see the society as a platform for the learning of conceptual science and hence context-based teaching uses approaches adopted in science teaching where contexts and applications of science are used as the starting point for the development of scientific ideas. This contrasts with more traditional approaches that cover scientific ideas first, before looking at applications (Bennett, Lubben & Hogarth, 2007). The most recent round of science curriculum reform has seen a renewed interest in a number of countries in a greater use of real world contexts in the teaching of science (Ratcliffe & Robin, 2009; Lavonen & Laaksonen, 2009; Gilbert *et al*., 2011). However, the idea of embedding science teaching and learning in contexts that are real and meaningful to learners was explored extensively in the late 1980s (Fensham, 2009).

Context-based courses are increasingly used to address major challenges that science education currently faces: lack of clear purpose, content overload, incoherent learning by students, lack of relevance to students, lack of transfer of learning to new contexts and inadequate emphasis (Gilbert, 2006). Crucial for these innovations, like all others in the field of science education, is the way teachers interact with the new ideas and developed teaching materials for implementation in classroom practices (Vos, Taconis, Jochems, Wim, & Pilot, 2011).

2.1.4. Social issue-based learning

In contrast to STS teaching, the aims of the socio-scientific issue movement is to focus more specifically on empowering students to handle the science-based issues that shape their current world and those which will determine their future world (Driver *et al*., 2000; Kolstø, 2001). It is really a subset of STL where the issue becomes more of a focus and the conceptual science may or may not have been acquired prior to tackling the issue.

The Socio-scientific Issues (SSI) movement has advanced a vision of school science that prioritizes student experiences with contemporary social dilemmas related to, or based on, science. The underlying idea is that school science should reflect the dynamic interactions of science and society with emphases not only on the science behind contemporary issues confronting all citizens, but also the associated social, political, economic, and moral challenges. Research findings suggest that individuals are naturally inclined to consider these socio-cultural factors when confronted with SSI (Sadler & Zeidler, 2005a). However teacher efforts to distil "the science" from SSI can lead to the exclusion of other contextual factors and encourage the compartmentalization of school science. When isolated in this fashion, school science experiences are likely to have little influence on student behaviours and practices in response to the kinds of authentic problems individuals face as participants of modern democracies (Sadler, Chambers & Zeidler, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Therefore, the SSI movement has advocated situating real-world issues in science classrooms as platforms for learner exploration of traditional science content along with the social realities of scientific practice (Sadler & Fowler, 2006).

Socio-scientific issues encompass social dilemmas with conceptual or technological links to science. The process of resolving these issues is best characterized by informal reasoning which describes the generation and evaluation of positions in response to complex situations (Sadler, 2004), i.e. socio-scientific issues require students to generate informed decisions supported by their arguments (Foong & Daniel, 2010). Several science educators have argued for the inclusion of socio-scientific issues in science classrooms, citing their central role in the development of a responsible citizenry capable of applying scientific knowledge and habits of mind (Driver *et al.*, 2000; Kolstø, 2001; Zeidler, 1984). Their efforts to infuse socio-scientific issues into science curricula are not the first intent on making classroom science more reflective of the society in which it exists as opposed to an isolated, irrelevant academic discipline.

Socio-scientific issues, where conceptual science acquisition is also intended, is actually a subset of STL. While STL has come about as an attempt to address the relevance and hence student motivation for the learning of science and has adopted a socio-scientific focus, SSI is more about a recognition that meaningful science is best approach through issues that citizens are called upon to address and which require a scientific input. The in-service courses were this conceived as STL but with the strong recognition that SSI as a subset, could be a meaningful manner in which to address creativity and decision making.

2.2. Curricula and competencies, acquired in science education

Scientific literacy and its components

Enhancement of STL (scientific and technological literacy) is the major goal of science education, including the Estonian new curriculum (2010), where STL was suitably taken to mean:

> *"...developing the ability to creatively utilise sound science knowledge in everyday life to solve problems, make decisions and hence improve the quality of life"* (Holbrook & Rannikmäe, 1997).

A more updated definition for scientific and technological literacy has been suggested:

> *"STL, as the major goal of science education, is the need to develop the ability to utilise sound science knowledge creatively in everyday life by solving problem and making reasoned decisions, involving value judgements and communication skills"* (Rannikmäe *et al.,* 2010a).

In a definition of STL as discussed by Laius *et al.* (2008) the creative utilisation of knowledge is highlighted pointing to the importance of students' creativity.

2.2.1. Creativity in education

The term "creativity" is used in the science education literature to refer to teaching and learning processes based on recognising problems and discrepancies in an accepted content, looking at things in different ways, making unexpected links among apparently discrepant elements of information and developing one's own solutions to problems and similar processes, rather than simply memorising prescribed content (Cropley & Cropley, 2008). Creativity, in the sense of creative thinking, is currently receiving increased attention in education; more and more school curricula now mention it, but the increased interest in creativity has occurred as if without reference to any value framework (Rutland & Barlex, 2008; Kaufman, 2006; Craft, 2006).

The concept of creativity is hard to define, as creativity may be found in any domain of human activity (Clegg, 2008). But it is generally agreed that creativity is the generation of ideas that are novel and of value (Hennessey & Amabile, 2010). The importance of creativity for students, as future citizens, is an important goal advanced by most educators (Edwards & Blake, 2007; Shoshani & Hazi, 2007; Kaufman, 2006; Craft, 2006; Runco, 2004). The problem, however, is how to get teachers prepared to improve students' creativity in their everyday work in the classroom and for this to assist their own development in this area.

Creativity is nowadays widely defined as the production of relevant and effective novelty (Kronfeldner, 2009; Cropley & Cropley, 2008; Kaufman, 2003). Genuine creativity requires a further element over and above mere novelty: an idea, a product or a response must be relevant to the issue at stake and must offer some kind of genuine solution; it must be effective (Cropley, 1999). Creativity is also a collection of attitudes and abilities that lead a person to produce creative thoughts, ideas or images (Fisher, 1995). Sternberg and Lubart (1999) perceived creativity as being generated by six factors: intelligence, knowledge, cognitive style, personality, motivation and environment. Although described separately, those "ingredients" are far from being separate and mostly they interact with each other.

Research has shown that creative solutions typically result from discovering new associations among frames from previously disparate areas of knowledge networks within the context of the problem at hand (Mobley, Doares & Mumford, 1992). The creative process, however, is not simply driven by random combinations of frames. Rather, creativity is often characterized as the result of effortful application of knowledge to the domain of interest (Sternberg, 1998). Thus, creativity emerges when two or more knowledge frames, not previously associated with one another, are activated together in the context of some new problem (Santanen, Robert & de Vreede, 2004).

Creativity has been generally recognised earlier, but it was expected that it would emerge on an intuitive level as a by-product of a learning objective rather than being explicitly planned (Kokotsaki, 2011). Nevertheless, as one might expect, creativity has been highly valued by many teachers while others, contextualised their responses, refer to examination results as more important than creativity. This presents a tension, as teachers claim to personally value creativity, but at the same time feel that students do not need to demonstrate creativity to get higher grades in examinations. Although creativity is implicit in the assessment criteria of examination boards, for example, generating ideas, it is not explicitly mentioned in the National Curriculum Programmes of Study (Nicholl & McLellan, 2008). Teachers it seems are forced to make some form of choice between fostering creativity in their students and ensuring they perform well in examinations to reduce dissonance (Craft & Jeffrey, 2008).

Thus, in education, there exists a problem with complex interplay of power between performance and creativity agendas. Current educational discourse highlights the importance of creativity, which is eminently suited to the multiple needs of life in the twenty-first century and which calls for enhanced skills of adaptation, flexibility, initiative and the ability to use knowledge in different ways. Still it remains common to evaluate the schools by their performance solely according to the results of examinations. This potential dilemma, where teachers are called upon to balance the valuing of creativity with the constraints of the classroom (Burnard & White, 2008; Nicholl & McLellan, 2008; Simmons & Thompson, 2008; Beghetto, 2007) is shown to be false by a striking practical demonstration. The differences between learning through creativity-oriented teaching and learning via more traditional approaches, is highlighted in the differences between mathematics teaching in Japanese secondary schools and in their American and German counterparts. These are described in the now almost infamous TIMSS study (2003), where there is substantial evidence that a creative approach in Japanese school has beneficial effects on the acquisition of traditional knowledge and skills. In the TIMSS study, Japanese children were the 3rd best mathematics achievers, out of pupils from 41 countries involved, whereas the Germans and Americans (using more traditional approaches) were placed 23rd and 28th accordingly (Cropley & Cropley, 2008). This confirms the need and importance of moving creativity from the margins of formal education to its centre (McWilliam & Haukka, 2008).

A more recent aspect in the field of creativity in education has been explored by McWilliam and Dawson (2008) in their research on the pedagogical significance of recent shifts in scholarly attention away from the first generation of creativity towards second generation understanding of creativity that locates the creative enterprise from an individual to a collaborative and purposeful activity.

There is also a recognised need for teacher training about creativity (Morais & Azevedo, 2011). Pleschova (2007) summarized the favourable effects of fostering creativity in a simple and straightforward manner: it motivates students more and helps them learn better. She also drew attention to the fact – worth mentioning here, although it lies outside the scope of the present paper – that teaching based on creativity also makes teachers more motivated.

There are five key capabilities which stand out as being essential in order to be a worker in the creative sector: (1) The capability to *communicate and express new ideas* via strong narratives which make use of rich language, and rich multimedia presentation tools; (2) Almost all new ideas are developed and refined in a social context when the idea is described to another person. A person's "nodal network" needs to be enhanced by significant *social contact and interaction*; (3) Almost all significant innovations now have a *"social creativity"* factor. This means that the creator needs to be aware of social fashions and trends and understand the nature of being human. Being only technically creative is not sufficient; (4) The *capacity to synthesize* different ideas in different contexts into a single understanding and be able to "interrogate" the new understanding to look for new possibilities provides a powerful gateway for creativity; and (5) The *capacity to deconstruct other people's ideas* and then apply new understanding or ideas to the reconstruction process allows the possibility of new creative opportunities (Treadwell, 2008).

Prior studies have investigated the gender issues within the domain of creativity and have obtained conflicting results (Furnham, Batey, Booth, Patel & Lozinskaja, 2011; Stoltzfus *et al.*, 2011; Furnham. & Nederstrom, 2010). There is thus attention being given to current research to the students' gender in the analysis of results. The gender aspect is this explored in this study.

2.2.2. Scientific creativity

Accepting that the conception of creativity is very broad, we narrowed our focus of research to scientific creativity. The definition of "scientific creativity" can be conceptualized as individual and social capacities for solving complex scientific and technical problems in an innovative and productive way (Heller, 2007). In this study, as the research focuses on science education, the term "creativity" is used, hereafter, in this more narrow meaning of scientific creativity.

Generally, the hypothetical construct "scientific ability" can be defined as scientific thinking potential, or as a special talent for excellence in the (natural) sciences. Similar to this definition, "scientific creativity" or "technical creativity" can be conceptualized as individual and social capacities for solving complex scientific and technical problems in an innovative and productive way (Heller, 2007).

Hu and Adey (2002) define scientific creativity as a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information. According to Erez (2004), scientific creativity includes developing a range of creative abilities, including being imaginative and playing with ideas and analogies; picking up and follow clues when working in the laboratory; and avoiding "confirmation bias". All these are abilities that should be used in accordance with critical thinking and the search for evidence-based conclusions.

This study aims to use scientific creativity test results as an indicator of students' change during STL intervention strictly within science education domain, rather than attempt a deep consideration of the cognitive nature of creativity itself.

2.2.3. Linking scientific creativity to problem solving and decision making

While noting that the vast majority of students will neither become scientists nor need to have an in-depth knowledge in the way scientists work, scientific creativity remains an important educational goal because it is heavily connected to two highlighted skills in the STL definition "solving problems" and "making decisions". Chang and Chiub (2008) support the STL goal of science education which is not only to learn specific scientific knowledge, but to develop skills of scientific thinking and argumentation that plays an important role in high-level brain-storming, such as critical reasoning, creative thinking, and problem-solving. The most powerful long-range predictors of professional success in science and technology are apparently domain specific problem solving abilities and the problem solving which requires the production of innovative solutions.

Such approaches to scientific problem solving also refers to the importance of students' scientific creativity (Casakin, 2008).

2.2.4. Reasoning and argumentation

The argumentative theory of reasoning is a recent attempt to show that reasoning is a fundamentally social ability and reasoning has evolved to serve argumentative ends: finding and evaluating arguments in a dialogic context. (Mercier, 2011).

According to Brousseau and Gibel (2005), the word "reasoning" refers to a domain which is not restricted to the formal, logical or mathematical forms of reasoning. In the context of science, reasoning historically referred to formal reasoning characterized by rules of logic and mathematics and the formal processes of deduction or induction lead thinkers to necessary conclusions. Unlike scientific investigations, the premises of formal reasoning are fixed and unchanging and conclusions are necessary derivatives. In informal reasoning, on the other hand, premises can change as additional information becomes available, and conclusions are not self-evident (Perkins, Farady & Bushey, 1991). Informal reasoning involves the generation and evaluation of positions in response to complex issues that lack clear-cut solutions (Sadler, 2004). Argumentation represents a powerful tool for promoting collective and individual reasoning. As several authors have argued, explanation via argumentation is related to critical thinking and problem solving, as well as to the construction and validation of scientific knowledge (Acar, Turkmenb & Roychoudhuryc, 2010; Stark, Puhl & Krause, 2009; von Aufschnaiter, Erduran, Osborne & Simon, 2008; Erduran & Jiménez-Alexaindre, M., 2008; Nussbaum, Sinatra & Poliquin, 2008; Rojas-Drummond & Zapata, 2004).

Argumentation can be defined as the act of providing reasons to make admissible a certain position, opinion or conclusion, or to confront others' positions, opinions or conclusions (Sadler, 2004). The support can refer to different types of reasons, including tests, justifications, contextual demonstrations, examples, analogies and beliefs. At the same time, an argument may contain, besides supporting statements, a conclusion. An argument is initiated when someone makes an assertion which establishes a position and is followed by one or more supports, although the order could be inverted. An argument can be expressed by one of the participants in a discussion, or appear as part of an exchange between two or more participants in a conversation. Also, an argument can be developed across several turns. An argument is a set of interventions which relate to a particular assertion establishing a position and which share the same intention. The argument finishes when the participant(s) change perspective or position. Another relevant aspect of arguments is that they are circumscribed by a certain meaningful activity (Rojas-Drummond & Zapata, 2004).

Some of the interest in argumentation stems from the need to teach students reasoning skills (Nussbaum, 2008). Key conclusions by Nussbaum in his review are that for collaborative discourse and argumentation to enhance conceptual understanding of content, there needs to be a focus in the discussions on resolving socio-cognitive conflict, considering and evaluating diverse views, understanding conceptual principles, and creating social and cognitive norms, where participants will use and, just as importantly, model for one another elaborative and meta-cognitive strategies.

Individuals can express informal reasoning through dialogical argumentation (Driver *et al.,* 2000); however, informal reasoning and argumentation represent unique constructs. Informal reasoning refers to the cognitive and affective processes involved in the negotiation of complex issues and the formation or adoption of a position. Argumentation refers to the expression of informal reasoning. The problem with this distinction lies in the fact that the constructs are practically indistinguishable from an empirical perspective. Argumentation is the means by which researchers gain access to informal reasoning, but they must do so with some trepidation.

While it is valid to assert that strong argumentation reveals strong informal reasoning, the opposite claim, weak argumentation denotes weak informal reasoning, is not necessarily the case (Sadler & Zeidler, 2005a). Adept arguments must be based on proficient informal reasoning, but naive arguments might be the result of either insufficient informal reasoning or poorly articulated, but proficient informal reasoning (Means & Voss, 1996). An investigation expressly focused on argumentation need not be burdened by the discrepancy; however, a study of informal reasoning through argumentation necessarily assumes the problematic association

According to the sociological and philosophical studies of science, science educators have begun to view argumentation as a central scientific practice which students should learn (Sandoval & Millwood, 2005). They see argumentation as the means by which researchers gain access to reasoning, although this must be done with some trepidation. Reasoning is a central component of cognition that depends on theories of comprehension, memory, learning, visual perception, planning, problem-solving, and decision-making (Holvikivi, 2007). But, it is transmitted through communication, which means that promoting strong communication skills of students is recognised as import in written, oral and symbolic forms. According to sociological and philosophical studies of science, science educators have begun to view argumentation as a central scientific practice, which students need to develop (Erduran, Ardac & Yakmaci-Guzel, 2006; Sandoval & Millwood, 2005). According to the study by Coffin and O'Halloran (2008), argumentation skills can enhance an individual's democratic participation in the contemporary society.

Argumentation has been a topic of interest and research for years and there are good reasons for this. One of them is that a series of studies have demonstrated the positive effects of discussing ideas upon learning (Candela, 1997;

King, 1994, 1995). An important characteristic of argumentation is that it emerges from the need to solve a difference of opinion through exploration of the justification of competing points of view. Therefore, everyday communication includes argumentation. Argumentation provides humans with a very powerful thinking tool, given that it allows individuals to deny, criticise and justify concepts and facts, as well as find opposing views and generate a new perspective in social interaction or in self-deliberation. In addition, argumentation is important because it prepares individuals for scientific language. Thus, when learning science, students do not learn only from their own perceptions, but also from the ways we describe, explain, justify and argue in this domain. In conclusion, argumentation provides a rich terrain for research and inquiry, given its importance for solving differences and reaching consensus, as well as its central role in thinking and scientific language. For example, Wilkinson (1986) analysed parallelisms between narrative and argumentative skills in children, and their emergence at young ages.

Argumentation has also gained renewed prominence as a theme and approach for classroom experiences as well as a focus for educational research (Sadler & Fowler, 2006). Argumentation is central to the practice of science and, by extension, should assume an equally central role in science classrooms (Duschl & Osborne, 2002). Toulmin's (1958) philosophical exploration of argumentation has had profound impacts on the study and assessment of argumentation, particularly with respect to science education. Toulmin's Argument Pattern (TAP) provides a framework for analyzing argument structure and specifies features such as claims, data, warrants, backings, and rebuttals.

In order to determine the structure and complexity of reasoning and argumentation the majority of researchers have used modifications of classification scheme based on Toulmin's (1958) argumentation pattern (TAP), describing different levels of reasoning (measured through argumentation). For instance, three levels were identified by Brousseau and Gibel (2005); four levels by Venville and Dawson (2010) and five levels by Foong and Daniel (2010), Osborne *et al.* (2004), also Sadler and Zeidler (2005a).

There are limitations for the use of TAP for the assessment of argumentation in the theoretical framework (Erduran *et al.*, 2004). In the current study, problems associated with structural analyses of arguments are minimised, by the parsing of claims, warrants, backings, etc. Rather than assessing all argument structures identified by TAP, the focus of analysis is put on the justification quality of argumentation that is considered to represent the best indicator of students' reasoning abilities.

2.2.5. Socio-scientific reasoning

Patterns of socio-scientific argumentation have been investigated in contexts such as human genetic issues (Zohar & Nemet, 2002), local environmental issues (Patronis, Potari & Spiliotopoulou, 1999). A common assumption underlying much of this work suggests that learners' content knowledge, related to the SSI under consideration, significantly influences argumentation practice (Dawson & Schibeci, 2003; Patronis *et al.*, 1999; Yang & Anderson, 2003). The idea that individuals rely on their scientific understandings to analyze and justify their positions regarding SSI intuitively appeals to science educators, particularly those who conceptualize the purposes of science education as the bridging of science into the lives of students. In their study, Sadler and Fowler (2006) take up the challenge of exploring relationships between students' understanding of relevant science concepts and their socio-scientific argumentation practices.

Beyond the intuitive appeal of presumed links between content knowledge and argumentation, educators have reason to support this hypothesis. Two fairly recent reports have documented a significant influence of content knowledge in student negotiation of ill-structured problems related to meiosis (Wynne *et al.,* 2001) and the spread and treatment of HIV (Keselman, Kaufman & Patel, 2004). Other findings, more closely aligned with the SSI agenda, also support a link between knowledge and reasoning or argumentation (Wu & Tsai, 2007; Hogan, 2002; Tytler, Duggan & Gott, 2001; Zohar & Nemet, 2002), but the foci of these studies were not directly related to informing these relationships, and the evidence was not particularly strong with regards to this issue (Sadler, 2004). Sadler and Zeidler (2005b), explore how socio-scientific argumentation in the context of genetic engineering issues varies across two groups of college students: one group of non-science majors with naive understanding of genetics and another group of science majors with well-developed understandings of genetics. There finding indicate that while both groups rely on similar patterns of reasoning (i.e., both groups reveal comparable tendencies to make use of rationalistic, intuitive, and emotive resources), the science majors demonstrate significantly higher quality argumentation than their peers. This study offers evidence in support of the presumed relationship between content knowledge and socio-scientific argumentation, but it also suffers from limitations, which necessarily restricts the applicability of its findings. Sampling is based on participant scores on a genetics knowledge test and a maximum-variation strategy. Although qualitative data is presented to support the conclusion that content knowledge is, in fact, one of the factors contributing to differences observed in argumentation, other group level variables may also contribute to the differences.

The findings of evaluation studies suggest that reasoning skills can be effectively developed from early age (Molnar, 2011) and there have been different results about gender-relatedness of reasoning skills) and the predictive values of reasoning abilities to achievement in scholastic scientific knowledge (Furnham *et al.,* 2011; Kuhn & Holling, 2009; Sadler & Fowler, 2006).

2.2.6. Linking reasoning to problem solving and decision making

According to Zeidler *et al*. (2007), students' socio-scientific decision making is connected to reasoning. This is because students have to reflect on issues in order to evaluate claims, analyze evidence, and consider the variety of viewpoints regarding ethical issues and judgments on scientific topics through social interaction and discourse – that is the essence of the reasoning process. Decision-making almost certainly involves students in analysing evidence and it is thus no surprise that it is considered important for students to learn how to interpret and evaluate evidence when making decisions and to present justified arguments that support their positions. No matter from which source information is gained, an important skill in handling information is to know how to disentangle opinions and interpretations from fact. The challenge for educators of future citizens is, therefore, to improve students' creative thinking skills so that they can analyse evidence that may be uncertain, or conflicting. That means using reasoning and argumentation (DeHaan, 2009; Maloney, 2007).

The final outcome will depend greatly on the capacity of education systems to recognise that the evolution of the mediated new education paradigm provides educators with the moral responsibility to provide learners with a unique set of critical thinking skills and attitudes. A great challenge is to create a balanced curriculum where learners are able to develop a broad range of competencies and dispositions, focusing on developing lifelong learning skills, values, attitudes and competencies. No matter how many educators argue that it was the same in their day, it simply isn't and young people are exposed to far more decision making than ever before and we need to prepare them much better for this decision making process so that it does not overwhelm them. Decision making where risks need to be assessed requires plenty of "what if" scenarios and the acknowledgement of risky behaviours combined with the development of self-confidence to make independent decisions when the assessment of risk clearly demonstrates that there is a high level of potential for harm. High-risk practices include the common ones such as drug taking, drink driving, casual sexual involvement, associating with those involved with criminal activity and not wearing seatbelts in cars. While an individual has a responsibility to manage this for themselves they also have a responsibility to help their friends make better decisions (Treadwell, 2008).

Problem-solving and decision-making skills require students to develop skills of reasoning and argumentation. Reasoning refers to the cognitive and affective processes involved in the negotiation of complex issues and the formation or adoption of positions. In addition, there is general agreement that the nature and development of scientific reasoning plays a central role in acquiring scientific literacy (Lawson, 2004). Research shows, however, that only if argumentation is specifically and explicitly addressed in the curriculum will students have the opportunity to explore its use in science (Zohar & Nemet, 2002; Osborne *et al*., 2004; Simon & Johnson, 2008). Decision making almost certainly involves people in analysing evidence. In short, effective argumentation skills are central to sound decision-making at a variety of different levels and argumentation may be important for learning scientific content as well (Maloney, 2007).

2.3. Learning environment

A classroom learning environment consists of a variety of components: the teacher, the learner, learning climate, learning organisation (curriculum), assessment and evaluation, teaching materials, encouraging creativity and communication (Pluckrose, 2000).

A supportive learning environment is crucial to students in many ways and can be defined as a community with its own culture and values providing a variety of learning methods and learning-places that support student learning (Ford *et al.,* 1996). Recent socio-economic changes have affected needs in science education and the quality of learning environment shapes the attitudes of both teachers and students and makes a difference to students' learning and higher-order skills, creativity among them (Jankowska & Atlay, 2008).

Teachers do make a difference and can create stimulating environments for learning, allowing to students' intellectual freedom in a safe environment where the student feels comfortable suggesting possibilities, asking questions, and initiating actions to test personal ideas (Besançon & Lubart, 2008). An intellectually safe classroom also provides multiple opportunities to interact with others and increase motivation and engagement (Anderman, Andrzejewski & Allen, 2011).

For this reason, teacher-centred approach which has a negative effect on learning should be abandoned and teaching activities should be individualized as much as possible. Student-centred learning environment and socially derived teaching approach (STL) can be even more effective in promoting more teacher cooperation, which has been pointed out by our previous research (Laius & Rannikmäe, 2006).

2.4. Impact of Teachers and their collaboration

More than ever, education will need to enable people to become effective learners, to be able to encountered new experiences, unfamiliar ideas and changing conditions confidently and creatively. In the wider sense it should also develop collaboration, a sense of community and shared responsibility (Watson, Miller & Patty, 2011; Jang, 2006; Graham, 2006).

Philosophy and history of science show that the perspective about what should count as the basic unit for doing science is changed. The established or received view of the individual scientist as the unit or agent of conceptual change is being replaced by a view that has communities of scientists as the fundamental unit of change (Duschl, 2003).

Collaboration has been pointed out in current study as an important component for teacher change by Wyatt-Smith *et al.* (2008), Bore (2006), also by Laius and Rannikmäe (2004). In the present study this was reinforced through the teachers' own critical analyses, as the teachers recognised before the intervention their lack of inquiry, reasoning and creative thinking skills (Paper I).

Teacher knowledge, experiences, and beliefs greatly impacts on what takes place within the classroom. Thus, teacher learning – the process of acquiring new ideas, changing or deleting old ones – is a key ingredient for educational reform (Anderson & Helms, 2001). At the same time, teachers, as well as students, must be challenged to become skilful thinkers and problem-solvers; work together within groups and teams; be creative; communicate effectively; apply what they learn to authentic needs within their own practices; and be flexible and adaptable to changes and discoveries (Davis, 2003).

Quite often teaching is an isolating profession. It is ironic that new teachers enter the profession because they like to work with people. Instead of collaborating with other teachers and working together as a team to help educate students, many new teachers end up alone in their classroom feeling a sense of isolation (Sandholtz & Dadlez, 2000). Numerous studies have shown that teachers have very little time during the day to work with other teachers, plan lessons as a team, or even talk with their colleagues. It is the many authors' belief that we must increase collaboration in our schools. Collaboration is essential for not only reducing the isolation of the profession, and for enhancing individual teacher's professional growth, but also for the impact it can have on schools and students. Participants in the seminar reported that the team-based approach to in-service courses had an impact on both individual teachers and on the schools. For the individuals, it appears the process increased their knowledge of teaching, altered their philosophy, improved their teaching, and increased connections with other educators (Suntisukwongchote, 2006; Huffman & Kalnin, 2003).

For any paradigm change, and certainly for reflecting on STL (scientific and technological literacy) ideas, it is essential for teachers to be involved in professional development (Gallagher, 1997). In recent research on professional development, researchers have been criticizing "traditional" approaches and advocating for newer, more collaborative models (Williams, Tabernik & Krivak, 2009; Hanley, Maringe & Ratcliffe, 2008). One form of professional development that was used to promote STL teaching was to guide teachers, through workshops, to create their own teaching materials, based on the STL philosophy. This approach was utilised in regional workshops around the world (Holbrook, 2003).

Butler *et al*. (2004) have described in their project of teacher professional development, how conceptual knowledge can be reshaped within collaborative learning communities whereas the teachers also reported an improved ability to communicate with their students. It is important to note, that positive attitudes toward science subjects depend on positive experiences from applications led in science classes in school. In addition the students' positive attitudes toward science subjects need to be fostered early in secondary education and the leading role is played by the teachers (Reid & Skryabina, 2002).

The most recent researchers has argued that communities of practice offer the most promising lens for sustained growth and change of teachers and they emphasize that it is the language of collaboration and dialogic processes that influence the development of learners within the community as it simultaneously shapes the identities of those who participate in it (Crafton & Kaiser, 2011).

The aim of the present research was to find out the relationships between the teachers' teamwork during the STL in-service courses and the change of attitudes towards science classes both of teachers and students.

2.5. Significance of students' science content knowledge

A common assumption made in literature regarding SSI presupposes a link between informal reasoning in the context of a socio-scientific issue and content knowledge related to that issue. On its surface, this certainly constitutes a reasonable claim. It seems intuitively obvious that individuals need to have an understanding of an issue in order to render informed decisions.

Despite the intuitive appeal of a direct relationship between knowledge and reasoning ability, research findings within the domain of informal reasoning do not provide convincing support. In a review of studies of reasoning and argumentation, Kuhn (1991) concludes that "the data show that a large sophisticated knowledge base in a content domain does not determine the quality of thinking skills used in the domain".

The study of Sadler and Zeidler (2005b) called for the exploration of three variables in the context of socio-scientific issues: content knowledge, informal reasoning patterns, and informal reasoning quality. This was consistent with other more general investigations of informal reasoning (Kuhn, 1991; Means & Voss, 1996) as well as those specifically targeting SSI (Kolstø, 2001; Sadler & Zeidler, 2004; Zeidler *et al.*, 2002). As mentioned in the theoretical framework, empirical distinctions between informal reasoning and argumentation can be difficult to draw but remain methodologically possible.

3. METHODOLOGY

3.1. Design of research

The phenomenographical methodology in this longitudinal study used for studying teachers is described in detail in Paper I. Also in this study, a mixed method was used for studying students as described in Papers I and IV.

The time-table and design for the research are given in Table 1.

Table 1. Time-table and design of research

Time	Activity	Publications
2005/2006	The chemistry and biology teachers' in-service training courses "The up-to-date trends in molecular and medical biology" ❑ Piloting and validating the 3-choice argumentation test ❑ Piloting and validating the 7-item scientific creativity test	6, 7, 8
2006/2007	The chemistry and biology teachers' in-service training courses "The development of students' creative and critical thinking skills through real-life situations in science classes"	II, 4, 5
2006	❑ Sampling of the teachers – 12 chemistry and biology teachers from same schools ❑ Seminar for the teachers: • introduction of STL philosophy, • design of STL teaching materials, • mechanisms of reasoning and creative thinking of students. ❑ Pre-questionnaires of learning environment and interviews for teachers	I, II
2006	Workshop for teachers and the collaborative construction of STL teaching materials, including various educational technologies.	Unpublished teaching materials
2006	❑ Sampling of students – 1 class from every 8 schools (248 students) as a sample ❑ Pre-tests of creativity for all students ❑ Pre-tests of reasoning for all students ❑ Pre-questionnaire of learning environment (CLES) for students	I, IV
2007	❑ Seminar of teachers – the analysing the results of the first STL teaching module	II
	❑ Enrolling the 8-week STL teaching module	

Time	Activity	Publications
2007	❑ Post-tests of creativity for all students ❑ Post-tests of reasoning for all students ❑ Pre-questionnaire of learning environment (CLES) for students ❑ Post-questionnaires of learning environment (CLES) and interviews of teachers	I, II, IV, 1, 2, 3,
2008	❑ A-year-after questionnaires of learning environment and delayed interviews of teachers	This dissertation, Table 3
2008	❑ Evaluating implication of PARSEL 3-stage teaching materials	III

3.2. Sample

The main sample for the current research was formed from 248 ninth grade students in 8 different Estonian primary and secondary schools. The schools were chosen based on 12 science teachers (8 chemistry and 4 biology) from 30 teachers who had participated in integrative in-service courses “Modern trends in molecular biology and biomedicine” and who voluntarily continued in the science teachers’ in-service course “The Development of Students’ Critical and Creative Thinking Skills through Real-life Socio-scientific Situations” in the following school year. All teachers in both studies were educated during Soviet times as single subject teachers.

By requiring students to undertake all pre- and post-tests, the number of students was reduced to 224 students when forming the final sample for longitudinal analysis. This approximately 10 % dropout was not taken to adversely affect the demography of the sample.

3.3. Data collection

3.3.1. Methodology for studying teachers

Building on research outcomes (Rannikmäe, 2001; Laius & Rannikmäe, 2004), a longitudinal intervention study was conducted during the period 2006–2007 which included an in-service intervention of 8 months emphasising different aspects of promoting scientific literacy among the students (Papers I and II).

Data were collected from all teachers using (a) pre- and post-questionnaires for teachers (b) semi-structured interviews conducted before and after the intervention, (c) through analysis of teacher created teaching materials and given lessons, and (d) a-year-after delayed questionnaire and semi-structured interviews for teachers.

The study focused on promoting teachers skills to foster students’ scientific creativity and reasoning skills through using socio-scientific issues. For this an interdisciplinary background was seen as important factor. This is because, during the intervention, teachers would be better placed to understand teaching materials taken from everyday life, where the man-made divisions of science are not reality. Eight teachers formed four school-based teams, working in pairs, while four chemistry teachers participated as individuals. The in-service course included four 2-day sessions. Supplementary teaching materials (Table 2), each designed for 2–3 lessons (module) were introduced to teachers, although later they were guided to develop their own. Teachers were asked to assess student's socio-scientific reasoning skills and scientific creativity during every module. The interview outcomes were analysed, using a phenomenographical approach, to determine categories of change of teacher's views and understanding related to new teaching philosophy, methods, teaching materials. Categories were validated by four independent experts (Paper II).

3.3.2. Methodology for studying students

The following **instruments** were used to investigate the levels of changes of students during the STL intervention (Paper I):

Constructivist learning Environment Survey (CLES)

Paper I describes the use of an adapted and shortened 28 item, five-point Likert scale, questionnaire taken from Iowa Chautauqua Program (ICP) that has been adapted the B. Fraser's questionnaire and validated it at the University of Iowa for investigating a constructivist learning environment survey (CLES). This was used to measure the learning environment of classrooms using the following four scales: (1) Personal relevance, (2) Shared control, (3) Student negotiation and (4) Attitude.

The scale measures student attitudes concerning important aspects of the classroom environment from the Instrument Package & User's Guide (1997) of the Iowa Chautauqua Program (ICP) and the scoring follows the methodology of Enger and Yager (1998). This instrument consists of positive and negative statements which must be answered on a scale that ranges from "Almost always" to "Almost never". For positive statements, the "Almost always" choice was recorded as 5, moving down to the "Almost never" choice which was recorded as 1. For negative item statements, the number procedure was reversed.

Scientific creativity test

To assess the students' creative thinking skills, scientific creativity test developed by Hu and Adey (2002) was translated into Estonian and administered with 30 teachers and their 298 ninth and tenth grade students during the first in-service year, analysed and modified into 5-item test that was piloted again by 61 one 9th grade students. The test was slightly modified (two items were dropped because they either lacked relevance to the Estonian curriculum or to students as determined by the results of 2005 pilot test, where most of students refused to solve these tasks, as too unfamiliar as design is not taught as a subject in Estonian schools). The procedure for managing the test and undertaking the analysis is described in Papers I and IV. The items in the test were scored and then standardised to five hierarchical levels (according to test score ranking) to make them comparable to the results of other test results of study.

Socio-scientific reasoning (argumentation) test

The first version of original socio-scientific reasoning test was created in the 2005/2006 school year and was administered with 10th grade students in 11 different Estonian schools. This sample was formed from 254 students (109 boys and 145 girls) whose teachers had voluntarily joined an in-service course "The development of students' creative and critical thinking through real-life situations in science classes". The test consisted of a three item SSI instrument on different real-life situations, based on: (1) cloning the favourite puppy, a situation based on modern science including ethical aspects; (2) the choice of yoghurt, an every-day life situation with a personal aspect; and (3) changing the law on the minimum level of alcohol while driving, a social problem with moral aspects. The instrument was used to investigate the argumentation patterns of 10th grade students to find out their preferences of different types of argumentation. For that reason, four different opinions for each item were given so that they all included scientific, social, personal or non-scientific argumentations. If the respondent could not find a suitable variant, he/she was permitted to give his/her own arguments. The analysis of results revealed that the male and female students used similar types of argumentation for each real-life situation, the students preferred scientific or social arguments and the quality of argumentation skills of students was relatively low and the qualitative levels of argumentation were mostly similar in every real-life situation (Laius & Rannikmäe, 2007). Based on these results for the next version of argumentation test two comparable real-life situations, with ties to both social and scientific issues, were compiled and piloted. The science teachers (14) validated these instruments during the in-service course. Sixty-one ninth-grade students, in one randomly chosen secondary school, piloted the instrument. According to statistical analysis the results were not statistically different and this was taken to mean that the two tests were comparable and that allowed them to use as pre- and post-test before and after the use of the 8-week STL teaching modules for students at a time when the socio-scientific teaching materials were used (Paper I).

Science content knowledge tests

In the fall of 2006 school year, before the intervention a biology test and chemistry tests were conducted to determine the students' level of knowledge, consisting both of 4 factual, 8 conceptual and 4 analytical questions in line with TIMSS test questions (TIMSS, 2003). The tests were scored and the results standardised to five hierarchical levels for further comparable analyses.

3.4. Data analysis

The research data obtained as a result of standardisation or categorisation was ordinal in character and to develop descriptive statistics (means and standard deviations) as well as undertake non-parametric tests, Wilcoxon Signed Ranks Test was used to analyse related samples and the Mann-Whitney U Test and Kruskall-Wallis test were employed for independent samples. One-way ANOVA was utilised for comparing means of more than two groups and specifically for comparing students of different groups and also non-parametric correlation analysis. All data were analyzed and figures created using the SPSS 18.0 statistical analysis program.

3.5. Validity and reliability

In this research, teachers' and students' questionnaires, tests, interviews and observations of study materials are used as measuring instruments. All such instruments cannot be precise. Compared to the natural sciences, no punctual methodology can be put forward. Thus the validity and reliability of the instruments and the methodology must be carefully examined (Table 2). The criteria for teacher categorisation were validated by the expert opinion method and triangulation was used in data collection between the interviews, questionnaires, tests and created teaching materials permitted the validity and reliability of the research to be determined.

The current research underlined the importance of internal validity, which shows the extent to which side effects that can affect the phenomena studied have been taken into account. In compiling the sample the following aspects were considered: (1) All the chemistry and biology teachers had graduated from University of Tartu; (2) None of the teachers was an author of the published instructional materials; (3) All of the teachers had worked as chemistry or biology teacher for more than 5 years; (4) None of the teachers had taken part in prior training related social issue-based learning; and (5) All students involved in the main study came from the ninth grade, thus all of them had taken the same subjects from the same curriculum.

Table 2. Validation and reliability of instruments used in the study

Instrument/method	Issue	Validation/reliability method used
Questionnaires for teachers (CLES (1) and professional development (2)	Content validity	Expert opinion method: two independent chemistry teachers and two independent scientists
	Reliability	Cronbach alpha (1) = 0.891 (2) = 0.785
Questionnaires for students (CLES (1), chemistry (2) and biology (3) tests)	Content validity	Expert opinion method: two independent chemistry teachers and two independent scientists; Piloting using 61 ninth grade students who did not participate in the actual study
	Reliability	Cronbach alpha (1) = 0.771 (2) = 0.754 (3) = 0.724
The formation of categories to describe teacher professional development and the description of movement between these categories	Validity	The method of expert opinion: two independent chemistry teachers and two independent scientists
	Reliability	The concurrency of expert opinions 85 %
Scoring of students' scientific creativity skills	Validity	Expert opinion method: two independent chemistry teachers and two independent scientists
	Reliability	Cronbach alpha = 0.901
Categorising of students' socio-scientific reasoning skills	Validity	Expert opinion method: two independent chemistry teachers and two independent scientists
	Reliability	The concurrency of expert opinions 82 % Cronbach alpha = 0.831
The description of the constructivist learning environment survey		Triangulation used: data was collected about the same characteristics (the motivating of students, the type of practical work used in class, the amount of research activities) from three different sources: teachers' questionnaire, teacher's interviews and students' questionnaire.
The division of students' scientific creativity and socio-scientific reasoning skills into five hierarchical levels	Validity	Expert opinion method: two independent chemistry teachers and two independent scientists

The requirement of external validity, related to the generalisation of the outcomes to all teachers of Estonia, is a limiting factor in the current study. However, the characteristics of teachers are described and in the discussion chapter there are recommendations for incorporation of the outcomes to curriculum of science subjects.

Reliability characterises the stability, consistency and suitability of the methodology used. Reliability shows how well the results of repeated measurements (by either the same researcher, or different experts) carried out in the same circumstances, coincide. Reliability also indicates whether a certain indicator measures consistently and continuously, in other words, how reliable the result of the measurement is. In the current research Cronbach alpha is used as an indicator of internal consistency to assess to what extent questions measuring the same phenomenon coincide.

4. RESULTS AND ANALYSIS

4.1. Change in the Professional Level of teachers

The change of teacher's professional level, measured in four hierarchical categories (see Paper II, Appendix 2) as an outcome of the longitudinal, collaborative in-service courses is described in detail in Paper II (with respect to Study B). This relates to 12 chemistry and biology teachers

Prior to the beginning of the in-service courses, outcomes from a pre-questionnaire (Appendix 2, Paper I) showed that 5 teachers used explanations in their classes as the only type of socio-scientific reasoning, while 6 teachers used reasoning tasks and introduced the structure of argumentation to their students. Only one teacher declared, before the intervention, that she assessed the students' reasoning tasks. After the intervention, none of the teachers remained on the lowest professional level and all teachers added reasoning tasks for students to their teaching repertoire with 4 out of the 12 teachers adding assessment of such tasks also.

The results of the current study (Table 4, Paper II) provided data to suggest that the teaching approach had moved towards interdisciplinary and problem-based teaching and the quality of compiling teaching materials indicated improvement, but only one third of teachers indicated they had changed their science classes into totally student-centred learning environments. A further positive effect of the in-service is shown (Table 1, Paper I) by the fact that the interdisciplinary and communication skills of teachers increased and the collaboration between them had a positive effect on their professional change.

Based on *post-in-service interviews* (Paper II), all teachers highly appreciated the design of the in-service courses. All teachers valued the interdisciplinary theoretical background, which, as they declared, gave them understanding and confidence to implement new types of teaching ideas in the classroom. More than half of the teachers agreed that they progressed in developing their own socio-scientific reasoning and scientific creativity skills as a product of collaboration during the workshops and classroom implementation feedback (Appendix 2, Paper I).

4.2. Change of learning environment

Table 5 in Paper I gives outcomes from the learning environment (CLES) questionnaire and shows teacher improvement on all scales of the learning environment. This indicates that whereas the learning environment in Estonian secondary schools' science classes had not changed to any significant degree during five years before the current study (see Table 1, Paper I), the in-service courses, promoting STL teaching, guided to a substantial positive increase of both teachers' and students' opinions and as a result, science classes turned from strongly teacher-centred classes to more student-centred. The teaching became more relevant to students on scales of *Personal relevance*, *Shared control* (cooperation of students and teachers), *Student negotiation* and *Attitude* towards learning science increased, according to statistically significantly t-test values at the p = 0.05 level (Table 5, Paper I).

4.3. Change in students' scientific creativity and socio-scientific reasoning skills

4.3.1. Scientific creativity

According to the results of the pre- and post-tests on scientific creativity, student responses on all items improved during the 8-week STL learning intervention (Table 3, Paper I). The most statistically significant increase at the p = 0.01 level, occurred in undertaking a creative experimental ability task and one on scientific imagination (p = 0.05). Science problem-solving tasks appeared to be the most complicated to improve as only a slight increase in students' ability was observed which was not statistically significant (p = 0.09). The task to cover science knowledge and thinking also showed a slight, non-statistically significant (p = 0.06), increase as indicated in Table 3, Paper I.

The intervention promoting scientific creativity skills was shown to be particularly successful as the overall mean positive changes of students' levels of scientific creativity skills were statistically significant in all participating schools as shown in Table 2, Paper IV.

4.3.2. Socio-scientific reasoning (argumentation)

Through analysing students' argumentation skills, as shown in Table 4, Paper I, the following three characteristics were identified as determining the patterns of students' reasoning skills:

(1) Total number of arguments given by students as a quantitative measure. The results revealed that more than half of the students (60%) are at the lowest quantitative level of argumentation and only 13% of students belong to the highest level of argumentation.
(2) Quality of the arguments depending on components of argumentation and the logic of reasoning. According to these results, less than one-third of the students could reason well with sufficient argumentation and without mistakes of logic. Interestingly, half of the students fell in the medium level and 17 % into the lowest level of quality of argumentation.
(3) Diversity of argumentation – three levels were indicated, depending on how many different versions students were able to suggest. Less than a quarter of the students (23 %) could look at the problem from more than two

aspects. The most significant results of the argumentation tests revealed that the biggest increase was in the number of arguments during the 8-week STL teaching intervention, while an increase in the diversity of arguments aspect was the smallest and this did not differentiate well between students. The quality of arguments was the most convenient measure to assess argumentation skills and it was decided to use this in the following analysis.

The significant mean positive changes of students' standardised levels of scientific creativity and socio-scientific reasoning skills by schools, as a result of the 8-week STL intervention, are indicated in Table 2, Paper IV. A comparison of the increases of students' scientific creativity skills and social-scientific reasoning showed that the positive change in socio-scientific reasoning skills were more than twice those for the mean increase in scientific creativity.

The overall outcomes in Paper IV reveal that only 5 students (2.2 %), who participated in this study, were at the highest (5th) level of scientific creativity, based on the pre-test and only 2 (0.9 %) students were associated with the fifth level of socio-scientific reasoning. However, after the 8-months teaching intervention, 10 students (4.5 %) illustrated the highest level of scientific creativity and 20 students (8.9 %) in socio-scientific reasoning skills, based on outcomes from the post-test.

4.4. Factors influencing the change of students' scientific creativity and socio-scientific reasoning skills

As shown in Paper IV, positive changes by the teachers in implementing the in-service course components resulted in an increase in students' mean scientific creativity and socio-scientific reasoning test results in all participating schools. These increases were investigated in relation to the impact of the following factors: (1) two teachers' working as a team, (2) teacher's acquired professional level; (3) change of teacher's professional level from the in-service courses; (4) level of students' chemistry and biology knowledge, and (5) gender of students.

4.4.1. Two teachers' working as a team

Figures 1 and 2, Paper IV, show the impact on students of the differences in teachers' integrative and interdisciplinary teamwork in favour of two teachers working as a team. Figure 1 shows that, in the case of zero change by students, the number of students who had been taught by two teachers was smaller, but the numbers were bigger when the number of students realised two changes of level. The overall difference in the increase of students' level of scientific creativity is, however, not statistically significant at the $p = 0.05$ level. Again comparing two teachers working collaboratively with teachers working alone, figure 2, Paper IV, illustrates change of level in students' socio-scientific reasoning skills which are statistically significant at the p = 0.001 level. These results show that two teachers working together induce a greater number of students' change of levels, both in scientific creativity and socio-scientific reasoning skills, but with the latter being more substantial.

Figure 3 in Paper IV illustrates the distribution of total change of levels by students, taught by one or two teachers, in their socio-scientific reasoning and scientific creativity skills, while Figure 1 below gives additional information about the percentage of students undergoing each increase in the number of changes for scientific creativity and socio-scientific reasoning levels. The students taught by two teachers underwent the larger number of changes in their development of scientific creativity and socio-scientific reasoning, whereas the students taught by one teacher stayed more or less at the same level of change (6.4 % against 1.3 % in case of students taught by two teachers). More than half the students showed only 1 or 2 changes (from a maximum of 10 possible changes). With one teacher involved, no students increased their level by 5 steps.

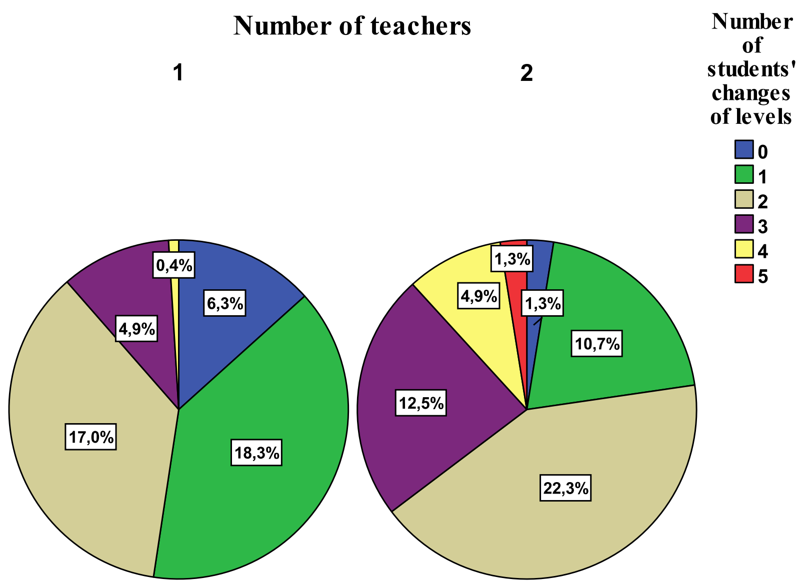

Figure 1. The percentage of students undergoing each number of changes of levels of scientific creativity and socio-scientific reasoning indicated in relation to the number of teachers.

4.4.2. Teacher's professional level

Figure 4, Paper IV illustrates the dependence of the professional level, acquired by teachers (which was determined using four professional levels for the teachers, and which was based on four, identified teaching characteristics, as described in Table 4, Paper II) on their students' total number of changes in scientific creativity and socio-scientific reasoning levels. The teachers' highest professional levels of STL teaching, acquired during the longitudinal in-service courses, had a statistically significant positive effect, at the $p = 0.001$ level, on their students' measured skills in creativity and reasoning, as indicated by the comparable results of groups of teachers at different professional levels (Figure 4, Paper IV).

Figure 5, Paper IV shows the dependence of the obtained professional level of STL teaching, gained by teachers during the in-service courses and supported by the impact from the number of teachers collaborating in the teaching, on the students' total number of changes of levels for scientific creativity and socio-scientific reasoning. Not surprisingly, the results show that the higher the professional level attained by the teacher, the greater the changes of level by some of their students. With high professional levels of the teachers, this student change reached as high as 3–4 levels of change. Most effective in inducing more students to achieve five changes in combining creativity and reasoning levels is the collaboration of two teachers, as only in this case are some students able to go through five changes related to increases in their scientific creativity and socio-scientific reasoning skills.

4.4.3. Change of teacher's professional level

The outcomes of an analysis on the impact of the degree of teachers' change of professional level on their students' changes in levels of creativity and reasoning are illustrated in Figures 4 and 5, Paper IV. Also, Table 3, paper IV gives actual percentages of students who achieved different change of levels, related to creativity and reasoning, which were related to the changes of categories of their teachers' professional levels from involvement in the in-service courses. A more detailed indication of the teacher change of levels is shown in Appendix 2, Paper II. Where the teachers had increased their category level of STL teaching by at least one step, their students, at a class level, also improved their measured skills more, compared to students of those teachers who had not raised their professional level. The student results from the scientific creativity and socio-scientific reasoning tests, for teachers exhibiting different teacher professional levels, were found to be statistically significant at the $p = 0.01$ level, as were the correlations between the number of changes in teachers' levels and the students' number of change in levels for scientific creativity and socio-scientific reasoning skills (Spearman rho's accordingly 0.242 and 0.298 at the $p = 0.01$ level).

Table 3. Teachers' change of professional levels a year after longitudinal in-service

Teacher	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
I Teaching approach												
Learning environment: Teacher-centred (1) – Mixed (2) – Student-centred (3)	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$1 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 3$	$3 \Rightarrow 3$	$2 \Rightarrow 3$	$2 \Rightarrow 3$	$2 \Rightarrow 2$	$3 \Rightarrow 3$
Starting the lesson: with textbook heading (1) – motivating example (2) – scenario with social issue (3)	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 3$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 4$	$3 \Rightarrow 3$	$2 \Rightarrow 3$	$3 \Rightarrow 3$	$3 \Rightarrow 3$	$3 \Rightarrow 3$
Teaching material: Scientific content and it's application (1) – Interdisciplinary scientific content (2) – Problem-based teaching (3)	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$1 \Rightarrow 3$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 3$	$3 \Rightarrow 3$	$2 \Rightarrow 3$	$3 \Rightarrow 3$	$2 \Rightarrow 2$	$3 \Rightarrow 3$
II Inter-disciplinarity and communication												
Knowledge: in one subject (1) – in two subjects (2) –in three subjects (3)	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 3$	$2 \Rightarrow 3$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$
Working alone (1) – Occasional consulting with colleagues (2) – Team-work with colleagues (3)	$2 \Rightarrow 1$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$2 \Rightarrow 1$	$2 \Rightarrow 2$	$3 \Rightarrow 3$	$3 \Rightarrow 3$	$2 \Rightarrow 3$	$3 \Rightarrow 3$	$2 \Rightarrow 1$	$3 \Rightarrow 3$
III Competency												
Preferred teaching methods: individual (1) – in pairs (2) – group-work (3)	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 2$	$3 \Rightarrow 3$	$2 \Rightarrow 2$	$2 \Rightarrow 2$	$3 \Rightarrow 3$	$3 \Rightarrow 4$	$3 \Rightarrow 3$	$3 \Rightarrow 3$	$3 \Rightarrow 2$	$3 \Rightarrow 3$

Teacher	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
Resources: Using ready-made materials (1) – Modifying materials (2) – Creating teaching materials (3)	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	3 ⇒ 3	2 ⇒ 2	3 ⇒ 3	2 ⇒ 2	2 ⇒ 2	3 ⇒ 3
Fostering reasoning: Reasoning type – explanation (1) – Reasoning tasks and introduction of argumentation structure to students (2) – Assessment of reasoning learning tasks (3)	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	3 ⇒ 2	2 ⇒ 2	2 ⇒ 2	3 ⇒ 4	2 ⇒ 2	3 ⇒ 3	3 ⇒ 3	2 ⇒ 2	3 ⇒ 3
Do not value creative thinking (1) – Using creative learning tasks (2) – Creative learning tasks and the assessment of these (3)	2 ⇒ 2	2 ⇒ 1	2 ⇒ 2	2⇒ 2	2 ⇒ 1	2 ⇒ 2	3 ⇒ 3	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	3 ⇒ 3
IV Overcoming the barriers												
Lack of time and/or resources (1) – External examination and/or overloaded curriculum (2) – No claimed obstacles (3)	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	3 ⇒ 2	2 ⇒ 2	2 ⇒ 2	4 ⇒ 4	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	4 ⇒ 4
Changes between levels during longitudinal in-service	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	2 ⇒ 3	1 ⇒ 2	1 ⇒ 2	3 ⇒ 4	2 ⇒ 3	2 ⇒ 3	2 ⇒ 3	2 ⇒ 2	3 ⇒ 4
Changes between levels a year after longitudinal in-service	2 ⇒ 2	2 ⇒ 2	2 ⇒ 2	**3 ⇒ 2**	2 ⇒2	2 ⇒ 2	4 ⇒ 4	3 ⇒ 3	3 ⇒3	3 ⇒ 3	2 ⇒ 2	4 ⇒ 4

A delayed questionnaire and semi-structured interviews were conducted one year after the end of the longitudinal teacher in-service courses to examine the retention of the obtained professional levels of the teachers. The results show (see Table 3) that 11 teachers out of 12 had retained their professional levels whereas one teacher had lowered her professional level by one step. This teacher had been participating in the longitudinal in-service courses alone and was not in a situation at school where collaboration with other science teachers was possible.

4.4.4. Level of students' chemistry and biology knowledge

A Kruskal-Wallis test analysis, appropriate for non-parametric, ordinal data was undertaken to relate the corresponding mean level of creativity at the pre-test and post test levels with a pre-test measure of students' biology and chemistry knowledge (Figure 2). A further Kruskal-Wallis test was undertake to relate the corresponding mean reasoning skill levels with pre- test biology and chemistry knowledge (Figure 3). Chi squared analysis was shown to be statistically significant in the case of figure 2 (Chi-squares were accordingly 9.35 and 10.20 with p values 0.009 and 0.006, but not for figure 3 (pre- and post-test Chi-squares were accordingly 0.78 and 2.36 with p values 0.78 and 2.36).

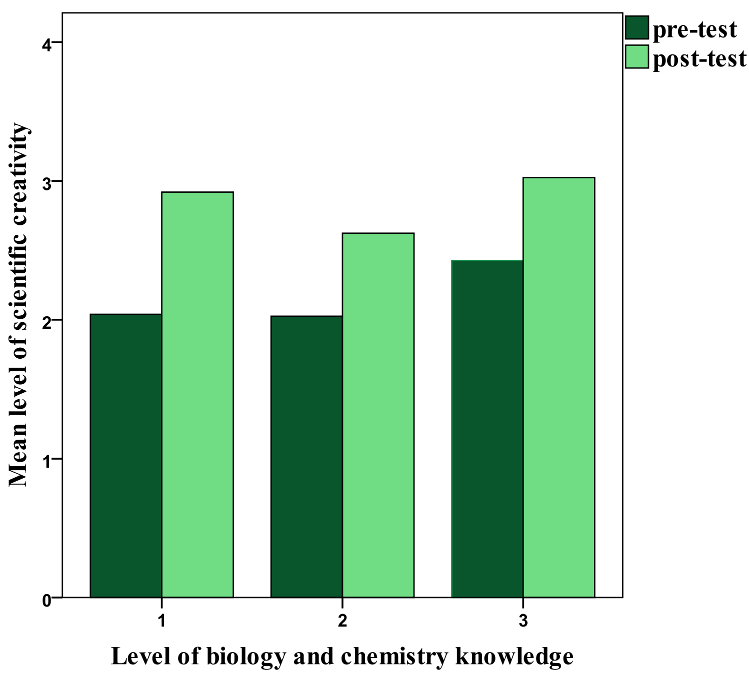

Figure 2. Dependence of students' pre- and post-test mean levels of scientific creativity skills on biology and chemistry knowledge level.

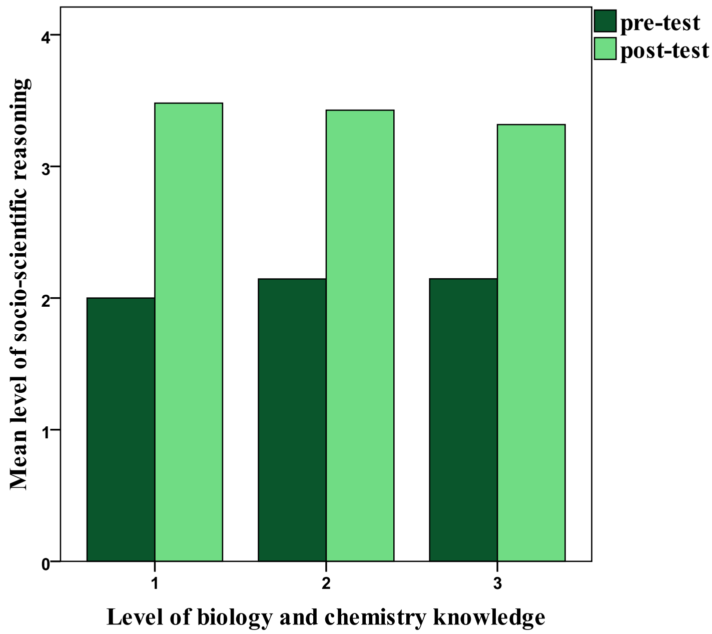

Figure 3. Dependence of students' pre- and post-test mean levels of socio-scientific reasoning skills on biology and chemistry knowledge level.

4.4.5. Gender

To determine the effect of gender on change of levels of scientific creativity and socio-scientific reasoning skill, a Mann-Whitney U test, suitable for relating non-parametric ordinal data to percentage of male sand females was carried out. Figure 4 shows a comparison of change of scientific creativity skills (Mann-Whitney U test: $Z = -0.039$, $p = 0.969$) for males and females while Figure 5 shows the corresponding chart in the case of change of socio-scientific reasoning skills (Mann-Whitney U test: $Z = -1.055$, $p = 0.291$) for males and females. The results were not statistically significant at the $p = 0.05$ level.

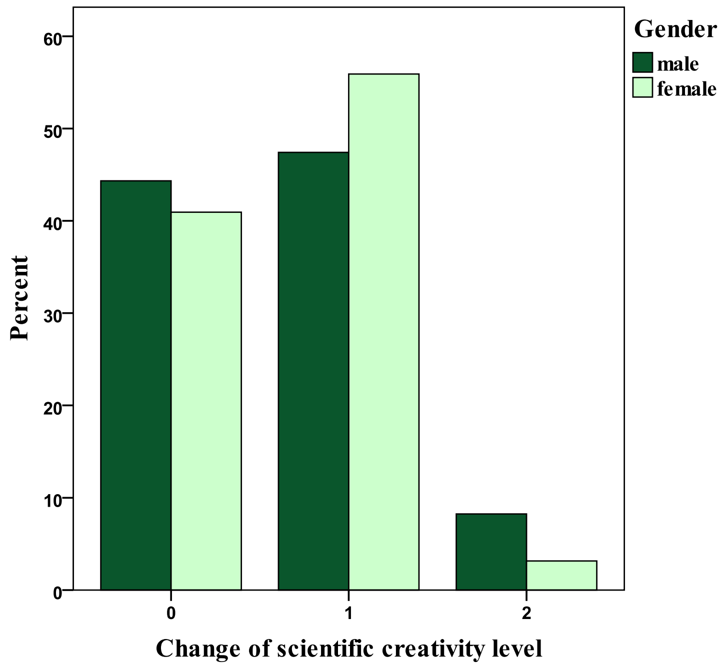

Figure 4. Change of students' level of scientific creativity skills.

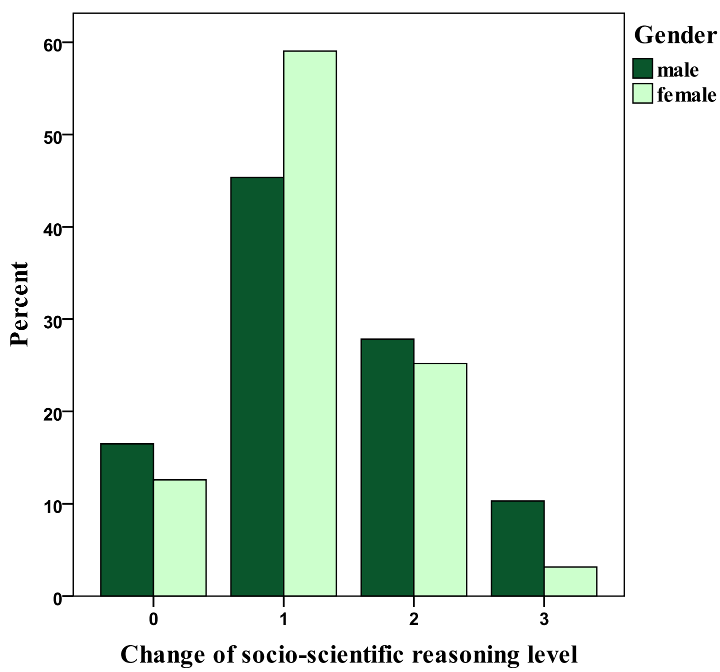

Figure 5. Change of students' level of socio-scientific reasoning skills.

4.5. The effectiveness of implementation of the in-service model in another situation

In order to give an answer to the fifth research question (*Whether the STL teaching model is effective in another situation?*). a detailed analysis of the implication and evaluation of a 2008 teacher in-service course on using a 3-stage STL teaching module was completed during a sixth framework developmental project called PARSEL (Popularity and Relevance of Science Education for Science Literacy) as described in Paper III. According to the results, the PARSEL project implementation was shown to be effective in a similar way to the results of the longitudinal study, both in improving the learning environment towards student-centred teaching (Table 1, Paper III) and also in increasing students' levels of socio-scientific reasoning (measured through argumentation) skills (Table 2, Paper III) and scientific creativity skills (Table 3, Paper III). This model can be helpful as a theoretical basis for planning other STL in-service courses, focused on student-centered learning environment that develops students' scientific literacy.

5. DISCUSSION

The situation in Estonian science education is quite typical to that of other countries both in Western and Eastern part of Europe. Students do not like learning science (Rannikmäe *et al*., 2010b). This is true even though the results by Estonian students in international studies such as the TIMSS (2006) and PISA (OECD, 2006) tests are high. However, the level of liking of school science by 15 year old Estonian students is among the lowest ten participating countries in PISA (Henno *et al.,* 2008). Here is a hidden problem with students' rather negative attitudes (Table 1, Paper I) compared to teachers' opinion about the learning environment and the growing gap between the students' real attitude and the teachers' supposition about it (Table 2, Paper I).

Although there have been changes during last years in the Estonian society, the classroom environment in science classes according to this study has not changed observably. The mean results of teachers' attitudes, based on the sample studied in this research, have become more positive, but at the same time students' increase of attitudes is significantly smaller (at the level $p = 0.01$). In the eyes of students there was little opportunity in science classes to communicate with each other (s*tudent negotiation*), or especially with the teacher (s*hared control*). This points to a situation showing that the learning environment, in the opinion of students, was still strongly teacher-centred and the goals of science education were oriented only towards the acquisition of factual knowledge and scoring highly on factually oriented, external examinations. The higher standard deviation in teachers' mean attitudes (0.81) indicates the tendency of improvements in the learning environment with the more enthusiastic teachers who had participated in-service courses during the longitudinal study (Table 1, Paper I). While this provides a premise for a movement to more up-to-date and relevant science teaching by some teachers, a considerable paradigmatic shift in teaching approaches is needed to solve the general situation in Estonian science education.

Research has shown that a paradigm shift in science education should start from teacher changes that bring about a change in learning environment, improves the students' attitude towards science subjects and makes science education more relevant in the eyes of students and society (Holbrook *et al*., 2008). Promoting teacher change starts from carefully conducted, in-service professional development (Rannikmäe, 2005). In the current study, therefore, efforts were directed to STL in-service courses, highlighting the development of students' scientific creativity and socio-scientific reasoning skills as important components of scientific literacy that were shown to be neglected in implementation of the Estonian Curriculum (OECD, 2006) and are further highlighted in a new, curriculum that is about to operate in the 2011–2012 academic year (Estonian Curriculum, 2010).

The longitudinal teachers' in-service courses were designed especially to deal with fostering students' scientific literacy and attitudes towards science classes, focusing on scientific creativity and socio-scientific reasoning skills through interdisciplinary and student-centred learning environments. In planning the in-service courses, a major goal, recognised from problems previously reported by Rannikmäe (2001), was to provide science teachers with sufficient knowledge from other science disciplines to create interdisciplinary teaching materials.

5.1. Change of teachers

By the end of the longitudinal in-service courses, the teachers highly valued, as indicated in post-interviews, the interdisciplinary theoretical background provided, which they indicated, gave them understanding and confidence to implement new types of teaching ideas in the classroom. However, teachers varied in their ability to include creativity and reasoning in their attempts to create teaching materials (Appendix 2, Paper II).

Phenomenographical categories of science teachers, identified in Table 4, Paper II, showed comparable components to those in the study by Rannikmäe (2001). This may be explained by the fact that similar samples of teachers had been chosen – chemistry and biology teachers with a Soviet pre-service background. In all courses, scientific literacy, as a goal for science teaching (Holbrook & Rannikmäe, 2007), was introduced to the teachers although only one third of the teachers reached to the identified professional level so as to be able to create meaningfully their own teaching materials. The identified change of professional levels indicate the direction of a paradigm shift in science teaching, which, in the current study, means moving towards teaching, which positively promotes scientific creativity and socio-scientific reasoning skills among the students.

After the teaching intervention, it was gratifying to note that all teachers increased their professional level (Appendix 2, Paper II) and all teachers were able to add reasoning tasks for students to their teaching practice and be capable of assessing them also. These findings reinforce the importance of findings from studies by Sadler and his co-authors (2004; 2006), indicating the need to link content knowledge with socio-scientific reasoning. It also pointed towards a reason for the lack of a prior shift by teachers. The availability of meaningful guidance in recognising the need for a change in learning environment is shown to be very important and points to the gains possible, at least by some teachers, through longitudinal in-service courses.

Of major importance was the fact that the four teachers, who had worked alone, did not show substantial positive change in their professional level, whereas the eight teachers, who had participating in collaborative teamwork between teachers in their schools, illustrated more substantial changes as a result of the in-service courses. Before the intervention, more than half of the teachers did not value the fostering of students' scientific creativity skills and only five teachers claimed to be using creative learning tasks in their lessons. After the teaching intervention, although one teacher remained at the lowest level on this scale, not valuing scientific creativity (Appendix 2, Paper II), nine teachers started, or continued to use creative learning tasks. The potential of the in-service was even more fully recognised by two teachers who began to assess these tasks, illustrating a change to the third level on the created competency scale.

Summative results from the longitudinal study (Figure 3 & Table 3, Paper IV) showed that two teachers, when working as a team, induced a greater number of student changes of level, both in scientific creativity and socio-scientific reasoning skills. This result is in line with outcomes from previous research (Rannikmäe, 2005) and provides support for the interpretation which recognises motivation to work as a team as an important contribution for enhancing in-service programmes. It further suggests that motivation is important for teachers in developing scientific literacy in their students, in this case in terms of promoting teaching towards scientific creativity and socio-scientific reasoning.

Teacher collaboration has been pointed out as an important component for teacher change by Wyatt-Smith *et al.* (2008) and also by Laius and Rannikmäe (2004). In the current study (Table 4, Paper II), this finding was obtained both through teacher questionnaires and interviews, showing that teachers recognised, before the intervention, their lack of teaching ability to create interdisciplinary teaching materials and enhance their students' reasoning and creative thinking skills. Teacher collaboration was, by utterances of participating teachers, seen as a key positive factor effecting teacher change and the results of this study (Figures 1, 2, 3 & Table 3, Paper IV) reinforced this. These findings confirmed outcomes from the author's previous study (Laius & Rannikmäe, 2004), indicating the crucial role of teachers' collaborative teamwork within the school. Similar results are also reported by other researchers: Watson *et al*. (2011), Jang (2006), Graham (2006), Suntisukwongchote (2006), Levine & Moreland (2004) and Duschl (2003). The current study revealed also that the teachers' teamwork was significantly more effective in influencing students' changes in scientific creativity and socio-scientific reasoning skills (Table 3, Paper IV) than the teachers working alone.

Beside the collaboration of teachers, other factors were found to have a positive impact on students' changes in the current study (Figure 5, Paper IV). These were the actual professional level of the teachers and the changes that were induced.

The teachers' enhanced competence during the longitudinal in-service courses, like ownership in creating teaching materials, had been considered important in directing teachers to adopt change in former studies (Rannikmäe, 2005). In the current study all teachers left the lowest professional level of content-oriented teaching and reached more interdisciplinary, competent and confident socio-scientific teaching abilities (Table 4, Paper II).

5.2. Change of students

The changes in students' scientific creativity skills showed significant positive increase in all tasks, except for the science problem-solving task (Table 3, Paper I). This task happened to be in the field shown to be the most difficult to improve and make substantial changes in these more difficult areas, like problem-solving and the skills needed to solve such tasks.

The research revealed that the students' scientific creativity and argumentation skills at the beginning of the study were relatively low (Tables 3 & 4, Paper I). These skills were not purposefully fostered in Estonian science classes. Even though the general part of the curriculum included the need for developing skills in students such as creativity, reasoning, problem-solving and decision-making, Estonian teachers chose pragmatism, faced with the dilemma whether to increase these skills or put the main efforts on student performance as this is still the main factor used for assessing the teachers and schools (Burnard & White, 2008; Nicholl & McLellan, 2008; Simmons & Thompson, 2008).

The longitudinal in-service courses can be considered effective in increasing the degree of impact of the teachers on their students' scientific creativity and socio-scientific reasoning skills (Table 2, paper IV). This showed the possibility, through teacher training, to make substantial changes in the learning environment and promote more seriously students' scientific literacy, related to scientific creativity and socio-scientific reasoning. This fits with prior research (Molnar, 2011, Furnham *et. al*., 2011; Sadler & Fowler, 2006; Erduran *et al.,* 2006) and encourages the hope that, with implementation of a new Estonian curriculum, science classes will be more relevant to students in their school work, in their every-day and future life and also fulfils the demands of society.

The impact of the STL teaching intervention was shown to relate to student gender in the case of scientific creativity but unrelated to gender in the field of socio-scientific reasoning skills. Similar findings have been reported by other researchers (Kuhn & Holling, 2009), Furnham & Nederstrom, 2010; Molnar, 2011; Furnham *et al.,* 2011). This suggests that, in future research, promoting the skills under research it will be important to consider the gender issue.

Within the current study, an interpretive model was created to show the fundamental influence of the learning environment on the students' scientific creativity and socio-scientific reasoning skills. This interlinked through different components as shown in Figure 1, Paper I. The model thus illustrates how decision making and problem solving are related and how scientific problem solving can feed socio-scientific decision making, once students have developed the appropriate abilities in fluency, flexibility and originality in their thinking. The importance of the learning environment in the model, including the potential impact of a conducive learning environment on problem solving and decision making, is in the interlinking with both reasoning and argumentation skills and with scientific creativity. This model is seen as helpful in designing in-service programmes promoting students' scientific literacy, including scientific creativity and socio-scientific skills.

6. CONCLUSIONS

The results of this research showed that the use of an interdisciplinary, science teacher STL in-service programme (stressing increased motivation for both teachers and students using increased socially derived teaching approaches, greater teacher/teacher and teachers/student communication and a greater degree of student-centred learning) was effective in changing both the teachers' and students' perceptions about science teaching, with respect to scientific literacy components such as scientific creativity and socio-scientific reasoning (argumentation) skill.

All teachers appreciated highly their participation in the in-service programme, related to their needs. This indicated the need for linking in-service courses with immediate implementation in the classroom and to the gaining of feedback on their success or concerns.

With respect to Research Question 1

> To what extent is it possible to instigate science teachers' change with respect to scientific creativity and socio-scientific reasoning through an STL in-service programme?

Before the in-service courses, the teachers seemed not to see links between students reasoning and creativity skills, even though this has been shown to be important in developing creative solutions in scientific research. A change of teachers' attitudes towards valuing those skills demanded overcoming various constraints and only teachers who decided to rise above those obstacles could teach and assess socio-scientific reasoning and scientific creativity tasks. For some teachers, the longitudinal in-service courses provided strong guidance in overcoming such constraints.

While all teachers exhibited change as a result of the intervention, the magnitude of the change was larger in cases where teachers were working as a team. More interdisciplinary collaboration occurred where teachers supported each other. The greatest change was related to appreciating the importance of socio-scientific issue based teaching materials and using these to motivate students. The smallest changes were related to classroom environment, as this still remained rather teacher-centred, few teachers exhibiting the full range of student-centred strategies.

The teachers generally appreciated more easily the importance of developing students' reasoning skills, rather than their scientific creativity, as reasoning skills seem traditionally to be connected more with the performance goals in science education.

With respect to Research Question 2

> How does the professional level of science teachers and the induced change, stimulated by a STL in-service provision, influence their students' scientific literacy, measured through scientific creativity and socio-scientific reasoning skills?

The professional level at which teachers could utilise the STL teaching approach impacted on the level in developing both students' scientific creativity and argumentation skills. This enabled students to solve problems and make well-grounded socio-scientific decisions in their every-day lives. As reasoning skills and scientific creativity were seen as very important premises for both problem solving and decision making abilities, there were signs that the students' problem solving and decision making improved alongside increases in the degree of student-centred STL teaching undertaken by the teacher.

With respect to Research Question 3

> What is the impact of teachers' integrative teamwork on the increase of their students' socio-scientific reasoning and scientific creativity skills?

The development of students' scientific creativity and socio-scientific reasoning (argumentation) skills was influenced by the number of the teachers working with the students, the degree of their teachers' changes and also by the changed learning environment. The gender factor was important only within the change of scientific creativity. The students' chemistry and biology level of content knowledge influenced significantly their scientific creativity skills, but the impact of science knowledge on socio-scientific reasoning skills occurred not to be statistically significant.

The relationships between scientific creativity, socio-scientific reasoning skills and scientific knowledge occurred to be in a line with results of previous research, e.g. the students at lower levels of scientific achievement are more likely to be changed during interventions.

With respect to Research Question 4

> What classroom environment factors, interrelated with the teachers' acquired levels of change from the STL in-service provision, impacted positively on the students' levels of scientific creativity and socio-scientific reasoning?

The change in attitudes and the higher level of collaboration and communication in the classroom made it possible to improve students' higher order thinking skills, such as reasoning and scientific creativity. Thus, the paradigm shift towards more effective student-centred learning environments and the use of socially derived teaching approaches were shown to be crucial for improving students' attitudes towards science learning and thereby to achieve the desired goals of an increased level of students' scientific literacy within its different components.

With respect to Research Question 5

Is the STL teaching model effective if used in another situation?

The 3-stage STL teaching in-service model was found to be effective in 8 more schools during the operation of the PARSEL project as showed by the significant improvement of students' scientific creativity and socio-scientific reasoning skills as components of scientific literacy.

In summary, it can be said that the intervention of STL teaching/learning approaches was effective in two ways: the students' opinions about their learning environment become more positive, especially in terms of relevance of science learning. Further, it can be affirmed that during purposeful STL in-service courses, using student-centred teaching methodology, it was possible to change the teachers' teaching approach to more student-centred teaching and this was reflected in the change of students' opinions about the learning environment, especially in increasing their attitude towards science classes. Students appreciated the freedom to communicate more with each other and with their teacher. As a result of this change of learning environment, the students began to significantly move towards liking the learning of science. At the same time, such a changed learning environment enabled them to increase their creative thinking and argumentation skills.

The current study confirmed once again that inducing changes in the classroom environment were very slow and time-consuming. But at the same time, the study showed that such changes were possible given appropriate conditions and motivation. This pointed to the need for a substantive paradigm shift in the learning environment to enable the teaching and hence the impact on the students learning to move forward.

6.1. Implications and recommendations

Implications from the intervention study on STL teaching/learning approaches are put forward in four directions:

(a) Purposeful STL in-service courses, using a student-centred teaching methodology, show that it is possible to change teachers' teaching approach to a more student-centred approach, as reflected in the change of students' opinions about their science learning environment. This has implications for future in-service provisions for teachers.

(b) The created learning environment enables students to increase their scientific creativity and socio-scientific reasoning (argumentation skills) significantly. The latter skills enable the students to solve problems and make well-grounded, socio-scientific decisions in their everyday lives. STL teaching adds a social dimension to developing these skills enabling students to increase their diversity of types of argumentation and become more creative in their reasoning. The implication is useful in designing teacher training that guides teachers to set a good learning environment for enhancing students' scientific literacy.

(c) The degree of teachers' professional change towards STL teaching, as a result of in-service training, has a positive impact on change of levels related to scientific creativity and socio-scientific reasoning. The implication confirms the need for longitudinal in-service courses for teachers to enable teachers to go through a paradigmatic change in their teaching.

(d) The development of students' scientific creativity and socio-scientific reasoning skills is significantly influenced by whether one science teacher was involved in a school, or whether two science teachers collaborated together in the same school, using the STL teaching approach in say, chemistry and biology lessons. The gains are more strongly illustrated where two teachers are involved working collaboratively. The implication suggests the need to put more emphasis on science teachers' collaboration at the school level.

(e) The instruments used for determining the learning environment, argumentation and scientific creativity were effective tools in detecting the changes in teaching and learning. Far more, the definition of scientific literacy (Holbrook & Rannikmäe, 1997), on which the two studies were based, needs to be modified, expanding the meaning of the component – "decision making." Handling socio-scientific issues demands not only problem solving and decision making skills, and in choosing between two options, more sophisticated arguments and options must be taken into consideration for making well reasoned decisions. An updated definition for scientific and technological literacy, based on the outcomes of this research, is recommended as:

> *"STL, as the major goal of science education, is the need to develop the ability to utilise sound science knowledge creatively in everyday life by solving problem and making reasoned decisions, involving value judgements and communication skills."*

6.2. Limitations of study

This study has been shown to have strong implications and is claimed to move the understanding of the classroom environment and the approach to motivating teachers toward a more positive approach, thus impacting on the students' motivation to learn science in school. Nevertheless this study has limitations as pointed out below.

The study was undertaken with a comparatively small sample number of teachers, who could not be taken as representative of Estonian teachers as a whole, The specific conditions under which the teachers were involved in the STL in-service programmes was only possible with such small numbers of teachers.

There is a limitation in the gains shown by teachers, as the teachers participating in this study, were all voluntarily accepted beforehand to train for the new philosophy associated with the STL teaching approach and their degree of change cannot be generalised to all science teachers of Estonia.

The number of teachers collaborating together is another limitation. in this study this was confined to two teachers who formed a team, but no extension can be put forward on the effectiveness of outcomes related to bigger numbers of teachers trying to collaboratively work together.

The students' gains are indicative of their teachers' impact and cannot be generalised to the whole population of students, as although the abilities of the students varied by participating schools they cannot be seen as representative of students in all schools in Estonia.

The description of the learning environment has its limitations as it was analysed only through four main characteristics; these cannot be claimed to be exhaustive.

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SUMMARY IN ESTONIAN

Longitudinaalne uurimistöö loodusainete õpetajate muutusest ja selle mõjust õpilaste loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamisoskuse kujunemisele

Doktoritöö esimene peatükk käsitleb uuritava probleemi aktuaalsust loodusteaduslikus hariduses. Rahvusvaheliselt on üles kerkinud probleem loodusteaduslike õppeainete ebapopulaarsusest ja elukaugusest, mis ei arenda õpilastes piisavalt loodusteaduslikule kirjaoskusele vajalikke oskusi. Lahendusena pakutakse välja igapäeva elu probleemide integreerimist õpetamisse, millega kaasneb õpilaste loovuse ja põhjendamisoskuse arendamine. Kõik see eeldab õpetamise paradigma muutmist ning viimasega kaasnevat õpetajate täienduskoolituse süsteemi väljatöötamist.

Käesoleva doktoritöö teises peatükis antakse ülevaade uurimistöödest eelnimetatud probleemide valdkonnas ning esitatakse teaduslikult põhjendatud lähtealused loodusteadusliku kirjaoskuse olulisi komponente – loodusteaduslikku loovust ja sotsiaal-teaduslikku põhjendamisoskust väärtustava ning õpilastele orienteeritud õpikeskkonda kujundava tervikliku kontseptsiooni väljatöötamiseks.

Doktoritöö eemärgid ja uurimisküsimused hõlmavad nelja valdkonda:

(1) Looduainete õpetajate paradigmaatiliste muutuste võimalikkuse uurimine STL (loodusteaduslik ja tehnoloogia-alane kirjaoskus) filosoofiale tugineva õpetajate täienduskoolituse raames;
(2) Loodusainete õpetajate õpetamise kompetentsuse arengul põhinevate õpikeskkonna muutused ja õpilaste muutused loodusteadusliku ja tehnoloogia-alase kirjaoskuse osaoskustes;
(3) Õpilaste loodusteadusliku kirjaoskuse osaoskuste – loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamisoskuse – arengut mõjutavate faktorite uurimine;
(4) Samalaadse kolme-astmelise STL täienduskoolituse tulemuste hindamine uues situatsioonis, PARSEL projekti raames.

Väljatöötatud tervikkontseptsioon põhineb järgnevatele seisukohtadele:

(1) Õpilaste loodusteaduslik ja tehnoloogia-alane kirjaoskus (STL) on loodusteadusliku hariduse integratiivne ja oluline osa, mille tähtsateks komponentideks on loodusteaduslik loovus ja sotsiaal-teaduslik põhjendamisoskus;
(2) Loodusteadusliku ja tehnoloogia-alase kirjaoskuse arendamiseks on vajalik luua õpilaskeskne õpikeskkond, mis lähtub ühiskonna vajadustest, baseerub STL filosoofial, on õpilastele relevantne ja motiveeriv ning arendab õpilaste rühma- ja koostööoskusi;
(3) Loodusteaduste õpetaja peab omama kaasaja teaduse arengule vastavaid ainealaseid teadmisi ja pedagoogilis-psühholoogilist kompetentsust, et

tagada teadmistepõhises ühiskonnas toimetuleva kodaniku kujundamine, kes on võimeline loovalt mõtlema ning probleemide lahendamisel sotsiaalteaduslikult põhjendama oma otsustusi.

STL kontseptsiooni realiseerimiseks viidi läbi pikaajaline õpetajate täienduskoolitus, mis koosnes kahest järjestikusest 8-kuulisest tsüklist, millest esimese (*Kaasaegsed suunad rakendusbioloogias ja biomeditsiinis*) käigus ühtlustati osalevate õpetajat keemia- ja bioloogia-alased interdistsiplinaarsed teadmised ning järgmise (*Loova ja kriitilise mõtlemise arendamine reaalelu situatsioonide kaudu loodusainete tundides*) tsükli raames tutvustati STL õpetamise filosoofiat ning õpilaste loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamisoskuse arendamise metoodikaid. Õpetajad töötasid interdistsiplinaarsete meeskondadena ning koostasid ühiselt STL õppematerjalid 4 õppemooduli jaoks, mida kasutati 8-nädalase õppeperioodi jooksul oma loodusainete tundides.

Pikaajalise koolituse efektiivsust hinnati õpetajate muutuste ja õpilaste loodusteadusliku loovuse ja sotsiaalteadusliku põhjendamise oskuste muutuse kaudu ning mõju püsivust kontrolliti aasta pärast koolitust järel-küsitluse ja -intervjuude abil. Koolitusmudeli ülekantavust uutesse tingimustesse uuriti rahvusvahelise FP 6 projekti PARSEL raames.

Aastatel 2005–2008 viidi läbi pikaajaline loodusainete õpetajate täienduskoolitus, milles osales 8 keemiaõpetajat ja 4 bioloogiaõpetajat ning nende poolt õpetatud 248 üheksandate klasside õpilast, nendest analüüsiti nende 224 õpilase andmeid, kes olid osalenud kõikide küsitluste ja testide tegemisel. Uurimistöö metoodikat, kasutatud instrumente ja andmeanalüüsi on käsitletud dissertatsiooni kolmandas peatükis, kus kirjeldatakse konstruktivistliku õpikeskkonna, loodusteadusliku loovuse ja sotsiaalteadusliku põhjendamisoskuse küsimustikke ning nende hindamise kriteeriume.

Töö tulemused ja järeldused kajastuvad 12 artiklis rahvusvaheliselt indekseeritud teadusajakirjades ja rahvusvaheliste konverentside väljaannetes. Nendest neli on esitatud ilmumise järjekorras käesoleva töö lisas.

I artikkel käsitleb õpikeskkonnaga ning loodusteadusliku kirjaoskusega seotud probleeme loodusainete tundides. Selles artiklis on kirjeldatud õpetajate täienduskoolituse protsessi ja disaini. Tulemused näitavad, et vaatamata Eesti ühiskonnas toimunud suurtele muutustele ja Riiklikus õppekavas sätestatud õppe eesmärkidele, ei ole reaalses õpikeskkonnas ja õpilaste loodusteadusliku kirjaoskuse komponentides kardinaalseid muudatusi aset leidnud – õpikeskkond on endiselt õpetaja-keskne ning õpilaste suhtumine alla keskmise. Artiklis on kirjeldatud uurimisinstrumente ja nende tulemuste analüüsi meetodeid. Esitletakse tulemused õpilaste loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamisoskuse tasemete kohta ning ära on toodud teoreetiline mudel õpikeskkonna ja loodusteadusliku kirjaoskuse komponentide vaheliste seoste kohta.

II artikkel on fokuseeritud loodusainete õpetajatele ning nende loodusteadusliku ja tehnoloogia-alase kompetentsuse arengule pikaajalise täienduskoolituse käigus. Selles kirjeldatakse õpetajate professionaalseid tasemeid ja nende muutusi fenomenograafiliste kategooriate abil, mille loomisel on kasutatud on kasutatud kümmet kolme-astmelist parameetrit. Töö tulemused näitavad, et õpetajate arengut saab kirjeldada nimetatud komponentide liikumisena hierarhiliste tasemete vahel, mille alusel saab iseloomustada õpetajate arengut ja selle muutusi. Liikumine hierarhiliste tasemete vahel madalamalt kõrgemale leidis aset kõigi õpetajate puhul, viies oluliste paradigmaatiliste muutuste ilmnemisele kahel õpetajal 12-st.

III artiklis antakse ülevaade kolme-astmelise STL mudeli kasutamise hindamisest uues olukorras ehk PARSEL projekti raames ja mis kinnitab mudeli efektiivsust, sest samade instrumentidega mõõtes saadi samuti usaldusväärsed positiivsed muutused õpikeskkonna ja õpilaste loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamisoskuse tasemetes.

IV artiklis antakse põhjalik ülevaade uurimistöös osalenud õpilaste loodusteadusliku loovuse ja sotsiaal-teadusliku põhjendamiskuse muutuste ja neid mõjutanud olulisemate tegurite kohta. Olulisteks mõjutajateks õpilaste muutmisel on: (1) kahe õpetaja töötamine koostöös õpilaste samaaegsel õpetamisel; (2) õpetajate omandatud professionaalne tase; (3) õpetajate professionaalse taseme muutuse ulatus täienduskoolituse käigus; (4) bioloogia- ja keemia-alaste teadmiste tase ja (5) õpilaste sugu.

Käesoleva töö tulemused kinnitavad õpetajate pikaajalise STL täienduskoolituse positiivset mõju õpikeskkonnale ja õpilastele, parandades märkimisväärselt nii õpilaste loodusteadusliku kirjaoskusega seotud oskusi kui ka nende hoiakuid loodusteaduste õppimise suhtes. Kuna käesolevas töös osales vaid piiratud arv õpetajaid, ei saa töö tulemusi täiendava uurimuseta üldistada kogu loodusaineid õpetavale õpetajaskonnale.

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Loodusteaduslik-tehnoloogiaalase kirjaoskuse (STL) ning õpilaste loova ja kriitilise mõtlemise ning põhjendamisoskuse kujundamine üldhariduskoolis.

DISSERTATIONES PEDAGOGICAE SCIENTIARUM UNIVERSITATIS TARTUENSIS

1. **Miia Rannikmäe.** Operationalisation of Scientific and Technological Literacy in the Teaching of Science. Tartu, 2001.
2. **Margus Pedaste.** Problem solving in web-based learning environment. Tartu, 2006.
3. **Klaara Kask.** A study of science teacher development towards open inquiry teaching through an intervention programme. Tartu, 2009.