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The development of inventive thinking skills in the upper secondary language classroom

Alexander Sokol[a,*], David Oget[b], Michel Sonntag[b], Nikolai Khomenko[b]

[a] TA Group, 14 P.Lejina Street, 96, Riga, LV-1029, Latvia
[b] LGECO, INSA, Strasbourg, France

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ABSTRACT

The given paper presents the results of an empirical study into the efficacy of the Thinking Approach (TA) to language teaching and learning which is aimed at the development of students' inventive thinking skills in the context of foreign language education, namely learning of English. The study was conducted among upper secondary students of two schools in Latvia and aimed to answer whether students working with the Thinking Approach demonstrate an increase in their inventive thinking skills. An inventive thinking test was employed as the research instrument. The results of the study suggest that students working with the TA demonstrate a significant increase in their inventive thinking skills in comparison with the control group ($t = 3.32$, $p = 0.001$). At the same time a number of limiting factors that appeared in the process of the study due to its naturalistic setting call for further research that could increase the reliability of the findings.

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1. Introduction

Teaching thinking skills is not a new idea. Numerous programmes have been developed for teaching thinking as a separate subject: Feuerstein's (1990) Instrumental Enrichment, de Bono's (Bono, 1973–1975) CORT lessons, Lipman's (2003) Philosophy for Children, Blagg's (1993) Somerset Thinking Skills Course and many others. Many researchers have dealt with integration of thinking skills training into subject matter instruction (Swartz, 2000; Wiske, 1998; Zohar & Nemet, 2002). At the same time, in this seeming abundance of research, there are practically no study reports on attempts to integrate thinking skills instruction with teaching of a foreign language—see, for example, Baumfield et al. (2004, p. 33) where the authors point out that studies in the fields of humanities and art are not represented. The given study undertakes to investigate the effects of incorporating thinking skills instruction into the programme of teaching a foreign language, namely English.

2. Teaching method

2.1. Theory of Inventive Problem Solving (TRIZ)

We define inventive thinking proficiency as an ability to effectively solve non-typical (creative) problems in various domains avoiding a large number of trials and errors. In the context of this study we adopt the understanding of a non-typical problem as the one for which no solution exists or is not known to the problem-solver. This understanding

* Corresponding author at: Tel.: +371 29486240.
E-mail address: Alexander.Sokol@thinking-approach.org (A. Sokol).

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comes from the Theory of Inventive Problem Solving (TRIZ)—a theory developed in the former Soviet Union by Genrich Altshuller and his colleagues in the second part of the last century (Altshuller & Shapiro, 1956). The theory started as a technique for invention, then grew into an algorithm for solving inventive problems (known as ARIZ) and finally developed into a scientific theory for invention, creativity and innovation. The problem Altshuller tried to solve by developing TRIZ can be summarised as follows: how can one build an appropriate solution making as few trials and errors as possible (or not making any whatsoever) and spending as little time as possible on selection of an appropriate idea? Altshuller's answer was the development of a theory based on three postulates: the postulate of objective laws (engineering systems evolve according to specific laws of system evolution—these laws can be discovered and used for problem solving), the postulate of contradictions (to move to the next stage of evolution of a system, it is necessary to resolve certain contradictions that appear as an obstacle and usually referred to as a problem) and the postulate of a specific situation (each inventive problem appears in a specific situation). Each postulate is manifested in TRIZ by a system of fundamental models and a set of specific instruments based on these models (Khomenko & Ashtiani, 2007). Lately, TRIZ has been recognised in an English-speaking world as a possible framework for the development of thinking skills (Moseley et al., 2004). A recent publication in Thinking Skills and Creativity where understanding of inventive thinking goes back to TRIZ (Barak & Mesika, 2007) is another evidence to an increasing acceptance of TRIZ.

2.2. General Theory of Powerful Thinking (OTSM)

It is necessary to note that TRIZ appeared as a science for engineering systems and may not be fully appropriate for educational research. Therefore, we propose OTSM (the Russian acronym for the General Theory of Powerful Thinking) as a more appropriate framework for teaching thinking. OTSM is one of the modern branches of Classical TRIZ that was proposed by the author of Classical TRIZ Genrich Altshuller (Altshuller & Filkovsky, 1975). OTSM started to appear in the middle of the1980s when more and more TRIZ experts began to apply TRIZ to non-engineering interdisciplinary problems. Regular success of those attempts led to the appearance of TRIZ in various educational programmes, even those not necessarily requiring the engineering background. As a result, Altshuller proposed to develop TRIZ further as a powerful instrument for solving complex interdisciplinary problems. In addition, in the middle of the 1980s many TRIZ experts started teaching their own and other children to solve problems. This process resulted in new requirements to TRIZ and enhanced the development of OTSM.

Three groups of axioms lie at the heart of OTSM: the main axiom of OTSM or the axiom of description, axioms for the description of the thinking process and axioms for the description of the world. Like in TRIZ, axioms are manifested in a system of models and specific tools for problem solving based on them. It is necessary to note that OTSM offers a domain independent system of models and tools and, thus, is more universally applicable in comparison with Classical TRIZ. To illustrate the application of OTSM based instruments we will describe one case study. Unfortunately, due to space limitations of this paper, a lot of details will have to be omitted.

OTSM based instruments should be considered as a kind of LEGO set. Depending on a specific problem situation an appropriate combination of these instruments is used. Below we provide a short description of instruments that were used for this specific case study.

Initially, the problem was posed by the customer – a French company Electricity De France (EDF) – in the following way: there is a pilot power plant that is efficient in terms of energy production, however the operational costs are too high. It is necessary to decrease manufacturing and exploitation costs.

The main technology of the power plant is transformation of biomass (small particles of wood 3–6 sm.) into biogas. During this process the power plant produces heat energy that is used for heating water and houses in winter. The biogas works as fuel for the engine that rotates the generator (instead of petrol). The generator produces electricity. The problem appears because the biogas has a lot of very small solid particles and vapour of tar. Tar and solid particles may destroy the engine. Therefore, it is necessary to clean biogas. The purification system of the power plant costs a lot and needs special maintenance. Moreover, additional supply materials are necessary for functioning of the purification system. This system makes the power plant too expensive. The customer would like to find a way to decrease the cost of the power plant equipment and exploitation.

In order to deal with the problem situation, a team of professionals was organised. The team comprised EDF experts in specific knowledge domains relevant to the new technology of energy production and OTSM-TRIZ experts as professional coaches in solving complex interdisciplinary problem situations. Following the OTSM based approach, the problem was treated in the following way. The team developed an OTSM Network of Problems (NoP) in order to obtain a big picture and better formalise the representation of the problem situation. The NoP is a kind of semantic network aimed at presenting knowledge about the problem situation according to certain formal rules. The initial NoP included almost 100 problems connected with each other, for example: (1) it is necessary to reduce the pollution of the power plant; (2) in order to eliminate the vapour of tar it is necessary to wash the biogas under a special shower, however this shower costs a lot and it leads to the appearance of a large number of various problems that have to be solved (3) in order to filter small solid particles, the biogas should be cooled down from 1000 °C to at least 150 °C, as existing filters cannot function under such a high temperature: (4) a special radiator is used for cooling the biogas, however this leads to the condensation of the vapour of tar; as a result, it sticks to the radiator and eventually blocks the flow of biogas, etc. More information about the problems can be found in Khomenko and De Guio (2007).

When the network of problems was developed, special rules were applied for analysing it and making a conclusion about a set of problems that underlie the problem situation. As we wrote above, in this specific case the problem network included more than one hundred problems connected to each other. The OTSM NoP helped us discover a set of problems that had to be addressed first: (1) A filter for small particles could be eliminated if it was possible to produce the biogas without thin powder of solid particles; this would dramatically decrease the cost of the power plant and its exploitation as well; (2) If the biogas could be produced without the vapour of tar, it would be possible to eliminate a special shower for the biogas in the same way as the filter; (3) How can one improve the transportation of the heat energy from the combustion chamber (a chamber where the heat energy is produced) to the gasification chamber (a chamber where the heat energy is used for the transformation of the biomass into the biogas)?

It is necessary to stress that some of these key problems were not evident before, however the professionals agreed with the OTSM coach that exactly these problems underlie the whole problem situation. For the selected problems, a set of contradictions was developed according to the rules of Classical TRIZ and especially its main instrument—ARIZ-85C. Contradiction is the next step in the analysis of a problem that brings the problem solver closer to understanding the root of a problem and, thus, making a step toward building a solution. One of the formulated contradictions looked as follows: in order to produce clean biogas, heat should be produced directly in the gasification chamber, however the production of heat requires oxygen. Unfortunately, oxygen is not good for the gasification process.

The formulated contradictions were organised into the OTSM Network of Contradiction (NoC). Then this NoC was analysed following certain rules. As a result, it was discovered that the whole problem situation is caused by ceramic balls 5–8 mm in diameter. These ceramic balls are used as a carrier for the heat energy transfer from the combustion chamber to the gasification chamber. Finally, the problem to be solved was formulated according to the postulate of a specific situation of Classical TRIZ, and the knowledge about this specific situation was obtained while developing the Network of Problems. In order to eliminate the roots of all the problems and avoid solving them all, we had to find a way for the power plant to work without these ceramic balls. Nobody had posed the key problem of the power plant this way before. As usually, this led to the appearance of many controversial opinions. An expert described a new set of problems to be faced. A new network of problems was created and a new iteration was done with the Network of Contradictions. These contradictions were resolved and a set of partial solutions was obtained.

A partial solution means that a solution has an interesting positive aspect, however it also has a negative aspect. For example, a filter was introduced to filter small solid particles. The filter works well but it requires cleaning. For this, it is necessary to stop the power plant and this is unacceptable. Another type of partial solutions comprises those that solve one group of problems, however some other problems remain unsolved. For example, if two filters for solid particles are introduced, then the power plant can work without interruption. While one filter is cleaned, the second works and vice versa. This helps to have the biogas clean. However, these filters cannot filter the vapour of tar. The problem of tar vapour still exists even if two filters for solid particles are introduced.

For these partial solutions another instrument of Classical TRIZ was applied—the mechanism of system convergence. This enabled us to obtain an appropriate solution. This solution passed preliminary evaluation and computer simulation. As a result, an additional positive result for the market was discovered. The proposed solution can find one important niche in the market that is presently not covered by any other known technology. The patent was filed with the priority from March 31, 2006 (European Patent 0602840).

Presently, the research is focusing on the development of a working prototype of the new power plant based on the new technology that allows to clean biogas before cooling it. This technology makes it possible to eliminate solid particles and tar vapour from hot biogas (900–1100 °C). The general idea of the solution is to produce a special kind of siphon and let hot biogas go through this siphon. When the biogas bubbles through the siphon, both tar and solid particles of wood crack into biogas. It means we do not only clean the biogas but also obtain an additional amount of it. Thus, a complex and expensive cleaning system is eliminated or sufficiently simplified. Additional biogas is produced and the manufacturing and exploitation costs of the power plant dramatically decrease.

As we can see, the OTSM problem solving process model reminds a water flow where problems move and change in time all the time. This flow permanently changes the set of appropriate problem networks. That is why this OTSM based instrument was named the Problem Flow Networks (PFN) Approach. The PFN approach integrates all known instruments of Classical TRIZ and OTSM into a unified system of problem solving instruments (Khomenko, De Guio, Lelait, Kaikov, 2007).

During the last 20 years, many OTSM related experimental educational programmes have been developed and tested (Khomenko & Sidorchuk, 2006; Nesterenko 1996–1999). As a result, a new branch of pedagogy appeared, namely OTSM-TRIZ pedagogy. This approach proposes an alternative way that could be integrated into traditional education. The next step would be construction of the educational process based on OTSM-TRIZ models for knowledge representation and operation. This meta knowledge could be obtained already at the pre-school stage and used afterwards for developing new knowledge, mostly by helping students discover and construct this new knowledge (Khomenko & Sidorchuk, 2006; Murashkovska, 1994–2001; Murashkovska & Valums, 1995; Nesterenko, 1995; Nesterenko & Golitsina, 2003; Sokol, 2005b; Sokol et al., 2002a).

In order to teach OTSM to various groups of learners, a non-linear approach has been developed. It means that topics and skills are learned and developed not one by one or in a cyclic manner as in the traditional educational approaches, but simultaneously in their interconnections. Students learn fundamental models for knowledge representation and operation as a system, where all the elements are linked to each other. Learning by doing is a second educational principle in addition to the non-linear educational approach. In OTSM lessons, learners deal not only with educational problems but also with real world problems.

2.3. The Thinking Approach to language teaching and learning

The given paper does not aim at giving a detailed description of the Thinking Approach (TA). In short, we can define the TA as a methodology for an integrated development of language and inventive thinking skills of learners in the framework of the OTSM-TRIZ pedagogy described above. The teacher's role is that of a coach who scaffolds learners in the process of building models in response to certain tasks (problems). The teacher does not provide any answer him/herself. The form of the models students are expected to develop can be pre-defined while the content comes from learners. For example, when working with grammar, learners are expected to build their grammar models on the basis of the Element – Name of Feature – Value of Feature (ENV) model of OTSM-TRIZ. It means that learners are expected to describe the difference between grammar structures on the basis of a set of parameters (names of features) and their values. For example, working with verbs in English as a foreign language, learners look for various parameters that can describe Action (Element), such as Time, Vision, Factuality, etc. The latter in their turn can have different values, e.g. such a parameter as time can have values past, pre-past, pre-present, etc.

The TA is based on the idea of a non-linear nature of learning and thus non-linear organisation of the learning/teaching process. Instead of a linear or cyclic curriculum model the TA offers a modular course based on a number of learning technologies. Technologies serve as bases for the four vectors of the TA: (1) language as the object of study, students learning to see language as a system (the Creative Grammar Technology); (2) communication as the object of study – language used as one of the means for solving problems (interpretation) and using language as one of the means for solving problems (the Text Technology); (3) problem solving as the object of study—students learning to see how various problem solving models work in a system (the Yes–No Technology); and (4) learning as the object of study—providing learners with possibilities for transfer of knowledge and skills to new contexts and educate a learner who wishes and is ready to accept full responsibility for his/her learning and knows how to make learning a success (the Self-Study and the Research Technologies).

The TA technologies listed above are interconnected and make a system. Work with one technology always includes elements of the other. For example, when working with the Text Technology, learners also do language tasks and are involved in the types of work we described in the Creative Grammar Technology, i.e. facing a problem, development of a model of a solution and a collection of examples beyond the scope of the model. Besides this, there are elements characteristic of all TA technologies. These are mainly tasks dealing with various elements of the Self-Study Technology, such as formulation of learning goals and evaluation of processes and products of work. This is easy to explain as the Self-Study Technology underlies the work with all other technologies. Possible relationships between various technologies are presented in Fig. 1 below.

As shown in Fig. 1, at each particular moment of time a focus in the TA classroom is either on language as such (language as the object of study), communication (understood as a purposeful exchange of various kinds of texts) or thinking (understood as the process of solving non-typical problems). As oval shapes cross, in a particular moment the focus can be on two objects (e.g. language and problem solving when learners are involved into developing a model of how a particular structure is used

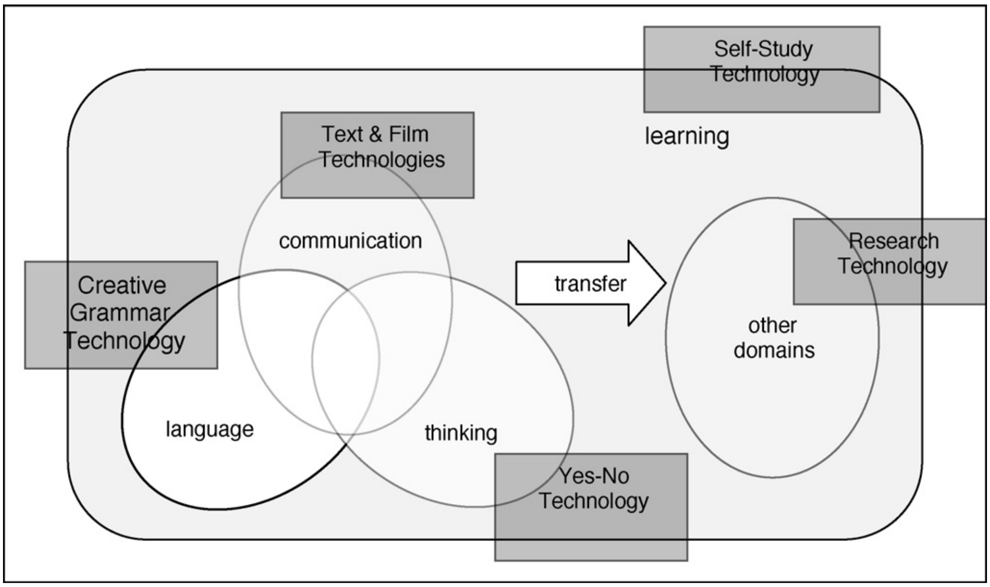

Fig. 1. Relationships between TA technologies.

in the Creative Grammar Technology) or even three of them (e.g. when learners are involved into doing a point of view task in Text Technology and construct the language of a new narrator). At the same time, the focus of a particular task may be transfer of either language or problem-solving skills (or both) to other fields (e.g. preparation of a presentation of project results in the Research Technology). And, finally, all of the above tasks are seen as elements of learning to learn and thus are a part of the Self Study Technology[1].

3. Context of the study

3.1. Background and methodology

The study on the efficacy of the use of teaching inventive thinking in a foreign language classroom was started in 1999 by one of the authors working as a teacher of English in a secondary school in Latvia. The main purpose of the study was to assist in the development of an approach to teaching inventive thinking within a foreign language instruction. As the teacher was the primary instrument of data collection and the purpose was mainly discovery and exploration, the study was qualitative in nature (Johnson & Onwuegbuzie, 2004, p. 18). This is also supported by the fact that the main tools used by the researcher were observation and content analysis of students' works. By 2003 the main features of the teaching methods became clear and it was decided to extend the methods used in the study. The authors agree with the opinion that quantitative methods can be helpful in a qualitative study (Westerman, 2006; Yanchar, 2006), therefore an experimental test and a questionnaire collecting quantitative data were added to the repertoire of tools in 2003. From that year on, we also started collecting data on control groups. However, our research still remains enriching rather than theory building (Stiles, 2006, p. 258). Since 2003 up to date, we have been using a large repertoire of both qualitative and quantitative tools to both develop the teaching method and study its efficacy. Thus, we believe that our research can be defined as the one of a mixed methods design (Johnson & Onwuegbuzie, 2004, p. 17).

In this particular paper we would like to report on the part of the research conducted during the academic year 2004–2005. In that period our study had a more quantitative focus as, after several years of dealing with primarily qualitative data, the researchers felt the need to compliment it with quantitative data, especially since this was the time when the second research site appeared (see Section 3.2 below). Although there were many issues interfering with the quasi-experimental design we adopted (these will be described in detail further on in this paper), the data collected during that year helped us a lot in understanding the process of teaching inventive thinking within a foreign language instruction. Moreover, one could treat the data we obtained as an example of what Yanchar refers to as an alternative measurement, as a student's questionnaire or test score has always been "an interpretive account of his or her action and experience at a given time rather than an invariant index of a static ability" (Yanchar, 2006, p. 222). We find this point very important from the ethical point of view as well. From the very beginning, students participating in the intervention are told that the programme is aimed to help them develop inventive thinking skills along with language skills and the tests administered in the course of study should be primarily seen as tools to help them understand if and to what extent they make progress. The results of the tests are always discussed with learners and feedback is provided.

One of the aims of the given study is to find out to what extent the use of the Thinking Approach to language teaching and learning (Sokol, 2002–2003; Sokol, 2005a, 2007; Sokol, Galpern, Lasevich, & Dobrovolska, 2002b) contributes to the development of the students' language and inventive thinking skills. As the study has been going on since 2003, it may be considered to belong to the group of longitudinal ones and as Wilson (2000, p. 37) points out "longitudinal studies of the efficacy of teaching thinking are significantly absent".

In the present paper, however, we will focus only on the question of inventive thinking skills and consider the data collected during the academic year of 2004–2005. Our research question can be formulated as follows: do students working with the TA demonstrate an increase in their inventive thinking skills? Elsewhere we have also considered the question of students' beliefs on their progress in thinking during this period (Sokol et al., submitted for publication). At present, we are also preparing a publication summarising the qualitative data collected in the study to provide a broader perspective on the subject of the investigation.

3.2. Setting

The method used in the study is a comparison between an experimental group and a control group. The study is conducted in two secondary schools in Latvia. The schools were chosen as at present these are the only two schools in the country where groups of upper-secondary school students study English with the Thinking Approach programme. In both schools, students start working with the TA in form 10, thus having had certain experience with more traditional programmes before (see below).

The TA was first introduced in School No. 1 in 2003 by the head English teacher after finishing a TA training conducted by one of the authors. Starting from September 2003, the first two groups of 10 formers (15–16 years old) started working with

[1] Unfortunately, due to space limits of this paper we cannot provide more detailed information about the teaching method. An interested reader is advised to refer to the Thinking Approach Project website for additional information on the approach (www.thinking-approach.org).

the TA programme (the same teacher, 72 h of training completed by the beginning of intervention). Since then, continuous support for the teacher has been provided both electronically and in the course of regular monthly 1-day workshops for TA teachers.

Elements of the TA started being introduced by one of the authors in School No. 2 in 1997 and students began working with the TA programme starting from year 2000. We distinguish between the time when the TA became the basis of the English curriculum (a full programme) and the time when it was used as an addition to a more traditional curriculum (elements).

3.3. Participants

3.3.1. School No. 1

The first school is a prestigious Russian medium school located in the second largest town of the country. Students come from different socio-economic backgrounds ranging from low to high. In terms of academic achievement, students' performance in upper-secondary level is above average in the country. There is one form for each year at the upper-secondary level. All students from forms 10 and 11 (16–18 years old) took part in the study ($n = 54$). Practically, all students have studied English as the first foreign language[2] since the first form (7 years old)[3].

Both forms have English lessons five times a week. They are divided into two groups ($n = 14$ and $n = 14$ in form 10 and $n = 14$ and $n = 12$ in form 11). Groups are not homogeneous in terms of language proficiency but students' levels are comparable (S.D. = 6.8 and 8.6; S.D. = 8.0 and 6.4 at the maximum number of points equalling 75)[4].

The groups in form 11 started working with the TA in September 2003, thus they had already done a year's work with the programme by the time when the data for the given report started to be collected. The groups from form 10 started working with the programme in September 2004.

3.3.2. School No. 2

The second school is a school with a core curriculum in human sciences located in the capital city. The school is one of the three schools in the country where German is studied as the first foreign language, thus students come to school from different parts of the city. Social economic background of students is different and ranges from low to high. In terms of academic achievement the school is higher than average but considerably lower than School 1, especially in sciences.

There is one parallel of forms 11 and students are divided into two groups. One group ($n = 12$) started working with the TA programme in September 2003. The second group ($n = 15$) taught by another teacher works with the so-called traditional programme and is used as a control group in the study. A limiting factor is that the groups have a different number of contact hours per week, 5 h in the TA group and 3 h in the control group[5]. There are two parallel forms 10 in the school. They are not divided into groups when learning English. Students of one of the forms ($n = 18$) learn English with the TA programme (started in September 2004) and students of the other form work ($n = 18$) with the so-called traditional programme. The same limiting factor exists in terms of the number of contact hours per week—5 in TA groups and 3 in comparison groups.

Students in School 2 start learning English as a second foreign language[6] in form 8. However, a number of students started learning English earlier, either in other schools (if they joined School No. 2 at a later stage) or attending a language school or taking private lessons. This fact probably explains very diverse language levels in the groups. (S.D. = 15.9 in form 10, and S.D. = 14.0 in form 11 at the maximum number of points equalling 75).

4. Data collection tools

4.1. Inventive thinking test

4.1.1. Development and validation of thinking tests

To the best of our knowledge there are no specific assessment tools developed to evaluate students' achievements in terms of inventive thinking skills as conceptualised in (Khomenko & Sokol, 2000). At the same time, we have come to the conclusion that the tools used for assessment of creativity, critical thinking or intelligence are not applicable in our context as their primary concern is usually with a different set of skills (Sokol, 2007). Due to this reason a decision was made to develop a new test for measuring students' inventive thinking skills.

The system of inventive thinking skills as described in Khomenko and Sokol (2000) was taken as a starting point for the new test. First, the areas of inventive thinking to be covered in the tests were defined. These are reflected as inventive

[2] As the study was conducted in the Russian medium school, English is a second foreign language per se. The first foreign language students are exposed to is Latvian which is the official state language and thus can be called a second rather than a foreign language.

[3] A few students joined the school at a later stage and thus may have started learning English later than the first form.

[4] Data come from the language progress test administered in September 2004.

[5] We are well aware that the difference in contact hours may have seriously affected the results of our findings. However, due to the naturalistic setting of our research, it was impossible to change this parameter. Therefore, our main conclusions in the given paper will be based on observing progress within groups. Comparison of results between groups will be presented, however it should be treated with due caution.

[6] As School No. 2 is also a Russian medium school, English is in fact a third foreign language—see footnote number 2.

Table 1
Inventive thinking skills in September 2004 test

Assessment parameter	Inventive thinking skills
Number of features mentioned	Describe elements by defining parameters and their values: describe parameters and their values as elements that have their own parameters and their values. describe immaterial elements by means of lists of parameters and their values.
Variety of features mentioned	Describe elements as systems that have their sub-systems and are themselves parts of different super-systems: describe an element as a collection of other elements. describe an element as a part of larger set of elements.
Ability to take account of a specific context of one's school	Describe elements as systems that have their sub-systems and are themselves parts of different super-systems describe an element as a part of larger set of elements. describe an element as a part of the hierarchy of different other elements.
Motivation of choice (explanation why particular features/groups of features are important)	Describe elements by defining parameters and their values: define the function of an element as a change of one value under a specific parameter. Describe situations recognizing and distinguishing the influence of objective and subjective factors distinguish between objective and subjective factors when building models of elements define those objective factors that determine the peculiarities of a given situation establish connections between the objective factors determining peculiarities of a given situation and the subjective factors that call for its change
Way of presenting ideas	Describe elements by defining parameters and their values: describe parameters and their values as elements that have their own parameters and their values. describe immaterial elements by means of lists of parameters and their values. define the function of an element as a change of one value under a specific parameter. Describe elements as systems that have their sub-systems and are themselves parts of different super-systems describe an element as a collection of other elements. describe an element as a part of larger set of elements. describe an element as a part of the hierarchy of different other elements.

thinking skills listed for each of the tests in Tables 1 and 2 below. Then, assessment parameters under which each of the skills can be demonstrated were defined. After that, sample tests were developed. These tests were discussed by two groups of experts. The first group comprised experts in OTSM-TRIZ while the second one included experts in foreign language teaching. The tests were amended following the experts' advice and then given to several learners not taking part in the study. After that, further modifications were made and final versions of the tests were developed. Examples of both tests are given in Appendix A.

The Delphi Report (Facione, 1990) proposes the following criteria for evaluating an assessment strategy or instrument for purposes of critical thinking: content validity, construct validity, reliability and fairness. The same criteria were used when validating inventive thinking tasks for the purposes of the present research.

4.1.1.1. Content validity. Two tests, one in September 2004 and one in May 2005, were administered to students. The tests were aimed to assess the inventive thinking skills presented in Tables 1 and 2 below and their corresponding sub-skills[7] (see Khomenko and Sokol (2000) and Sokol (2007) for a full list of inventive thinking skills). The tables below demonstrate the place of skills in both tests.

Tables 1 and 2 demonstrate that in addition to a detailed conceptualisation of inventive thinking skills presented in Khomenko and Sokol (2000) and Sokol (2007), we had a clear understanding of those inventive thinking skills targeted by the assessment strategy we had chosen. Another factor involved in content validity, however, is ensuring that answers are not the result of mere memorization and rote learning. As none of the groups participating in the study was exposed to the given types of task in the course of learning, nor the themes of school improvement or further learning (the themes of the tests offered to learners—see Appendix A for details) were covered in the programmes, we believe that there are no reasons to expect the effect of memorization or rote learning on test results.

Facione (1990) also mentions dispositions as an important factor of a critical thinking assessment. We consider that dispositions are also important for the assessment of inventive thinking skills. At the same time we agree with Ennis (1997a) that if one explicitly tests for dispositions, "people can often feign the appearance of a disposition without really having it." This is the reason for not informing students about testing for dispositions in any of the thinking tasks we offered to them.

[7] Here and elsewhere in the text, we do not use the word "ability" in our definitions as we speak of both skills and dispositions and therefore a formulation that starts with a verb appears to be more relevant in our context.

Table 2
Inventive thinking skills in May 2005 test

Assessment parameter	Inventive thinking skills
Quality of classification	Describe elements by defining parameters and their values; describe parameters and their values as elements that have their own parameters and their values. Describe immaterial elements by means of lists of parameters and their values. Define the function of an element as a change of one value under a specific parameter
Number and variety of problems	Describe elements by defining parameters and their values; describe parameters and their values as elements that have their own parameters and their values. Describe immaterial elements by means of lists of parameters and their values. Describe elements as systems that have their sub-systems and are themselves parts of different super-systems describe an element as a collection of other elements. Describe an element as a part of larger set of elements. Transform the description of a problem situation in view of emerging contradictions combine the opposites. Define undesirable consequences of positive necessary results and positive consequences of negative undesirable results. Describe the underlying cause of a problem as a contradiction
Quality of formulations	Transform the description of a problem situation in view of emerging contradictions combine the opposites. Define undesirable consequences of positive necessary results and positive consequences of negative undesirable results. Describe the underlying cause of a problem as a contradiction. See a contradiction as an obstacle on the way from the resources of initial situation to the ideal final solution. Intensify contradiction in order to reduce the space of possible solutions
Motivation of choice	Describe situations recognizing and distinguishing the influence of objective and subjective factors distinguish between objective and subjective factors when building models of elements. Define those objective factors that determine the peculiarities of a given situation. Establish connections between the objective factors determining peculiarities of a given situation and the subjective factors that call for its change
Presentation of ideas	Describe elements by defining parameters and their values; describe parameters and their values as elements that have their own parameters and their values. Describe immaterial elements by means of lists of parameters and their values. Define the function of an element as a change of one value under a specific parameter. Describe elements as systems that have their sub-systems and are themselves parts of different super-systems describe an element as a collection of other elements. Describe an element as a part of larger set of elements. Describe an element as a part of the hierarchy of different other elements

4.1.1.2. Construct validity. According to Loevinger (1957) quoted in Cohen, Manion, and Morrison (2003) construct validity is the queen of the types of validity. Our analysis of the September 2004 and May 2005 inventive thinking test papers conducted in summer 2005 demonstrates that students who applied the inventive thinking skills listed in Tables 1 and 2 scored higher in the tests and generally produced much better answers than students who merely answered on the basis of their previous experience or subjective beliefs (see Table 3 below for the results of correlation between the scores on separate assessment parameters and total scores). As relationships between scores for certain parts of the test and total scores appear significant in the absolute majority of cases ($r > 0.7$) for both experimental and control groups, we may assume that a high achievement in each part of the test is a result of inventive thinking skills developed while a poor achievement is a result of weak inventive thinking skills.

4.1.1.3. Reliability. One of the important indicators of reliability is consistency in evaluation conducted by different markers. Unfortunately, both tests were marked by one of the authors only and a further research is necessary to check whether such consistency exists.

One may also assume that writing a thinking test in a foreign language could affect the reliability of our findings. While such a possibility theoretically exists, we found no significant correlation between language and thinking tests scores ($r = 0.46$ in September 2004 Test and $r = 0.42$ in May 2005 Test), nor students' own assessments of their progress in language and thinking seriously correlated ($r = 0.51$).

4.1.1.4. Fairness. Both thinking tasks were constructed to ensure that all students are in a similar situation in terms of factual knowledge required for performing the task and no groups of students are in a disadvantageous position. In the September

Table 3
Correlation between total scores on the test and scores on separate assessment parameters

September 2004 Test. All groups ($N = 103$)		May 2005 Test. All groups ($N = 103$)	
Evaluation parameters	Total score	Evaluation parameters	Total score
Number of features	$r = 0.58$	Classification	$r = 0.80$
Variety of features	$r = 0.67$	Number and variety of problems	$r = 0.92$
Context	$r = 0.80$	Formulation of problems	$r = 0.84$
Motivation	$r = 0.82$	Motivation	$r = 0.90$
Presentation	$r = 0.77$	Presentation	$r = 0.87$

Table 4
General summary of t-test results for experimental and control groups

General summary
t-Test: Experimental vs. Comparison Groups. Two-Sample Assuming Unequal Variances. ($t = 3.32$, $p = 0.001$, $N = 100$)
TA Groups: summary
t-Test: Paired Two Sample for Means ($t = 1.73$, $p = 0.08$, $N = 73$)
Non-TA Groups: summary
t-Test: Paired Two Sample for Means ($t = -3.13$, $p = 0.004$, $N = 27$)

Table 5
The numbers of students demonstrating inventive thinking dispositions during September 2004 and May 2005 inventive thinking tests

Group		Students demonstrating dispositions—September-04		Students demonstrating dispositions—May-05
School 1. Form 10.	2	(7.7%)	13	(48.1%)
School 1. Form 11.	7	(26.9%)	12	(46.2%)
School 2. Form 10.	0	(0%)	3	(23.1%)
School 2. Form 11.	2	(20%)	6	(60%)
Control. Form 10.	0	(0%)	0	(0%)
Control. Form 11.	0	(0%)	0	(0%)

2004 Test we assume that all students have similar knowledge of their own school[8] and in the May 2005 Test we expect students to have comparable knowledge about possibilities for further education.

4.1.2. Administration and marking of the tests

Both inventive thinking tests were administered simultaneously to all the groups in September 2004 (during the first week of the school year) and May 2005 (2 weeks before the end of the school year). Students were not informed about the test format before the pre-test and were told that the test format would be approximately the same before the post-test. The time given for both tests was 40 min. Students were not given any clarification apart from language assistance in understanding the wording of the actual task and the evaluation guidelines. Students were allowed to ask language questions or use a dictionary.

The tests were marked following the marking scale presented in Appendix A.

5. Findings

5.1. Summary of results

Test results were analysed statistically employing a *t*-test for paired two samples for evaluation of changes within separate groups of students and TA and comparison populations as a whole, and a *t*-test for two independent samples for comparison of control and experimental groups.

Table 4 presents a general summary of *t*-test results for experimental and comparison groups.

In addition to the comparison of scores, the correlation analysis was conducted for comparing the relationship between scores in different rubrics of the test and the total score. The results of the analysis are presented in Table 3.

We also analysed the test papers on the subject of inventive thinking dispositions. We agree with Perkins, Jay, and Tishman (1993, p. 6) who define dispositions as ‘tendencies toward patterns of intellectual activity that condition and guide cognitive behaviour specifically.’ We also agree with Ennis (1997a) that dispositions are definitely not a part of thinking skills. Inventive thinking dispositions are connected with associated abilities or skills, however manifestation of a disposition does not necessarily mean being skilful in application of this or that model. At the same time, dispositions are important in order to be an effective inventive thinker, therefore we were interested whether students subjected to experimental treatment demonstrate an increase in inventive thinking dispositions. In the context of the given research we consider that an inventive thinking disposition was manifested if a student explicitly employed one or several OTSM-TRIZ models when performing the task. Table 5 demonstrates numbers of students disposed to think inventively in each of the groups.

5.2. Interpretation of results

Although our results demonstrate that experimental groups performed much better on the inventive thinking tests ($t = 3.32$, $p = 0.001$), we believe a close look at the results is needed before any conclusion could be made.

[8] Several students may be in a disadvantageous position here in case they have just joined the school and are not aware of the context, however as only two of our subjects fall into this group we assume that it could not make a significant impact on test results.

Due to naturalistic conditions of this research, there is a strong limiting factor in the design of the study, i.e. a different number of contact hours per week in experimental and control groups. Although we believe that this factor did not have any significant influence on our findings, a further research with more similar conditions for experimental and control groups is needed to prove this assumption. A number of other factors could also have influenced the outcome of the experiment. One of them is a different level in language competence between experimental and control groups. Although our data demonstrates no significant correlation between language and thinking test results ($r = 0.46$ for the September test and $r = 0.42$ for the May test)[9], we agree that further investigations are necessary to be more confident about it. Another factor is students' attitude to tests as such. It is probable that experimental groups took the tests more seriously than control groups which could also affect the results. Notwithstanding all the above, we would like to note that the difference in performance between the experimental and control groups is quite impressive, therefore we believe that our findings deserve some consideration.

We also believe that due to the nature of our research, it is important to consider the changes within experimental groups as such. Comparing the four experimental groups, we see that both groups of 10 formers demonstrated significant changes in thinking skills ($t = 3.69$, $p = 0.001$ and $t = 3.59$, $p = 0.004$) while no significant changes have been observed among groups of 11 formers[10]. Moreover, one group of 11 formers demonstrated a significantly worse performance on the May test. What are possible factors that could account for the above differences?

One possible explanation of the difference between performance in Form 10 and Form 11 groups may lie in the fact that the former started working with the TA programme in September 2004, i.e. at the same time when the pre-test was conducted, while the latter had already worked with the programme for one academic year in School 1 and half a year in School 2. We may suppose that progress in thinking skills is more dramatic during the first year of learning.

We believe that a special consideration should be given to changes in the performance of the group of 11 formers from School 1. What are possible explanations of the fact that the group which performed significantly better on the pre-test ($M = 5.29$ against $M = 3.06$, 3.12 and 3.73 in the rest of the groups) not only demonstrated a decrease in results but was also outperformed by all other experimental groups?

In our opinion, a number of factors could account for this change. Most probably, the situation we observed was a result of an interaction of various factors where each separate factor played a certain role in the overall system effect. Let us consider some possible factors more specifically.

Factor 1: Although the September and May tests are comparable in terms of the way they were assessed, there are a number of differences between them considering the groups of inventive thinking skills required for successful performance of the task. The September test deals mainly with skills from Groups 2 and 3 (Khomenko & Sokol, 2000) while the May test also requires skills from Group 4, namely those connected with the use of contradiction models from OTSM-TRIZ. It is important to note that OTSM-TRIZ models associated with the above groups of skills, and thus necessary for successful performance of a task, are different. If the September test mainly requires basic skills in the application of the Element – Name of Feature – Value of Feature (ENV) model, the May test asks not only for more advanced skills associated with the ENV model, but also presupposes the ability to describe situations using the Multi-screen model (more advanced application of the ENV Model) (Khomenko, 2004) and the ability to operate with contradictions. It may be assumed that basic skills associated with the use of the ENV model are also developed in the course of learning many exact subjects and students who perform better in those disciplines may also perform better on tasks associated with these skills. As Form 11 students from School 1 are better at exact subjects than the rest of students from experimental groups, it may account for a better performance in the September test. This factor may also account for the fact that students from control groups performed significantly worse during the May tests ($t = -3{,}14$, $p = 0.004$, $n = 27$).

Factor 2: It is also necessary to note that by September 2004 Form 11 from School 1 had had the longest exposure to the TA programme which could also affect their performance in the September test.

Factor 3: The analysis of the May papers shows that many Form 11 students from School 1 automatically took the task as being fully isomorphous to the task offered in the September test demonstrating quite an impressive use of the ENV model but failing to recognise the necessity to employ the model of contradiction. This factor may point to both the lack of a disposition associated with the use of the contradiction model and/or a mere inattentiveness when dealing with a task.

Factor 4: One of the differences of the TA programme is a non-linear planning of a syllabus (Sokol, 2007). It means that students may deal with similar themes at different times and at different depth. When analysing the results of the tests, the teacher from School 1 admitted that they hardly dealt with contradictions explicitly during the academic year 2004–2005.

Factor 5: Teacher effect. It has been widely noted that the role of the teacher is quite important in the implementation of thinking programmes (Burden & Nichols, 2000, p. 298; Perkins, 2003, p. 2; Wiske, 1998, p. 24) and others. As the contradictions models may be considered more difficult to teach in comparison with the ENV model and the teacher in School 1 has less expertise in OTSM-TRIZ than the teacher in School 2, this could also account for the differences in acquisition of skills and development of dispositions.

[9] It is interesting that this result is very close to the one we obtained in correlation between students' self-assessment of their progress in language and inventive thinking ($r = 0.51$).

[10] The group of 11 formers from School 2 demonstrated an increase significant at alpha = 0.1 ($t = 1.86$, $p = 0.099$).

Let us stress one again that we consider that no single factor should be considered central in the explanation of the differences in results. We believe in the systemic effect of various variables, therefore all conclusions, including those we tentatively offer here, should be taken with caution. There is still very little research on the effects of teaching OTSM-TRIZ in subject-matter courses and one should be careful not to jump to conclusions. On the other hand, we believe that our data could be valuable for further research on the integration of OTSM-TRIZ in educational curricula. These data can also be interested in the context of infusion thinking programmes (Baumfield et al., 2004, p. 30; Ennis, 1997b, p. 1; Swartz, 2000) as to the best of our knowledge the TA is one of the few thinking intervention in the area of foreign language education.

When turning to inventive thinking dispositions, it is necessary to note that all TA groups demonstrated an increase in the number of students disposed to think inventively. The total increase with the experimental groups amounted to 35% ($n = 73$). Although not all of these students were equally good in terms of inventive thinking skills and manifestation of a disposition does not necessarily mean that it was the best possible disposition in a particular situation (see above the discussion of possible reasons for weak performance of Form 11 students from School 1 in the May 2005 test), we consider that manifestation of a disposition when working on a task different from the ones students have practised during the school year allows us to assume a possibility of a far transfer (Perkins & Salomon, 1992, p. 2) of inventive thinking dispositions. Furthermore, we would like to note that no student from the control groups has demonstrated an inventive thinking disposition when working on a test task. Admitting that various factors could account for the given situation, two conclusions could still be made. First, inventive thinking dispositions do not develop by themselves. And, second, the TA programme could be considered a tool for the development of inventive thinking dispositions in the context of foreign language education.

6. Conclusions

The aim of the present study is to find out to what extent the use of the Thinking Approach to language teaching contributes to the development of students' language and inventive thinking skills. The given paper presents the results we have obtained in inventive thinking skills by summer 2005. Our purpose was to find out whether students working with the TA programme demonstrate an increase in their inventive thinking skills.

Students working with the TA programme demonstrated a significant gain in thinking skills when comparing their performances on a pre and post-tests to the control group. We also found out that the TA groups of 10 formers performed better on thinking tests (both of them demonstrated a significant increase) in comparison with form 11 groups. The most surprising finding about results of the thinking test was a significantly worse performance of a group of 11 formers from school 1 which are assumingly the strongest group in terms of thinking skills. Possible reasons for such a situation were discussed in part of this article. We believe that further research is necessary to either validate or reject our assumptions. We also plan to introduce more qualitative research tools to obtain richer data.

Appendix A

A.1. Thinking Test—September 2004

A.1.1. Written task (students are allowed to use dictionaries).

Your school administration is working on improving your school. A part of work is to collect students' ideas on what needs to be done to make your school better. You are asked to offer your ideas by listing features of the school as you want to see it and providing your comments on them.

(a) Make a list of features of your school as you want to see it.
(b) Explain why these features are important.

A.1.2. Evaluation

The following criteria will be used in assessing your work:

- number of features you mention;
- variety of features you mention;
- ability to take account of a specific context of your school;
- explanation why particular features/groups of features are important;
- way of presenting your ideas.

Marking scale for September 2004 test is shown in Table A.1.

Table A.1
Marking scale for September 2004 test

Parameter	Evaluation
Number of features mentioned	2 points—20 features The mark is calculated assuming that 20 features is 100%. For examples, if a student has 15 features it will make a mark of 1.5
Variety of features mentioned	2 points—8 different parameters/names of features are considered The mark is calculated assuming that 8 parameters is 100%. For examples, if a student has 4 parameters it will make a mark of 1
Ability to take account of a specific context of one's school	2 points—all features mentioned take account of a specific context of your school The mark is calculated assuming that 20 features is 100%. For example, if a student has mentioned 15 features and 10 of them are relevant to a specific school context, his/her mark is 1
Motivation of choice (explanation why particular features/groups of features are important)	2 points—the role of all parameters/names of features in provision of a function is formulated[a]. The mark is calculated assuming that the role of 8 parameters makes 100%. For example, if a student mentions 4 parameters and formulates the role of 2 of them, his/her mark is 0.5. The final mark is multiplied by a quotient (from 0 to 1) demonstrating the quality of function formulation[b]. Thus, if the mark is 0.5 and the quality quotient equals 0.7 the final mark will be 0.35
Way of presenting ideas	2 points—the work implies a specific target reader who is addressed directly (max. 0.5 points) layout is clear and well-thought over (max. 0.5 points) formulations are understandable (max. 0.5 point) structure of work (max. 0.5 points)

[a] Parameters can be either evaluation or control parameters. For example, if one of the aims of schools is to attract more learners, such a parameter as 'location' will be a control parameter (different values of this parameter will affect the values of evaluation parameters, e.g. potential learners will also depend on location). Potential learners will be one of the evaluation parameters (e.g. potential learners will be many if location is good, rating is high, etc.).

[b] Function formulation: verb – object/element; verb—name of feature of element that must be changed – value of feature (old) and value of feature (new).

A.2. Thinking Test—May 2005

A.2.1. Written task (students are allowed to use dictionaries)

You are taking part in the international project 'Success Generation'. At the first stage of the project, partners from different countries collect problems they face in different fields. Each member of your group is asked to come up with a list of problems one has to solve when choosing the place for further studies.

Write your part of the project work which will include the following:

1. Classification of problems one faces when choosing a place for further studies.
2. Clear formulation of problems one has to solve when choosing the place for further studies.
3. Explanation why exactly these problems have been chosen by you.

Table A.2
Marking scale for May 2005 test

Parameter	Evaluation
Quality of classification	Max. points—2; based on parameters—max. 0.5; points groups do not overlap—max. 0.5; points at least three groups and at least 2 problems in each—max. 0.5 points; classification helps present the problems (classification and problems go together)—max. 0.5 points
Number and variety of problems	Max. points—2; same problems formulated in different words must be crossed out; all problems counted my be relevant to the task (i.e. problems related to future studies); two points are given if the number of problems is 8 and all the problems are different (the problem is considered to be different if at least one conflicting parameter involved in the problem is different). If it is not clear what kind of problem is meant from the formulation it is NOT counted; the mark is calculated taking account of the number of different problems formulated by the student as related to the max number of problems and multiplied by the max mark, for example 4 problems will give a mark of $4/8 \times 2 = 1$
Quality of formulations	Max. points—2; conflicting parameters and their interactions identified (full contradiction formulated)—2 points; aim and obstacle identified (contradiction of problem solver formulated)—1 point; aim and barriers are mentioned but not clearly identified—0.5 points; the eventual mark is calculated taking account the percentage of problems with this or that formulation
Motivation of choice	Max. points—2; no motivation is given or motivation is purely subjective (I think)—0 points; motivation is based on some objective factors but they are not presented systematically—1 point (sometimes can be present as a part of problem formulation); motivation is based on objective factors which are presented systematically—2 points; the final mark is adjusted taking account of the number of problems formulated (8 is 100%)
Presentation of ideas	Max. points—2; target reader is clear and addressed directly—0.5 points; layout of the work is clear and helps to reach its purposes—max. 0.5 points; formulations are clear and easy to follow—max. 0.5 points; structure of the work helps to present it—max 0.5 points

A.2.2. Evaluation

The following criteria will be used in assessing your work:

- Quality of classification.
- Number of problems you formulate.
- Variety of problems.
- Quality of problem formulations (in a well-formulated problem it must be clear where exactly the problem lies).

Marking scale for May 2005 test is shown in Table A.2.

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