Introduction

In modern society new learning methods, especially in engineering education, are mainly required to transfer huge amount of knowledge within a limited time in the condition of continuous creative process. This is clearly contradictory requirements. And one of the most topical issues in modern education is the resolution of such contradiction.

In this contradiction three main parameters can be extracted:

- time spent on training (T);
- amount of acquired knowledge (Q);
- elicited student's creative potential (C).

Let’s consider the defined contradiction in term of ideal final result. Ideal final result (IFR) is a model of the unimprovable / idealized solution. In the specific situation IFR is usually unachievable. It is a landmark during the process of solving (Altshuller, 1984).

According to the contradiction IFR will be achieved if a student receives an unlimited amount of knowledge spending no time and elicited student's creative potential is infinite, i.e. when $T \to 0$, $Q \to \infty$ and $C \to \infty$.

Under real conditions IFR is unreachable, so conventionally we shall assume that to achieve IFR the following requirement should be satisfied:

$$T = \min \cap \quad Q = \max \cap \quad C = \max. \qquad (1)$$

Under the use of existing and common learning methods, requirement (1) is not satisfied. Let’s consider the most popular of existing approaches to educational process (figures 1,2).

Considering different approaches to education (Berdonosov, Zhivotova, 2014), we can identify some trends in these approaches.

Learner-focused teaching methods have greater efficiency. In the context of modern labor market requirements, competency approach replaced the traditional approach to education. However, development of methods and technologies that allow resolving the fundamental contradiction in education is demanded.

Let’s analyze the considered methods and approaches in education in respect that it is impossible to reach IFR applying them (figure 3).

There are three ways to improve educational methods:

- Improvement of multi-level differentiation approach to maximize the amount of acquired knowledge;
- Improvement of project-based learning approach to maximize eliciting students' creative potential;
- Improvement of case-study method in order to minimize the time spent on studying.

We offer using the TRIZ evolutionary approach (Berdonosov, 2006), which implements all three ways mentioned above in some extent. TRIZ evolutionary approach allows minimizing time spent for learning and increasing efficiency of knowledge acquisition.

Main Principles of the TRIZ Evolutionary Approach

Methodology of learning based on the TRIZ evolutionary approach assumes that training is conducted using TRIZ evolutionary maps that represent the systematized knowledge of the specific knowledge field.

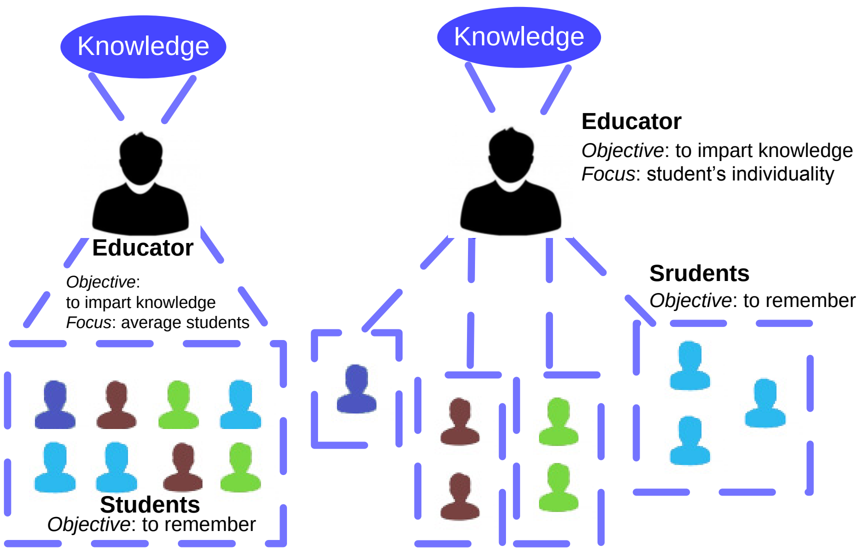

Figure 1: Left - Traditional learning technology (T=const, Q=const, C=min);
Right - Concept of multi-level differentiation (T = min, Q = max, C ≠ max)

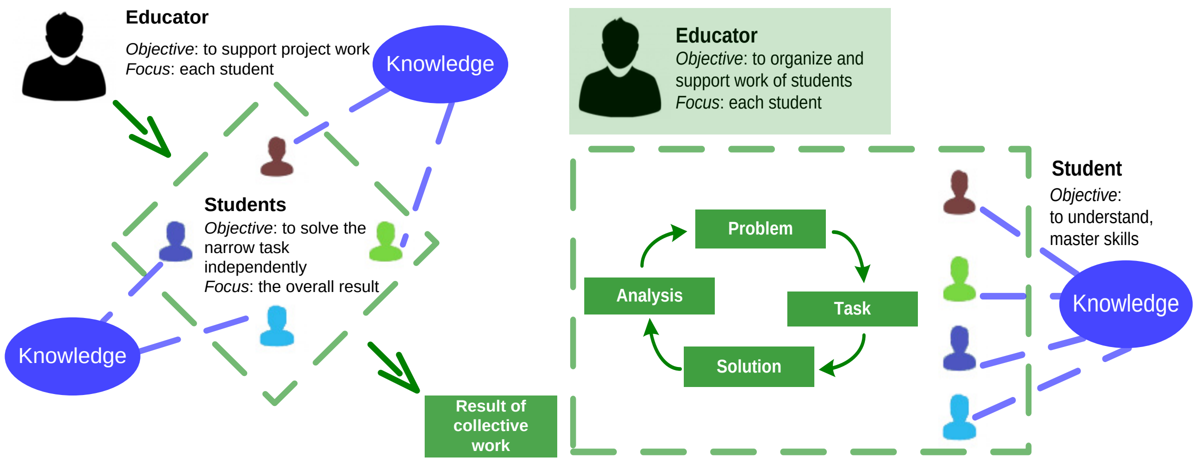

Figure 2: Left - Project-based learning approach (T = min, Q ≠ max, C = max);
Right - Case-study method (T ≠ min, Q = max, C = max)

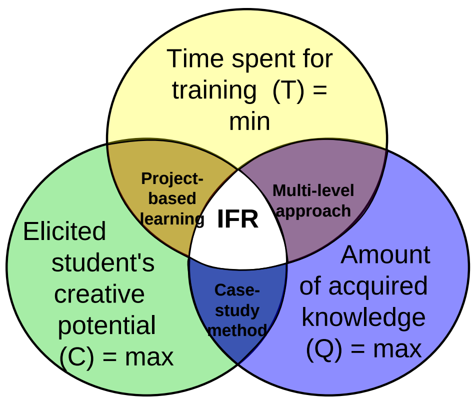

Figure 3: Impossibility to reach IFR applying existing learning methods

The TRIZ evolutionary approach is defined by the following conceptual statements.

Firstly, evolution of a system starts from a base element (a system). Such an element can be a pioneer or the significant development stage (fragment) of a pioneer element. The example of such a base element for a wheel is a tree cut.

Secondly, contradictions between growing requirements of society to a system and limited capacity of this system are considered as moving forces of evolution. For example, an owner of the first wheel had wanted to increase its maneuverability, increasing a wheel diameter, but in this case the wheel would have been heavier.

Thirdly, a system moves to the next evolutionary stage when contradiction(s) are eliminated. Besides, TRIZ tools that help eliminate contradictions can be always identified. In the case of a wheel inventive principles of “segmentation” and “taking out” were used to eliminate contradictions. Wooden wheel was assembled with the following parts: a rim, spokes and a central part. This allowed significantly increasing the wheel diameter while maintaining the wheel weight.

Fourthly, all stages of the base element (system) evolution can be visualized with the help of a TRIZ evolutionary map. Such a map is a tree where the base element is a root and stages (iterations) of evolution are branches. Such a representation allows systematizing knowledge in different fields effectively. Notably, TRIZ evolutionary maps of different knowledge fields are very similar. The map not only represents cause-effect relations of a system development, but allows predicting the next stage of the system evolution.

Methodology of Using the TRIZ Evolutionary Approach in Educational Process

Preparatory Phase

During preparation of an educational course based on applying the TRIZ evolutionary approach, it is required to analyze the TRIZ evolution of a chosen knowledge field. Analysis of the TRIZ evolution includes the following steps:

Step 1 – description of the source object. The source object of TRIZ evolution is a system, which implements the fundamentals of a knowledge field for the first time.

Step 2 – identification of contradictions in this object. Contradictions are moving forces of the evolution; development in the considered knowledge field is performed by the revealed contradiction elimination. The more detailed contradictions are formulated, the more accurate TRIZ evolution analysis will be.

Step 3 – identification of the TRIZ tools, which helps to resolve identified contradictions. Analysis of TRIZ tools, which eliminate contradictions at different stages of the knowledge field development, allows identifying main trends of the considered knowledge field development.

Step 4 – description of the following objects, which resolves some contradictions. This step allows defining direction of further development and objects that eliminate revealed contradictions, if there is contradictions elimination.

Then, *steps 2-4* are repeated for all the most significant object of the knowledge field with a desired degree of detailization.

Step 5 – construction and analysis of the TRIZ evolutionary map. The TRIZ evolutionary map is a scheme, elements of which are objects of TRIZ evolution; TRIZ tools, which provide a transition to the next stages; connections between objects, shown by arrows. Each arrow is an iteration of the TRIZ evolution. Iteration can be also defined as a transition from an object to the group of objects of TRIZ evolution.

Implementation Phase

Learning methodology based on usage of the TRIZ evolutionary maps includes the following steps (Berdonosov, Zhivotova, 2014):

1. Students learn all TRIZ tools. If there are some reasons and they can't learn all tools, they will learn just contradictions resolving tools. It should be noted that TRIZ is a theory, which is purposed to the development of creativity and mental skills, and is widely acknowledged. For example, in Komsomolsk-na-Amure State Technical University there are a number of courses, which offer students to learn different TRIZ tools. Such a course is "Development of creative imagination", which is taught in almost all faculties of the University.
2. After that, students start a study of the discipline from the simplest set of knowledge (source objects of TRIZ evolution). They are offered to solve the simplest task.
3. Then, complexity of the task is increased and again students are offered to solve it.
4. Next they identify contradictions and try to resolve them, using TRIZ tools, i.e. they have to offer a more ideal mechanism of settling the task or, at least, to describe properties that should be included in that mechanism. Thus, students "discover" all following elements of the TRIZ evolutionary map.

It can be said, that the methodology is a cyclic sequence (figure 4). Cycle depth depends on the amount of knowledge to be the studied (number of TRIZ evolutionary map objects).

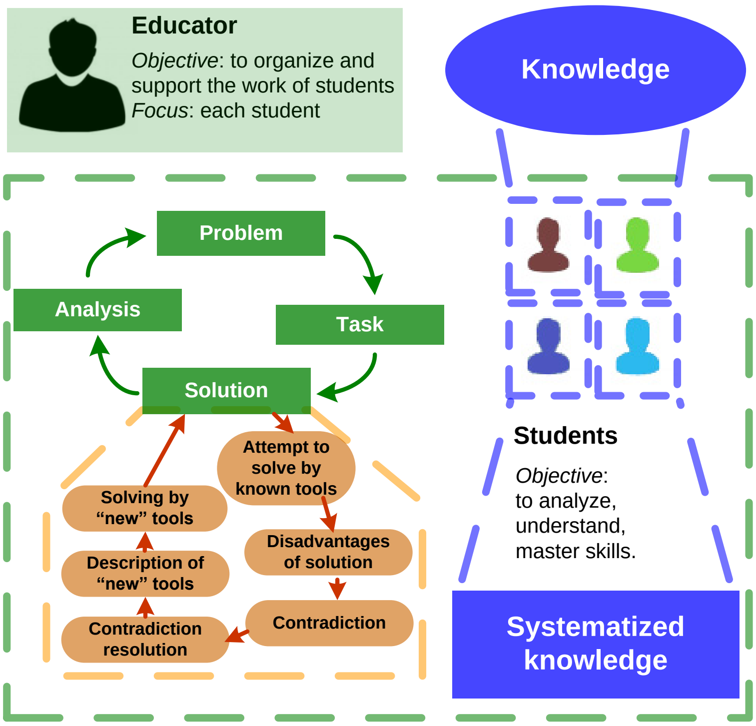

Figure 4: TRIZ Evolutionary Approach

At each iteration a student performs the following steps:

1. Setting and formalization of the task.
2. Solving the task using the source objects of TRIZ evolution.
3. Analysis of the solution: identifying shortcomings of the solution; formulation of technical contradictions.

4. Solving technical contradictions, using TRIZ tools.
5. Describing a new mechanism.
6. Solving the task using mechanisms, identified in contradictions resolution.

Further, let's consider application of the described methodology on the example of the object-oriented programming (OOP) study.

Application of the TRIZ Evolutionary Approach to the Process of the Object-Oriented Programming Study

Preparatory Phase (Systematization of knowledge in OOP)

Before implementing the approach in educational process, it is required to analyze the TRIZ evolution of a chosen knowledge field, in particular, knowledge in OOP. In general, the object-oriented approach to software development is based on four main mechanisms: abstraction, encapsulation, polymorphism and inheritance (Booch, 1998). Due to the limited volume of the paper, we will consider only one of these mechanisms, it is Inheritance. Inheritance is a mechanism to declare new data types on the basis of existing types in such way that the attributes and methods of the base types become the members of the subtype.

Let's perform analysis basing on the steps described above.

Step 1 – Source object of the OOP TRIZ evolution is Simula-67 and set of mechanisms implemented in this language. As the Simula-67 (Dahl, 2002) is a "firstborn" of the OOP, set of mechanisms implemented in the language cannot be ideal.

Step 2 – Due to increasing complexity of object-oriented tasks, software developers met a number of contradictions. For example, at realization of the mechanism of single inheritance, there is a contradiction on Simula-67: with increasing number of parent classes amount of duplicated data unacceptably increases.

Step 3 – The revealed contradiction can be solved using the inventive principle of "Merging". Duplicated parameters could be stored in one of the classes and other classes could inherit several classes.

Step 4 – The described solution was firstly implemented in C++ programming language (Stroustrup, 2000). Thus, the first iteration of the TRIZ evolution performed.

Step 5 – The complete TRIZ evolutionary map of "Inheritance" group of OOP mechanisms is represented in figure 5.

Implementation Phase

Further, let's consider an example of the case with a set of tasks to study the first iteration of the described TRIZ evolutionary map.

Students start learning from the source object. In this case it is Simula-67 and the base mechanism – single inheritance. The first stage of the course is a lecture about the OOP concept, its main principles and the first OOP language features. Further, the process of learning shall be performed in accordance with the following algorithm:

1. Setting and formalization of the task

Setting the task (the task shall be described by an educator): Some educational institutions are required to develop an application to display information about students and staff of the institution. Students can also be employees of the institution.

Formalization of the task (offered for students): Classes "Student" and "Employee" have common parameters: "Name" and "Age", as well as unique parameters: "Student" - "Year of study", "Employee" - "Salary" and "Experience". Additional class "Student Employee" must be also declared. "Year of study", "Salary" and "Experience" are also parameters

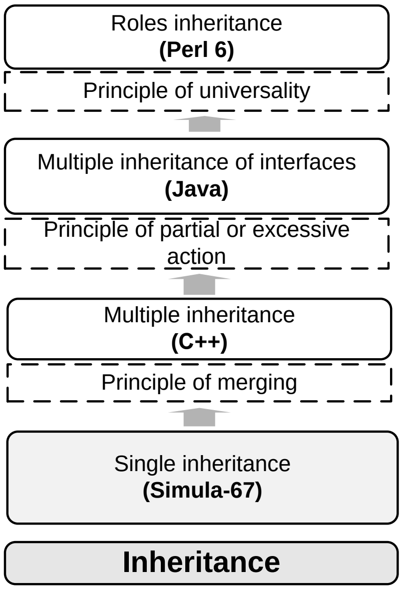

Figure 5: TRIZ evolutionary map of “Inheritance” group of OOP mechanisms

2. Solving the task using the source objects of TRIZ evolution

Students shall solve the formalized task, using the information of the first lecture and discussing the main concept of the solution in groups. Reference example of the solution concept: the task can be settled by the first object-oriented programming language - Simula-67. Let's declare three classes: "Person", which will store common parameters; classes "Student", "Employee", which will store the unique parameters. It is necessary to describe an additional class "Student-Employee". This class inherits from "Employee" class and describes an additional property "Year". Further, students are offered to develop a program, which will solve the task.

3. Analysis of the solution (students perform the task in groups in the form of discussion)

Reference example of the discussion results: This solution has some disadvantages. For example, if the student becomes an employee of the institution, it will be necessary to create an object of "Student - Employee" class. It is irrational to initialize an object twice: as an instance of "Student" class and as an instance of "Student - Employee" class because it will lead to creation of two similar object of "Person" class. Similarly, the "Year" property will be also duplicated. In general, this solution leads to redundancy and duplication of data that will undoubtedly influence the operation of program and the amount of memory if the amount of data increases. Thus, there are the following contradictions. Contradiction 1: with increasing number of parent classes amount of duplicated data unacceptably increases. Contradiction 2: with increasing amount of data storage space unacceptably increases.

4. Solving technical contradictions using the TRIZ tools (Students are offered to describe several solutions, using the TRIZ tools)

Reference example: Found contradictions can be resolved using the principle of merging. Duplicated parameters can be combined in one of the classes and the mechanism can be implemented that allows classes to inherit from several parent classes.

5. Solving the task using mechanisms, identified in contradictions resolution (This step supposes that students attend the lecture on applying mechanisms, which they identified in the step 4, in particular – multiple inheritance. After that they are offered to formalize the task considering a new possible solution)

The described solution was represented in C++ programming language, through the implementation of the multiple inheritance mechanism. This inheritance mechanism reduces the duplication of data. For example, by initializing Student-Employee Class, parent class properties are defined once, thus reducing the need for repeating information. Further, students are offered to develop a program, which solves the formalized task, in C++.

Thereby, the first iteration of the TRIZ evolution of “Inheritance” group of OOP mechanisms performed. Similarly, subsequent iterations of the TRIZ evolution shall be performed and students step by step shall “discover” new mechanisms implementing the object-oriented programming main principles.

Discussions

The considered methodology was applied to Komsomolsk-na-Amure State Technical University and showed its efficiency. Students studied object-oriented programming as a specialized course and as an additional course as part of "Development of creative imagination" track. In additional course the TRIZ evolutionary approach was used. At the end of the course the students were asked to take part in the survey in order to estimate their reaction of the training. The average estimation of students training satisfaction during the specialized course is 4.6 points; during the additional course - 4.8 points. In general, more than 50 students in the Komsomolsk-na-Amure State Technical University have learned and apply the TRIZ evolutionary approach.

The TRIZ evolutionary approach allows not only organizing and structuring knowledge by means of the TRIZ evolutionary maps, but also significantly improving efficiency of knowledge accumulation, its representation and studying in the form of systematized blocks. The approach can be used for groups and individuals.

In general, the usage of the TRIZ evolutionary map helps to considerably increase the efficiency of studying not only by the systematization of knowledge in a particular knowledge field, but by formulation of contradictions.

The analysis “from contradiction to contradiction” allows systematizing information about the problem, formalizing it, and describing it carefully. It considerably reduces time for finding the solution.

However, there are some disadvantages of the method. Thus, as any case-study method, the educational methodology based on the TRIZ evolutionary approach requires student competence. Students should be able to work independently. To study effectively, firstly, a student will have to master a certain amount of knowledge in special and general subjects, including knowledge in the TRIZ. Effectiveness of the methodology based on the TRIZ evolutionary approach also requires a deeper research at different levels of estimation, which may include the reaction of students on the training program, the reaction of educators on training program and its results, estimation of learning effectiveness among students.

Conclusion

Despite the above noted disadvantages and research perspectives, the results of the first application show that students’ satisfaction is higher than traditional educational methods. Besides, educational process based on cases complies with the necessity of solving real practical tasks, which are inextricably linked to the theoretical material.

The methodology considers learning capabilities of each student, which improves the motivation to knowledge field through the solving of the most interesting practical issues for student.

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