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The constructivist approach as a concept of active learning and teaching of optimization processes at technical universities

Marcela Lascsakova
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Applied Mathematics and Informatics, Letná 9, 042 00 Košice, Slovak Republic, EU, marcela.lascsakova@tuke.sk

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Abstract: As we move toward a more competitive global economy, the demand for highly qualified people to create and manage more efficient logistics systems, such as flows and management of materials or information, human flows, and supply chains, increases. Without logistics, the commercial world would grind to a halt. Businesses depend on logistics professionals to keep production and delivery moving forward which makes logistics education crucial. Companies expect their future employees to gain practical information, and to master what they are learning. Students must know how to apply what they learn. This is a reason why increasing importance is attributed to the constructivist approach to teaching and learning in university education. Through experiments or simulation of processes, and group work based on previous experience and knowledge, students better uncover the laws of phenomena. By actively engaging in the learning process, deeper and long-term applicable knowledge about the studied processes is acquired. The goal of this article is to implement the constructivist approach in the education of operational research and logistics at technical universities.

1 Introduction

The constructivist approach to learning and teaching has recently become very popular in school education. The idea that knowledge is a human construction supported by experience, first stated by Vico in the 18th century and further extended by Kant, greatly affected the epistemology of Piaget, who is considered to be the forerunner of the constructivism theory for the process of learning. This theory was formally introduced by von Glasersfeld who developed his ideas in the Piaget Foundation of the United States in 1975 [1].

According to the constructivist view, knowledge is not passively received from the environment but actively constructed by synthesizing past knowledge and experience with new information. The “coming to know” is a process of adaptation based on and constantly modified by the individual’s experience of the world [1-3].

In recent years, constructivism approach has gained popularity in teaching and learning of mathematics in primary and secondary education. However, in tertiary education, it seems that most teachers still prefer the traditional way of delivering explicit mathematics instruction. While processes studied in primary and secondary schools are relatively simple, problems tackled at the university level are more complex, time-consuming, and often span across various branches of knowledge. Therefore, incorporating constructivist approach to solving such tasks is significantly more challenging. Nevertheless, universities need to integrate such working methods into the educational process so that students are compelled to contemplate the causal relationships of processes and actively seek problem-solving strategies [4,5]. Actively solved tasks urge students not to rely on algorithmic solutions but encourage them to think about the factors influencing the course of processes, develop the ability to choose suitable problem-solving methods, work in groups, listen to others, and effectively present and defend their opinions [6,7]. Students educated in this manner subsequently achieve better results in their studies and practice [5,8]. Moreover, an increasing number of students in primary and secondary schools are being educated using constructivist methods, therefore universities should be prepared for these students.

Mathematics has been recognised as a subject that enhances higher order skills because on the one hand, it requires abstract thinking, and on the other, promotes use and application of knowledge [9,10]. At first, it is essetial to identify an area of mathematics suitable for a constructivist teaching approach. One excellent area is operational research and logistics, specifically optimization problem-solving. Nowadays, each modern technical expert is required to have some awareness and sensitivity to the logistical flow of materials and information during the production process [11,12]. In the field of process optimization, a significant number of modified problem-solving methods have been developed. These methods are mostly iterative, generating a sequence of solutions in which each subsequent solution achieves a better value in terms of optimizing the process. Graphical and simplex methods are fundamental methods among the approaches to solving optimization problems in standard form with two decision variables [13]. Naturally, it is possible to use appropriate mathematical software to solve optimization problems, but we recommend to introduce this tool only after students have mastered and understood the principles of solving such problems. Software tools are suitable for solving other types of optimization problems that involve a larger number of variables, constraints, or problems not in standard form, and allow us to find solutions to solved problems quickly. However, without an understanding of the essence of problem-solving, progress in exploring new methods and approaches to solving optimization problems can not be made.

A new interesting approach to solving optimization problems is combining both fundamental methods simultaneously. That enables students to observe the sequence of problem-solving steps, not only from an algorithmic perspective but also to perceive the graphical significance of these steps, which, in turn, helps them understand the logical coherence of the algorithm steps. Therefore, students are encouraged to consider and find connections that are often overlooked in algorithmic problem-solving. In the presented preparatory phase, the step-by-step solution of the chosen problem is linked with challenging questions and discussion with students to support critical analysis of the mathematical content. Working in groups is recommended, and students' ideas are continuously presented.

2 Linear programming problem

Let's consider a linear programming problem (LPP) in the standard form. That means,

Let's maximize the objective function (1)

$$z(x_1, x_2, \dots, x_n) = \sum_{j=1}^{n} c_j x_j, \qquad (1)$$

subject to (2)

$$\sum_{j=1}^{n} a_{ij} x_j \le b_i, \qquad (2)$$

$$x_j \ge 0,$$

for $b_i > 0,\ i = 1, 2, \dots, m,\ j = 1, 2, \dots, n.$

Let's choose a specific linear programming problem and demonstrate the proposed working method with students. The solved LPP is as follows:

The firm produced two kinds of products P_1 and P_2. The production is limited by the quantity of resources S_1 and S_2 and machines' capacity M per month. There are 1800 units of resource S_1 and 1600 units of resource S_2 per month. Machines M are capable of being operated for at most 860 hours per month. Each piece of product P_1 requires 6 units of resource S_1 and 1 unit of resource S_2. Each piece of the product P_2 requires 3 units of resource S_1 and 4 units of resource S_2. Both products P_1 and P_2 require 2 hours of processing time on machines M. On each sale, the firm makes a profit of 3€ per piece of product P_1 sold and 4€ per piece of product P_2 sold. How many of each type of products should be produced to maximize the total monthly profit?

2.1 Mathematical formulation of LPP

At first, the solved linear programming problem is mathematically formulated. This step might be demanding for students. They need to realize the desired relationships between variables and recognize technological parameters with their impact on maximizing the objective. Therefore, creating more mathematical models of optimization problems with students is highly recommended.

How can the provided information be structured clearly? Creating a table of given data helps to organize and structure the provided information and leads to a better understanding of the mathematical model construction process. The input data of the solved problem can be written in the form of the following table, Table 1.

Table 1 Input data of the solved LPP

	Product P_1	Product P_2	Available quantity
Resource S_1	6	3	1800
Resource S_2	1	4	1600
Machines M	2	2	860
Profit	3	4	

According to a standard form of LPP and Table 1, the mathematical formulation of the solved LPP has the following form:

Let's find the values of two variables, x_1, and x_2, such that they maximize the objective function

$$z(x_1, x_2) = 3x_1 + 4x_2,$$

subject to the following constraints (3)

$$\begin{aligned} 6x_1 + 3x_2 &\le 1800, \\ x_1 + 4x_2 &\le 1600, \\ 2x_1 + 2x_2 &\le 860, \\ x_1 &\ge 0, \\ x_2 &\ge 0. \end{aligned} \qquad (3)$$

2.2 A constructivist approach to solving LPP

The optimal solution to the solved problem can be found by the graphical method [13]. *How can a mathematical model be graphically represented?* At first, let's plot all inequalities (3) on a graph on the x_1x_2-coordinate plane. *How can the inequalities $x_1 \ge 0$ and $x_2 \ge 0$ be graphically interpreted?* Since the two decision variables x_1 and x_2 are non-negative, let's consider only the first quadrant of the x_1x_2-coordinate plane. *What do the other constraints graphically mean?* Graphing each constraint, a half-plane is obtained. The first constraint in the first quadrant is represented by a region (Figure 1).

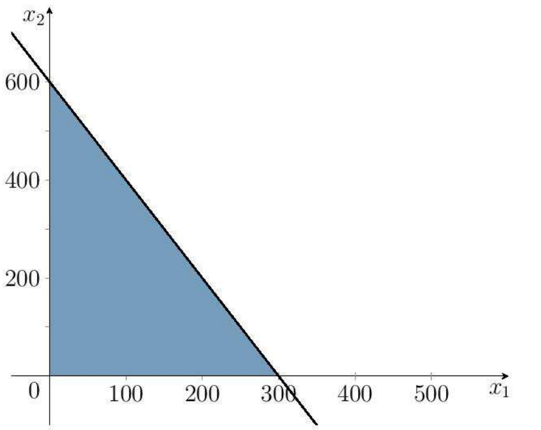

Figure 1 Half-plane $6x_1 + 3x_2 \leq 1800$ in the first quadrant

The feasible region is just the intersection of three half-planes in the first quadrant (Figure 2).

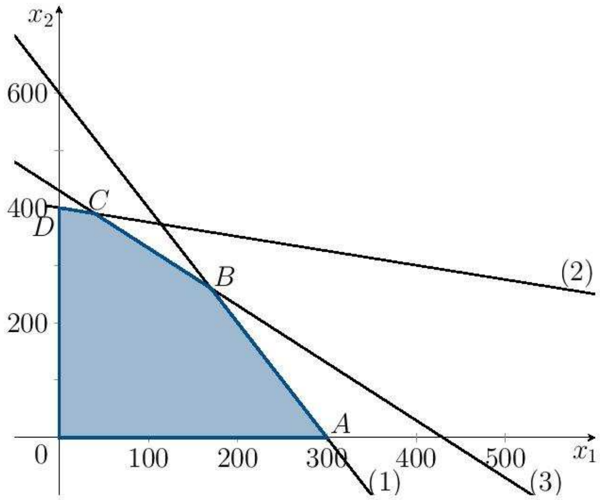

Figure 2 Feasible region

At which point of the feasible region does the objective function $z(x_1, x_2) = 3x_1 + 4x_2$ reach its maximum value? By theory, if the feasible region is bounded, then the objective function has both a maximum and a minimum value on the feasible region, and each of these occurs at a corner point (vertex) of the feasible region. *Which vertex of the bounded feasible region maximizes the objective function?* The optimal solution is found by testing the objective function at each vertex. At first, the coordinates of each vertex of the feasible region are found, O=[0;0], A=[300;0], B=[170;260], C=[40;390], D=[0;400]. The coordinates of vertices O, A, and D are visible from the graph. The coordinates of points B, and C are obtained by solving the systems of two linear equations which correspond to equations of intersecting lines. By determining the values of the objective function at each vertex, the maximum value can be found

z(O)=3*0+4*0=0,
z(A)=3*300+4*0=900,
z(B)=3*170+4*260=1550,
z(C)=3*40+4*390=**1680**,
z(D)=3*0+4*400=1600.

The coordinates of vertex C represent the optimal solution of the given maximization problem, $x_1 = 40$, $x_2 = 390$, and z(C)=1680€ is a maximum value, the highest obtained profit of the firm under given circumstances.

Let's analyze determining the optimal solution to the same problem step by step to understand the meaning of performed steps and look for connections in the procedure of solving the task with a graphical solution. Simultaneously, let's look at calculating the solution to the task using the simplex method [13].

How can different limitations of the observed process expressed by a system of inequalities of different types be mathematically unified? A linear programming problem in standard form can be transformed into a system of linear equations. The corresponding system of three constraint equations has the form (4)

$$\begin{aligned} 6x_1 + 3x_2 + s_1 &= 1800, \\ x_1 + 4x_2 + s_2 &= 1600 \\ 2x_1 + 2x_2 + s_3 &= 860, \end{aligned} \qquad (4)$$

where $s_1 \geq 0,\ s_2 \geq 0,\ s_3 \geq 0$.

The objective function can be written in the equivalent form

$$-3x_1 - 4x_2 - 0s_1 - 0s_2 - 0s_3 + z = 0.$$

Therefore, the initial tableau of the simplex method is as follows, see Table 2.

Table 2 Initial tableau of the simplex method

Base	x_1	x_2	s_1	s_2	s_3	z	b_i
s_1	6	3	1	0	0	0	1800
s_2	1	4	0	1	0	0	1600
s_3	2	2	0	0	1	0	860
z	-3	-4	0	0	0	1	0

How many solutions have systems of linear equations (4)*?* The system of three constraint equations contains five unknowns. From linear algebra, we know that such a system has infinitely many solutions. *How can solutions be determined?* These solutions can be obtained by arbitrarily choosing the values of two variables and calculating the values of the remaining three variables from the given system of equations (4). Since each slack variable s_i, $i = 1, 2, 3$ appears in exactly one equation, the process of expressing it will be straightforward. After some manipulations, we obtain

$$\begin{aligned} s_1 &= 1800 - 6x_1 - 3x_2, \\ s_2 &= 1600 - x_1 - 4x_2, \\ s_3 &= 860 - 2x_1 - 2x_2. \end{aligned} \qquad (5)$$

The values of variables $s_1,$ s_2, and s_3 can be obtained by choosing the values $x_1 = 0$, and $x_2 = 0$. Then, by (5), $s_1 = 1800, s_2 = 1600$, and $s_3 = 860$. This allows us to determine the first basic feasible solution. *What does the initial basic feasible solution mean?* At first, let's consider a production plan where no products P_1 and P_2 are manufactured ($x_1 = 0,\ x_2 = 0$). In that case, the inventory levels of resources S_1 and S_2, as well as the available machines' hours M, remain unchanged, remaining in their original quantities (there are 1800 units of resource S_1 in stock, 1600 units of resource S_2, and 860 available machines' hours, $s_1 = 1800,\ s_2 = 1600,\ s_3 = 860$). *What is the graphical interpretation of the initial basic feasible solution?* The initial solution graphically corresponds to vertex O=[0;0] of the feasible region (Figure 3).

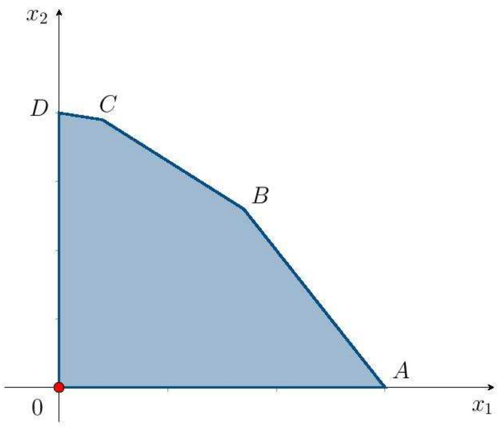

Figure 3 Initial basic feasible solution

What is the value of the objective function for the initial solution? Is it possible to increase this value by modifying the production plan (using a different feasible basic solution)? Is the obtained initial solution optimal? What is the meaning of the coefficients of the objective function? To determine whether the obtained solution is optimal, it is neccessary to assess if the value of the objective function $z(x_1, x_2) = 3x_1 + 4x_2 = 0€$ is maximized. Let's analyze the objective function $z = 3x_1 + 4x_2$. The coefficients of the function are non-negative, where one unit of product P_1 yields a profit of 3€ and one unit of product P_2 yields a profit of 4€ to the firm. Therefore, it is necessary to modify the production plan by introducing either product P_1 or product P_2 to increase the firm's profit (the value of the objective function). *Which product, not currently in the production plan, will yield a higher increase in profit?* By comparing the positive coefficients of the objective function (the unit profit from producing products P_1 and P_2), it was found that introducing the production of product P_2 will be more advantageous in terms of maximizing profit.

What is the maximum quantity of product P_2 that can be produced? The highest possible quantity of product P_2 should be produced. However, the available resource quantities limit the production. *Which resource has the most significant impact on the production of product P_2? How many products P_2 can be produced with the available quantity of resources and machines' capacity?* Let's examine each resource individually. There are 1800 units of resource S_1 in stock, and producing one piece of product P_2 requires 3 units of resource S_1. Therefore, 1800/3=600 pieces of product P_2 can be produced by using the available quantity of resource S_1. As for resource S_2, 1600/4=400 pieces of product P_2 can be made. The machines' hours M allows to produce 860/2=430 pieces of product P_2. The resource limiting production the most is the quantity of resource S_2, which determines that a maximum of 400 pieces of product P_2 can be produced.

How can the amount of manufactured product P_2 be expressed? Resource S_2 will be completely depleted, and thus the second inequality in the system (3) will be satisfied as an equation. The vector corresponding to the leaving variable s_2 will be replaced by the vector corresponding to the entering variable x_2 in the new production plan. Therefore, for the new basic variable x_2, the following condition holds

$$x_1 + 4x_2 + s_2 = 1600,$$
$$x_2 = 400 - \tfrac{1}{4}x_1 - \tfrac{1}{4}s_2. \tag{6}$$

How do the inventory of resource S_1 and machines' capacity M change through the production of product P_2? Since the production of product P_2 requires not only resource S_2 but also consumes resource S_1 and machines' hours M, the values of the remaining basic variables s_1 and s_3 are modified accordingly. Therefore, using equations (5) and (6), we obtain

$$s_1 = 1800 - 6x_1 - 3(400 - \tfrac{1}{4}x_1 - \tfrac{1}{4}s_2),$$
$$s_1 = 600 - \tfrac{21}{4}x_1 + \tfrac{3}{4}s_2, \tag{7}$$
$$s_3 = 860 - 2x_1 - 2(400 - \tfrac{1}{4}x_1 - \tfrac{1}{4}s_2),$$
$$s_3 = 60 - \tfrac{3}{2}x_1 + \tfrac{1}{2}s_2. \tag{8}$$

How can the current production plan be determined? How is the solution of a transformed system of linear equations acquired? Since the vectors corresponding to variables x_1 and s_2 are not in the basis (not included in the production plan), their values are chosen to be zero (no production of product P_1, and complete depletion of resource S_2). Therefore, the obtained values of the basic variables are as follows: $x_2 = 400,\ s_1 = 600,\ s_3 = 60$. Hence, when producing 400 pieces of product P_2, resource S_2 will be completely depleted. Resource S_1 will be consumed, leaving 600 unused units in stock. The remaining available machines' hours will be 60.

What is the graphical interpretation of the obtained solution? The entering base variable determines the direction of the displacement towards a new vertex of the feasible region. As x_2 is the entering variable, the displacement is carried out by the OD-edge to reach the D-vertex (Figure 4).

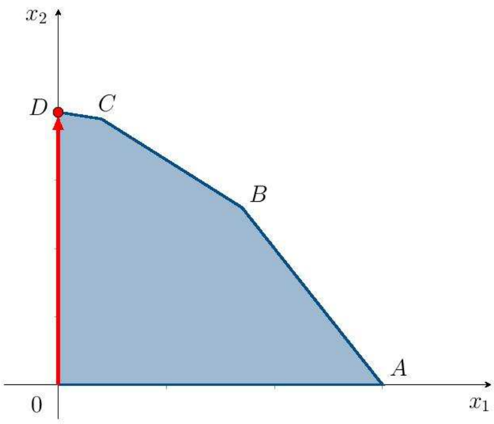

Figure 4 A new basic feasible solution

How will the profit be changed for the current production plan? Since the objective function obtains the form

$$z = 3x_1 + 4(400 - \tfrac{1}{4}x_1 - \tfrac{1}{4}s_2),$$
$$z = 1600 + 2x_1 - s_2, \qquad (9)$$

for $x_1 = 0$, $s_2 = 0$ (non-basic variables), the total profit will be $z = 1600€$.

By the simplex method [13], the initial tableau Table 2 is changed into Table 3, which is in accordance with the obtained relations (6), (7), (8), and (9).

Table 3 The second tableau of the simplex method

Base	x_1	x_2	s_1	s_2	s_3	z	b_i
s_1	$\frac{21}{4}$	0	1	$-\frac{3}{4}$	0	0	600
x_2	$\frac{1}{4}$	1	0	$\frac{1}{4}$	0	0	400
s_3	$\frac{3}{2}$	0	0	$-\frac{1}{2}$	1	0	60
z	-2	0	0	1	0	1	1600

Does the obtained solution optimize the objective function? Is profit 1600€ maximal? How does the profit corresponding to basic variables change? From the expression of the objective function (9), the modified profit for product P_1 and resource S_2 can also be determined. By introducing product P_1 into production and selling one unit of product P_1, the profit would increase by 2€. Including the vector corresponding to variable s_2 into the basis (to avoid completely depleting resource S_2), the value of the objective function would decrease by 1€. Since there is still a positive coefficient in the modified objective function, the obtained solution is not yet optimal. *What non-basic variable should enter the basis to maximize the obtained profit?* By changing the production plan, introducing product P_1 into production, the firm's profit can increase.

Why is a unit profit of non-basic variables changed? Interestingly, the original unit profit for product P_1 was 3€, but in the modified objective function it is 2€. This is due to the effect of changing the use of resources. The decrease is caused by the fact that when producing one unit of product P_1, the production quantity of P_2 products has to be reduced (due to insufficient capacity of resource S_2). Producing one unit of product P_1 consumes 1 unit of resource S_2, which is then missing in the production of P_2 products, and thus the number of products with a profit of 4€ needs to be reduced. To produce one unit of product P_2, 4 units of resource S_2 are needed. Therefore, the production of product P_2 needs to be reduced by 1/4 unit for each unit of product P_1 produced. The modified unit profit from one unit of P_1 is reduced by 1/4 of the profit from one unit of product P_2, which is $3 - \frac{1}{4} * 4 = 2€$.

How does the basis change? What will be the new production plan of the firm? By entering the vector corresponding to variable x_1 into the basis, which increases the value of the objective function, one vector corresponding to the existing variable leaves the basis. *How can the resource which limits the production of product P_1 the most be determined? What resource will also be completely depleted by new production?* The resource which limited the production of product P_1 the most is determined by calculating the ratios of modified available resources to positive modified technological coefficients (see them in equations (6), (7), and (8)). In some cases, the modified technological coefficients may become zero or even negative. In these cases, the ratios will not be calculated. (Dividing by zero is not possible, and if the technological coefficient is negative, the corresponding resource will not limit the introduction of the product into production. By introducing such a product into the production plan, resource will not be depleted further, but rather an increase in the available quantity of resource will occur.) The following ratios are acquired

$$\text{for } x_2: \frac{400}{\frac{1}{4}} = 1600,$$
$$\text{for } s_1: \frac{600}{\frac{21}{4}} = \frac{800}{7} \approx 114.3,$$
$$\text{for } s_3: \frac{60}{\frac{3}{2}} = 40.$$

The production of product P_1 is the most limited by the machines' capacity M. Therefore, the vector corresponding to variable s_3 is leaving the basis, while the vector corresponding to variable x_1 is entering the basis. *How can the quantity of manufactured product P_1 be determined?* Since (8) is the limiting constraint, it can be written in an equivalent form

$$\tfrac{3}{2}x_1 = 60 + \tfrac{1}{2}s_2 - s_3,$$
$$x_1 = 40 + \tfrac{1}{3}s_2 - \tfrac{2}{3}s_3. \qquad (10)$$

How are the expressions for determining the remaining basic variables x_2 and s_1 modified? The found expression (10) of basic variable x_1 allows to determine, using (6) and (7), the expressions of the other basic variables

$$x_2 = 400 - \frac{1}{4}(40 + \frac{1}{3}s_2 - \frac{2}{3}s_3) - \frac{1}{4}s_2,$$

$$x_2 = 390 - \frac{1}{3}s_2 + \frac{1}{6}s_3.$$

$$s_1 = 600 - \frac{21}{4}(40 + \frac{1}{3}s_2 - \frac{2}{3}s_3) + \frac{3}{4}s_2,$$

$$s_1 = 390 - s_2 + \frac{7}{2}s_3.$$

What is the next feasible solution to the solved problem? Which variables are equal to zero? If the non-basic variables are equal to zero again ($s_2 = 0,\ s_3 = 0$, that means resource S_2 and machines' hours M are fully depleted), the new values for the basic variables are obtained. The new feasible solution is $x_1 = 40, x_2 = 390$, $s_1 = 390$.

What is the modified profit of the firm? How is the value of the objective function changed? The value of the modified objective function is determined, using (9) and (10), by the expression

$$z = 1600 + 2(40 + \frac{1}{3}s_2 - \frac{2}{3}s_3) - s_2,$$

$$z = 1680 - \frac{1}{3}s_2 - \frac{4}{3}s_3. \qquad (11)$$

When $s_2 = 0,\ s_3 = 0,$ then the modified firm's profit will be 1680€.

Is the acquired solution optimal? Can another solution for which the value of the objective function is higher be found? Let's analyze the modified objective function (11). The modified coefficients in the objective function are negative or zero, so introducing vectors corresponding to variables s_2 and s_3 into the basis would decrease the profit (for one unit of resource S_2, the loss would be 1/3€, and for one unit of machines' hours M, the loss would be 4/3€). Therefore, the determined solution $x_1 = 40,\ x_2 = 390$, $s_1 = 390,\ s_2 = 0,\ s_3 = 0$ is optimal. This implies the production plan for the firm with the highest profit. The firm will produce 40 pieces of product P_1 and 390 pieces of product P_2. Resource S_2 and the processing time on machines' M will be fully utilized. Resource S_1 will remain unutilized with a remaining inventory of 390 units.

How can the optimal solution be graphically interpreted? A new displacement by DC-edge is made, up of C-vertex (Figure 5). At this point, the process ends. Vertex C is the optimal solution to the problem.

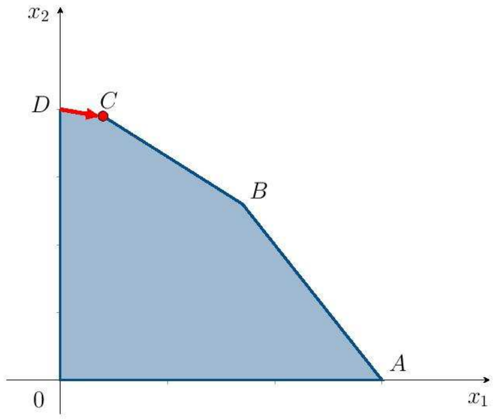

Figure 5 Optimal solution

Using the simplex method [13], the transformed tableau has the form of Table 4. Modified technological coefficients correspond to coefficients in the expressions of variables x_1, x_2, s_1, and the objective function z.

Table 4 The third tableau of the simplex method

Base	x_1	x_2	s_1	s_2	s_3	z	b_i
s_1	0	0	1	1	$-\frac{7}{2}$	0	390
x_2	0	1	0	$\frac{1}{3}$	$-\frac{1}{6}$	0	390
x_1	1	0	0	$-\frac{1}{3}$	$\frac{2}{3}$	0	40
z	0	0	0	$\frac{1}{3}$	$\frac{4}{3}$	1	1680

3 Conclusions

Logistics is the process of planning, organizing, and managing the movement of goods and raw materials in the supply chain. Currently, as new technologies change what logistics work entails, it is more important than ever to help students develop their critical skill set. The combination of critical-thinking skills and experience aids in a logistics professional's ability to anticipate and visualize processes from start to finish to optimise supply chain settings. It is challenging to find professionals who understand data and its role in logistics planning. Data is the key to making the right decisions, so the ability to analyze data and processes is the basis of education. This means solid knowledge of mathematics is very important. An essential part of good logistics flow is team management. Organizational skills are the requirements of a logistics manager. Teamwork is a vital component of any supply chain management system, as each role in these processes complements one another. Developing interpersonal skills such as patience, empathy, and active listening can help communicate ideas more effectively.

In the context of the rapid advancement of information technology, the educational process faces new and challenging tasks. Current university students are living under the pressure of an enormous amount of information being pushed onto them in varying quality. The easier accessibility of information conflicts with students' ability to select relevant sources and content based on critical thinking. Therefore, it is essential for students not to be only passive recipients of predetermined algorithmic procedures but to be active in the learning process. It is as well equally important to be able to analyze causal relationships and think about the sequence of steps while solving the problems. An active approach helps them also learn how to communicate properly, recognize errors in their opinions, argue and defend their solutions correctly.

The article aims to highlight the possibilities of a constructivist approach in teaching linear programming problems in the field of operational research and logistics in the context of university education. This approach provides a suitable environment for the development of students' critical thinking. Within solving the optimization problem two mathematical methods were connected and the algorithm was analyzed in detail step by step. The integration of multiple approaches helps students to see the problem in context and teaches them different ways how to analyze the problems and find solutions. This allows them to develop unconventional methods and approaches to problem-solving. Students acquire solution frameworks that they can subsequently apply to solve other problems. Understanding and identifying strengths and weaknesses in the used methods enables students to use the methods correctly and choose them effectively for solving problems.

The young generation will soon face the challenge of not succumbing to artificial intelligence and maintaining information technology at a level that serves humanity. Therefore, seeking new educational approaches that help strengthen students' skills of critical thinking is a very important necessity.

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Review process
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