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The method of "small groups" in teaching mathematics to students of technical universities

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Abstract

The article considers an approach to resolving the contradiction between the need to activate the educational and cognitive activities of students aimed at developing the mathematical thinking of future engineers, taking into account individual abilities and the established system of organizing classroom classes in higher mathematics, focused on front-line activities. The purpose of the study is to adapt the "small group" methodology for the study of mathematics by undergraduates, to develop and test educational and methodological support for this activity. The research hypothesis is that improving the effectiveness of mathematical and creative thinking formation can be achieved by organizing "small group" learning at different stages of learning new knowledge and developing intellectual skills, which provides: consideration of the psychological and pedagogical features and didactic properties of this method, as well as the specific conditions of its implementation in teaching mathematics; compliance with the specifics of the sections of the subject, the stage of cognitive activity and the didactic tasks of this stage; creation of a task bank and their typology by type of activity; development of methods for monitoring and organizing students' classroom work. Students' work in small groups is considered as one of the methods of interactive learning. The didactic properties and functions of the mathematics teaching methodology in collaboration are described. A model of interaction is defined, and its correspondence to the elements of cognitive activity and educational tasks is theoretically substantiated. The typological features of tasks for the "small group" methodology are indicated. The controlled results, semantic correspondences and computational criteria of learning in the development of computational skills, critical thinking, and analysis of results are determined. The positive aspects, possible difficulties are noted and the results of the application of the considered methodology are presented. The practical recommendations are aimed at organizing classroom classes in higher mathematics at technical universities, as well as at using advanced training courses for higher school teachers.

Keywords

interactive technologies; collaboration; mathematical training; motivation; creativity

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Методика «малых групп» в обучении математике студентов технических университетов

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Аннотация

В статье рассматривается подход к разрешению противоречия между необходимостью активизировать учебно-познавательную деятельность студентов, направленную на развитие математического мышления будущих инженеров, с учетом индивидуальных способностей и сложившейся системой организации аудиторных занятий по высшей математике, ориентированной на фронтальные виды деятельности. Цель исследования состоит в адаптации методики «малых групп» для изучения математики студентами младших курсов, разработке и апробации учебно-методического обеспечения этой деятельности. Гипотеза исследования – повышение эффективности формирования математического и креативного мышления может быть достигнуто организацией обучения студентов по методике «малых групп» на разных этапах усвоения нового знания и развития интеллектуальных умений, что предусматривает: учёт психолого-педагогических особенностей и дидактических свойств данного метода, а также специфических условий его реализации при обучении математике; соответствие специфике разделов предмета, этапу познавательной деятельности и дидактическим задачам этого этапа; создание банка заданий и их типологии по видам деятельности; разработку методики контроля и организации аудиторной работы студентов. Работа студентов в малых группах рассматривается как один из приёмов интерактивного обучения. Дано описание дидактических свойств и функций методики обучения математике в сотрудничестве. Определена модель взаимодействия, теоретически обосновано ее соответствие элементам познавательной деятельности и учебным задачам. Указаны типологические особенности заданий для методики «малых групп». Определены контролируемые результаты, семантические соответствия и расчетный критерий обучения при развитии вычислительных умений, критического мышления, анализа результатов. Отмечены положительные стороны, возможные затруднения и приведены результаты применения рассматриваемой методики. Практические рекомендации ориентированы на организацию аудиторных занятий по высшей математике технических университетов, а также на использование в курсах повышения квалификации преподавателей высшей школы.

Ключевые слова

интерактивные технологии; сотрудничество; математическое мышление; мотивация; креативность

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Introduction

An important aspect of modern education is not so much the assimilation of a certain amount of knowledge based on the teaching of fixed subjects, but rather the mastering of ways of thinking and reflexive activity (Antipin N.A., Gershunsky B.S., Dolzhenko O.V., Rozin V.M., etc.). Interactive teaching methods promote both self-reflection and self-change in pedagogical practice, and self-development, self-awareness of their capabilities and values by each learner.

Interaction is a method of cognition carried out in the forms of joint activity of students, when all participants in the educational process interact with each other, exchange information, solve problems together, evaluate the actions of colleagues and their own behavior. Interactive learning is primarily collaborative learning based on the student's interaction with the learning environment (Lapygin, 2018). The teacher here often acts as the organizer of the learning process, the leader of the group, the creator of conditions for the initiative and self-development of students. Interactive pedagogical technology is learning in collaboration or learning in small groups (P. Slavin, R. Johnson, D. Johnson, E. Aronson, Y. Sharan, S. Kagan, E. Cohen, S. Cook). Its main task is to organize active joint educational activities of students in different educational situations, to promote their social adaptation, the development of communicative and intellectual skills.

Russian psychologists have also dealt with the problems of small groups (Andreeva, 2016; Gaidar, 2013; Zhuravlev, Nestik, 2012; Sidorenkov, Sidorenkova, 2011a; Tretyakova, 2020; Umansky, 2001 et al). In foreign studies, a small learning group is defined as a group with three main characteristics: active participation, a specific task, and reflection (Agnihotri & Ngorosha, 2018).

Today, such educational activities not only do not lose their relevance, but also acquire new features. Its positive aspects include: increasing internal motivation for the performed activity (Moiseeva, Sannikova, 2018; Makarova, Denisov, 2021); increasing self-competence assessments (Kulikova et al., 2021); achieving higher academic achievements (Glazkova, Glazkov, 2021). At the same time, engagement can be considered as an important resource for achieving success, as well as a psychological characteristic of the degree of conformity of a student and the educational environment (Skinner et al., 2009; Pavlova, Krasnoryadtseva, 2021).

A "small group", as a socio-psychological concept, is understood as a small social group whose members are united by common activities and are in direct personal contact, which is the basis for the emergence of both emotional relationships and special values and norms of behavior (Zeer, 2010, Krichevsky, Dubovskaya, 2009). The didactic objectives of the "small group" methodology are: improving the ability to make decisions, solve typical and practice-oriented tasks, and improve socio-psychological competence, i.e. the ability to work in a team. To correlate one's individual view with an organized search for a solution, to make everyone's achievement, is the collective experience of the group (Houston, 2004). Collaborative learning is based on positive interdependence, in which a person acts as a subject of activity, is formed in activities and communication with other people, and determines the nature and characteristics of these processes (Johnson D., Johnson R, 2001, p. 63). The need for reflection as part of learning in collaboration has been emphasized in the course of consciousness research (Rossokhin, 2010).

Effective learning requires setting specific tasks that group activities are aimed at. These tasks should be clear to all members of the small group. Although individual group members may not fully participate equally in achieving the goal, due to their prior training, successful learning in small groups requires their active involvement. Small groups allow students to reflect on their own experiences, as well as on the experiences of other participants, thus contributing to a deep understanding of the material during training. A competent teacher, as a skilled facilitator, can direct this reflection in order to arrive at an agreed decision.

Methods

The analysis of information sources gave grounds to establish the methodological foundations of learning in collaboration, which was formed under the influence of the ideas of the theory of social interdependence (Kofka, Kurt Levin), the theory of cognitive development (J. Piaget, L.S. Vygotsky), theories of behavior (Skinner, Homans, Thibault, Kelly). In the context of the conducted research, the following methods were used: analysis of domestic and foreign psychological, pedagogical and methodological sources; study and generalization of domestic and foreign experience of teaching in small groups, pedagogical observation, surveys, conversations, the method of ascertaining and formative pedagogical experiment, methods of statistical processing of results.

Discussion

The norm of professional activity is the interaction of several teams solving complex tasks. Education in recent decades has been based primarily on the principles of individualism and competition. Today, the ability of specialists to solve tasks together is in demand, generating a variety of options and choosing the best one. It is important to optimally combine various aspects and sides of the educational process already in the first years, which requires the teaching staff to make an informed choice of appropriate teaching methods and technologies. This choice depends on the specific conditions of the actual educational process, primarily the student body, and implements the levels of future specialists included in the training program.

The modern specificity of higher education is that it is not "ready-made knowledge" that is assimilated, but conditions for personal construction and perception of this knowledge are created. The implementation of the subject-oriented approach provides for the widespread use of interactive forms of teaching and organization of extracurricular activities in order to form and develop soft and professional competencies of students. The university should apply a wide range of innovative learning technologies that develop teamwork, interpersonal communication, decision-making, and leadership skills. We welcome teaching in the format of author's courses in programs based on the research results of scientific schools that take into account professional specifics.

It is worth noting that each educational technology differs in certain features, has its own purpose and specific field of application. In higher education, subject-to-subject pedagogical influences become a priority, in which dialogical methods of communication, a joint search for truth, and diverse creative activities are brought to the fore. The methodology of "small groups" is based on the idea of rational cooperation, according to which different social roles and forms of interaction are implemented in comparison with

traditional education. Using this technique gives students with different levels of previous training the opportunity to participate in practical tasks as much as possible, to acquire cooperation skills, in particular, the ability to defend their own position, develop a common view, and resolve emerging contradictions. It is important to pay attention to the fact that the overall success depends on the personal contribution of everyone. The role of the teacher is also changing, becoming a consultant, moderator, and facilitator who guides the overall work. We focus on a number of circumstances regarding the "small group" methodology:

– time limit for each classroom session;
– group composition stability;
– the presence and manifestation of different levels of knowledge and skills of students;
– the heterogeneity of psychological types of students.

Unlike many natural science subjects (physics, chemistry, computer science), where laboratory practice is provided and the division into small groups is obvious and widespread, when studying higher mathematics, work in practical classes is mainly frontal and individual. When faced with innovative methods for the first time, teachers fear that they will have to spend a lot of effort and time on preparation, paying primary attention to the process at the expense of the content. How to ensure everyone's productivity? How can I increase motivation and convey to the student that he is responsible for the quality of his studies and his future relevance? At the same time, students should understand the purpose for which they are invited to work in small groups, what are the advantages of this format of joint study and elaboration of the material. Cooperation must take place, otherwise it is difficult to count on success.

The "small group" methodology is based on a number of principles: active interaction in the learning environment; positive interdependence; personal accountability; equal participation of each member of the group. In particular, the principle of positive interdependence is that the successful performance of the work of the whole group depends on the results of the work of each of the participants. To a greater or lesser extent, this principle can be implemented if you build a task of the "mosaic" type, where each group member creates a part of the final material, and the whole group presents a solution to the generalized task. Organizing small groups and encouraging their active work is one of the innovative approaches. In the course of its implementation, one has to face pedagogical and psychological difficulties.

Let's list the most typical ones.

1. Involving everyone in the work. The students are too passive. While one or two of them complete the task, the rest "sit out" or take minimal part.
2. Independent search. Students are not ready for theoretical and practical analysis of the assignment, but prefer to habitually ask questions or copy solutions from analog ones.
3. Tolerance and analysis. Not all the ideas proposed by the group members are taken into account and "worked out" in order to choose the best one.
4. Additional load. On the part of the teacher: increased time for preparatory work for the lesson (formation of a bank of tasks, target structuring of the studied material: terminology, basic skills, applied skills, creative thematic areas) and the need for mobile control during its implementation.

An essential factor determining the effectiveness of small groups is the creation of conditions that do not allow them to receive an assessment for someone else's work. Individual control and verification tasks, beyond working in small groups, based on the results of studying the material in the section or module, will allow you to evaluate the acquired knowledge and skills of each. The group should be interested in high marks from all its members, as this makes it possible to gain a greater amount of skills, assessed, for example, with additional points.

Results

The initial experience of working using the "small group" methodology often does not give optimistic results, both for teachers and students. But if you apply it repeatedly, the result is decent. For example, after several classes in small groups, students showed interest in this form and showed a statistically significant increase in the level of knowledge and skills based on the results of the modular control. Table 1 shows the correspondence between the percentage of completion of modular control tasks and the levels of educational achievements being formed (a non-linear scale).

Table 1. Correspondence of test scores to levels of educational achievement

Percentage estimates	Boundaries in points	The level of mastering knowledge and skills is a semantic scale
0 – 54%	0 – 11	low
55 – 70 %	12 – 14	basic
71 – 85 %	15 – 18	advanced
86 – 100 %	19 – 20	high

The method in question was used in the study of certain sections of higher mathematics by first and second year engineering students. As an example, we present the results of experimental exposure. For the ascertaining stage, the training material of the module "Differential calculus of functions of one variable" was worked out in practical classes. Traditional frontal methods of solving standard and individual tasks were used. According to the discipline program, the module ‘Differential calculus of functions of several variables’ is studied next, which is a logical continuation of the previous material. At the same time, it is a more complex section of the course, largely based on the previous knowledge and skills. Summarised results of the module control in groups of first-year students before and after the application of the method of work in ‘small groups’ are presented in Table 2.

Table 2. Levels of educational achievements in the study of two consecutive modules of higher mathematics course

Groups (pers)	**Module 1 - ascertaining stage (people)**		
	Basic	Advanced level	High level
Gr1 (22)	4	9	9
Gr2 (20)	2	7	11
Groups (pers)	**Module 2 - formative stage, after application of the ‘small groups’ methodology (people)**		
Gr1 (22)	2	13	7
Gr2 (20)	1	7	12

The nonparametric Cramer-Welch criterion was applied to evaluate the characteristics of the compared groups. The levels of educational achievements in the two groups are compared based on the results of traditional teaching in module 1 (ascertaining stage). The calculation of the empirical value of the criterion was carried out according to the well-known methodology (Novikov, 2004, p.46) and is equal to Tamp = 1.02, which is less than Tcrit, equal to 1.96. Therefore, the hypothesis of coincidence of educational characteristics of the groups is accepted at the level of statistical significance equal to 0.05. Let's compare the educational results shown at the control of knowledge on the materials of the next module after the application of the 'small groups' method. We calculate Tamp = 2.53, which is greater than Tcrit=1.96. Reliability of differences is observed at the end of studying the module 'Differential calculus of functions of several variables'. Thus, the input levels of educational achievements in the groups coincide, and the output levels (after the application of the 'small groups' method) are statistically significantly different. We emphasise once again that the material of the second module (under experimental conditions) is more complex, but based on the knowledge and skills acquired in the previous module.

Small group work should be analysed in a timely manner in terms of its organisation and effectiveness. For example, a quick analysis at the end of the lesson and/or a discussion of the collective activity in each group may be recommended. For this purpose, it is suggested that the individual work of the group members be evaluated by the following attributes: the student works independently on his/her part of the task, does not distract other group members; performs a fair, not less than other students, part of the work; helps, in case of difficulties, to improve the results of other members of the small group. Of course, these attributes are subjective, just like any other assessment. At the same time, their 'transparency', the possibility of collective control and responsibility - levelling possible subjectivism.

For successful implementation of the small group methodology, it is important that the teacher has the ability to listen, ask questions, show tolerance, and provide constructive feedback. Also, qualities significant to the joint fulfilment of the task should be encouraged, such as:

– trust in each other;
– mastery of unambiguous question wording;
– the ability to listen and hear objections and suggestions
– ability to give 'feedback' (on statements or actions in the group, teacher's recommendations);
– skills of transferring acquired knowledge and skills to each other;
– tolerance and ability to come to an agreement.

Considerable attention should be paid to the assessment process, which can be facilitated by the completion of group achievement sheets (both by the instructor and the students). These tables record individual student achievements for each assignment. After the completion of the learning activity, a group grade can be calculated from the data in the table $СП_j$ of each small group as an integral result according to the formula:

$$\text{СП}_j = \sum_{i=1}^{k} a_i IO_i,$$

where a_i - is the normalisation coefficient of the small group participant's status score ($0<a_i<1$); IO_i – individual evaluation of work (from 0 to 5); k-number of participants.

The status of a participant is determined according to the educational achievements of the previous stages of study and takes the highest value equal to one for excellent students. Individual assessment is usually an agreed opinion of the group members on the assessment of each participant's contribution to the overall result.

It is not necessary to use the method of ‘small groups’ at every practical training session. Here it is advisable to take into account the content of the studied material, the availability of tasks for ‘mosaic’ division. ‘Mosaic’ is consistent with the potential capabilities of students (from elementary actions and simple knowledge, to generalising conclusions and synthetic skills). It is not a problem for a teacher working with a student group for a long time, usually when studying an engineering course of higher mathematics (4 semesters or more), to form basic groups. However, if there is insufficient information about the educational progress of the students, it is appropriate to ask them to divide into small groups on their own. Conduct an entrance control, based on the results of which balanced groups can be formed. What is the optimal number of students in a small group? This is not an obvious question, but the answer to it directly affects, for example, the preparatory work of the teacher when preparing for a classroom session. Small groups usually consist of three to six students. Practice has shown that it is preferable to form basic groups of four people. Basic is a group formed for a long period of time (for example, for a semester or for the duration of the module). It can be reduced in size at the next session. If at some point there are two people left in the basic group, its members are temporarily combined with another, also incomplete group. It should be noted that the application of this methodology in specific student groups has a difficulty, namely, the variable composition of some small groups, those in which the participants who often miss classes due to illness, employment in social activities, for unfair attitude to study. In such cases, group grades in ‘mobile groups’ were not calculated, but a system of bonus points was used: for speed, originality, quality of learning the material.

It should be noted that experts in the field of group learning consider ‘heterogeneity of groups’ to be the defining characteristic of this methodology (Selevko, 1998, p.115). Heterogeneous groups are usually formed according to the scheme: one ‘strong’, two ‘average’ and one ‘weak’. However, there are no opportunities for interaction between ‘strong’ students and ‘strong’ students, and ‘weak’ students and ‘weak’ students. At the same time, students may get used to the status of ‘strong’ and ‘weak’, which will lead to the formation of undesirable stereotypes. Therefore, it is necessary to periodically create homogeneous groups or provide opportunities for intergroup communication, which allows expanding students' social experience, enhances the importance of communication skills, and creates conditions for getting acquainted with a variety of viewpoints on the task. At the same time, in groups where students of similar abilities and performance level are united, it is easier for ‘average’ and quiet students to prove themselves. We should not forget that a small group is not an entertainment during the study time, it is a full-fledged form of work in the classroom, the proper use of which leads to the achievement of certain educational and educational goals. Studying together, unlike studying alone, removes the fear of failure in weaker students, makes the knowledge of stronger students stronger, there is mutual enrichment of students.

The advantages of this methodology include intensification of the learning process. This, in most cases, leads to an increase in the level of educational results. Proper organisation

of classroom work stimulates satisfaction from the learning process, from the feeling of one's strength and abilities. The study of the problems of group learning leads to the conclusion that this type of activity will bring the desired results, not by itself, but in a rational combination with traditional methods.

Among the second-year students of the Faculty of Nature Management and Environmental Engineering of the Tver State Technical University, where the author of the article works, a written survey was conducted on the attitude to practical lessons on the method of 'small groups'. Here is a typical impression.

Student Ksenia. 'If you compare university with school, of course it is harder to study here. Every teacher wants us to know his subject perfectly. Only not all students are equally prepared. And also, having missed one of the lectures, it is very difficult to understand the material yourself. Practical classes are my independent actions on working out the lecture material, getting specific skills in mathematics. When we were offered to unite in small groups and solve tasks on higher mathematics together, and then collectively 'defend' them - it was a bit strange. We sat in a circle, opened the lectures and ... we don't know where to start. And so, at first, it was for all students in the classroom. The teacher, seeing our confusion, advised us to each choose a piece of the general assignment, start with definitions and look at examples from the lectures. I missed this lecture! We co-operated, began to sort it out together, looking for similar examples. I was guided by one of the students who is a good student, listened to his opinion about what theory to use, what formulas to apply, and part of the task, as I thought, was solved. But it was necessary to pass not separate parts, each his own, but the whole assignment. The way was already found, and we continued moving. Having fulfilled and formalised all the tasks, we went to hand them in. At that moment, another mini group was already defending their variant, which turned out to be incorrect. The teacher discussed with them the mistake of choosing the theoretical basis, why these formulas are not suitable and ... we realised that we were wrong too. One of the students in our group was indignant that he had spoken about the wrong choice right away, but we didn't listen to him. We went back to the place and started to redo it, but we were already consulting with each other, proving, explaining. We listened to the teacher's comments on the solutions of other groups. Finally, we coped, handed in this task and received the next one. As a result, in one pair we solved 3 collective tasks and two individual tasks each. The individual assignments were optional for those students who wanted to improve their final grade for the class. I personally understood the missed lecture material, which I would hardly have been able to do on my own. And I kept up with the other students. At the next practical session we all wanted to work in our small group again. It turned out to be interesting to learn something for oneself and to teach those who have not yet learnt very much. All students further expressed their desire to study in 'small groups'. So a few weeks passed and it was time to do the final assignment on the studied topic (module). And if earlier, we all wanted to write the module test at least for a credit number of points, now everyone wanted to get a higher grade. I felt in myself the strength to claim 20 points. However, it turned out to be only 18, but it was a success for me.

When the results were announced to us, it turned out that there was only one (!) satisfactory mark, and no twos at all. At the beginning of the next section – in practice – everyone wanted to work in mini groups again. By the way, the tasks for each group were different, so you can't write off, but it is possible to discuss - it is true that if one of the students

enjoys great authority and imposes his erroneous opinion, everyone suffers. If you realise this at the time, you can defend your own point of view - if you make a mistake, it's up to you. It's not very offensive. It is a pity that teachers have not worked with us in this way before. We had an interesting experience of interaction, which will be useful in our future profession.

Inferences

1. In accordance with modern trends in the development of the education system in Russia, the requirements for methods and means of teaching mathematics are actualised: they should create conditions for active learning and cognitive activities aimed at motivating independent thinking and mastering the methods of cooperation.
2. According to its psychological and pedagogical properties, the method of 'small groups' differs from other forms of group work in that it is aimed at the formation of intellectual skills of critical thinking. The organisation of student interaction (common task per group, mutual assistance, one assessment per group) implies the use of a wide variety of elaborated learning tasks.
3. The presented methodology for teaching students mathematics is not universal, its role is determined by the content and logic of learning and cognitive activity, but can be effectively used in conjunction with other methods of didactic system.
4. When forming a bank of tasks it is advisable to use the 'step to step' model to consolidate and improve computational, algorithmic and analytical skills. This model allows to involve students in different types of intellectual and communicative activities.
5. Each module of higher mathematics engineering course, when applying the 'small groups' methodology, should include: questions on terminology and basic concepts of a particular section; tasks on basic theoretical provisions; applied tasks oriented to mastering elements of critical thinking as a component of learning and cognitive competence. In the block of situational and modelling tasks it is important to include elements that involve: idea generation, work with information, forecasting, discussions.
6. Learning in small groups will be effective if students are informed about the rules of joint work and evaluation criteria; mini groups are formed in accordance with the psychological compatibility and learning level; the necessary handouts are prepared.
7. Experimental training confirmed the effectiveness of the 'small groups' methodology in the study of higher mathematics course sections. Feedback from students about the format of cooperative learning gives grounds to speak about their interest, increased motivation, personal performance, improved socialisation.
8. The use of 'small groups' methodology allows, without reducing the quality of acquired knowledge and skills, to form the skills necessary in communication, expands the ways of analysing and determining the ways of studying the problem.

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