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DEPARTMENT OF METHODOLOGY OF PHYSICS EDUCATION

Comparative analysis of atomic physics educational content in different countries

AUTOREFERAT

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Bulgaria's score in PISA 2018 (Science) is significantly lower than the OECD Member States' average score. The question arises as to whether this is due to the way in which Bulgarian students study natural sciences, or the volume of material studied, or other factors. National curricula are currently being reviewed. What are the problems and what are the prospects for Bulgarian atomic physics education in the first high school stage?

The methodology developed in this work identifies a number of ways in which the physics of the microscopic world can be taught. Teaching through various interactive methods leads to a significant improvement of the knowledge of Bulgarian students from a language school in Sofia. Also, there has been an improvement in students previously struggling with physics.

Some topics are conceptually more difficult to comprehend than others. The misconceptions of Bulgarian students do not differ significantly from the difficulties reported by foreign authors of articles in this field. The analysis of the study with students reveals the need for more time in class to master certain concepts. This also follows from the comparative analysis of curricula in different countries. Bulgarian students study some relatively abstract and partly conceptually difficult topics as early as the tenth grade, regardless of their focus (choosing a profile in the second high school stage). This is rarely seen in the programmes of countries included in the comparative analysis.

It is worth considering a national approach that prioritizes the deeper absorption of fewer topics in the first high school stage. The content does not need to be significantly reduced. The availability of elective cross-curricular "modules" within the physics curriculum at the first upper secondary level would encourage the implementation of an integrated approach on a national scale. Other options are also commented, including the benefits of career guidance in the curriculum.

In this work, perspectives are outlined that would facilitate the application of a variety of methods in class. In addition, it is demonstrated how comparative analyses contextualize national decisions in a given area. Reviews of articles reveal trends. In addition, the compact visualization of the content of a large number of articles is demonstrated. This is useful for both methodologists and teachers. Forming more teams that purposefully conduct surveys with students can reveal a lot about students, their teachers' teaching style, and the results of changes in the education system. An evaluation of education is probably worth conducting not only at the end of the year but also immediately after teaching certain topics or sections. Combining an even greater number of school surveys, article reviews and comparative analyses would help identify and facilitate proposals for future educational reforms.

Contents (Autoreferat)

Introduction. Topicality of the topic.

(**To readers**: Due to the limited volume, the content of this autoreferat does not include a large part of the figures, descriptions and conclusions that appear in the dissertation. Furthermore, the content has been translated from Bulgarian, using Microsoft Word.)

Does the physics curriculum in Bulgaria differ significantly from that studied in other countries? With this question, work on the present work began. It gradually included a number of other research issues, based on teaching experience, review of articles and discussions with colleagues from this period. In this way, the content of a dissertation, which was developed immediately after a national educational reform, is fixed (Ministry of Education and Science, 2015). In addition, the results of international research in the field of science education are used, as well as elements of a number of national and international conferences related to physics education, in the context of the global trend to offer and apply interactive methods in class (Bonwell & Eison, 1991; Union of Physicists in Bulgaria & Ministry of Education and Science, 2021).

It also discusses what the application of interactive methods in Bulgaria, the educational content of which is determined by the current curriculum, may look like. How can the effectiveness of these activities be verified quantitatively and what conclusions follow from this analysis? In particular, it examines how the application of various didactic methods is related to the educational content in physics and what similarities / differences are observed in the curricula (in atomic and subatomic physics) of Bulgaria and other countries (with significantly higher results from international studies). Benchmarking of curricula specifically takes place in other countries (Stadermann et al., 2019; Ramaila, 2020) and in general aims to draw conclusions that can be useful both for the national education system (Ramaila, 2020) and for the specification of global trends from a research point of view (of training methodologies) (Stadermann et al., 2019).

What do empirical observations from large-scale studies in the field of science (and physics) reveal and how can the relevant data motivate more in-depth research in Bulgaria? These and other questions outline the framework of the present work.

In Bulgaria, the curriculum is being reviewed (Ministry of Education and Science, 2022, 2023), and the hope is that the conclusions drawn here will be useful to the teams responsible for the layout and revisions of the curricula.

The dissertation study is an analysis of the educational content in atomic (and subatomic) physics. In view of the abovementioned questions and of the action taken during the research, let the concept of 'teaching content' be extended within the framework of this work by means of the following definition:

The curriculum includes both **the teaching material** (a program with separate topics) and the **way the topics are taught** (methods applied).

This definition highlights two possible research directions. On the one hand the curricula of selected countries can be examined and compared. In this case, the choice of the parties included in the comparative analysis is described and argued. On the other hand, the methods by which the relevant topics are presented to students can be explored. What are the global trends in the education of atomic and subatomic physics? How can the proposed activities be characterized so as to quickly and precisely orient interested readers? The question also arises how the statistical effect (in relation to knowledge upgrade) of individual methods can be determined and to what extent the authors of articles in this field include a quantitative assessment of the proposed activities.

The present work includes both strategies. The individual research activities are divided into three chapters, whereby each of the three initiatives aims at answering certain research questions. At the end of each chapter conclusions are formulated. The first chapter compares the training in atomic/subatomic physics in specific countries. The second chapter covers the characterization and categorization of proposed methods into topical articles from around the world, as well as the derivation of specific trends. The third chapter includes a detailed description of a study on the impact of the methods on the knowledge of Bulgarian students in 10th grade. In the last chapter (Glava IV) are compactly presented concrete conclusions about the Bulgarian education in physics and astronomy in the first high school stage.

Characterization of the dissertation study

The aim of the study is to draw conclusions in relation to the training material and applicable methods in atomic and subatomic physics that would support the implementation of an effective training process in Bulgaria.

The main **tasks** in this work include:

1. Conducting a comparative analysis of the curricula and content in atomic and subatomic physics (in general secondary education) in Bulgaria and other countries, based on specific data from various sources;
2. Conducting a secondary analysis of data from the international survey TIMSS Advanced 2015 (physics) in order to determine and confirm statistically significant relationships between the results of the most complex physical tasks and specific factors in physics education;
3. conducting a systematic review of international articles from the last 20 years, which will allow to study teaching methods in atomic and subatomic physics at secondary school stage in order to determine trends, ways to categorize (and characterize more precisely) the proposed activities, as well as the availability of quantitative data and analysis;
4. Planning, conducting, and processing empirical data from a practical study conducted with Bulgarian students from a language school in order to answer a number of research questions. The implementation of this tasks includes conducting a quantitative analysis of knowledge upgrading as a result of learning through various interactive methods in the field of school atomic and subatomic physics. as well as comparing the results with conclusions from other studies.

The object of the study are high school students who prepare general education and study elements of atomic and subatomic physics within an elective or compulsory subject physics (*and astronomy*), except for the target group of the second task (secondary analysis), which may include profiling students from more specialized high schools.

Subject of the study depends on the specific task:

Task 1 (comparative analysis): The physics content that students study in different countries is to be characterized and compared. Similarities and differences between curricula (such as documents) are also identified. If the curricula themselves are taken as an object, then the subject of the study represents the establishment of similarities and differences between their characteristics (in terms of scope, specific content, etc.);
Task 2 (secondary analysis): The subject in this task represents particular factors in learning which can be statistically confirmed to have a relation to the achievement of physics students;
Task 3 (review of articles): The methods proposed in the literature by which students can assimilate the concepts of atomic/subatomic physics are defined and characterized;
Task 4 (practical study): The subject of this study is the impact of various methods in class on the upgrading of knowledge of both all and the generally difficult students, on the acquisition of concepts that are reported in the literature to be problematic for learners and others.

The studies carried out in the present work purposefully **Cover** different countries and students from all over the world, depending on the specific task. This includes Bulgaria, a number of European countries, Japan, provinces in Canada, Australia and others. The data used to extract the necessary information are up-to-date - they have been published either in the last few years or at most 20 years ago, in the context of the review of articles. Only in some cases information from older articles is used.

The research questions in each of the above-mentioned studies (tasks) are presented at the beginning of the relevant chapter or section.

The course of the dissertation study involves the application of various **Methods**, through which the tasks are performed. A detailed description of them can be found in the relevant chapter or section. Compactly formulated, the methods used are as follows:

In Chapter I:

- Specification of the task comparative analysis of curricula *from the point of view of the comprehensive discipline* Comparative education*;*
- Definition and discussion of separate content indicators in the Bulgarian curriculum in physics and astronomy for 10. class;
- Performing secondary analysis of data from an international survey (TIMSS Advanced 2015) through statistical processing;
- Selection of countries (in the framework of benchmarking);
- Finding and summarizing specific information from articles, websites and books in different languages;
- Conducting comparative analysis of curricula (more precisely: *analysis of aspects*) and illustrating the results in a color table.

In Chapter II:

- Collecting educational articles from the last 20 years using inclusion criteria and a combination of words that is entered into a database (*Scopus*, *ERIC*, partially *Google Scholar*);
- Identification of *key features* by which to characterize the proposed activities in the selected articles;
- Analysis of each of the selected articles in order to identify the relevant key features;
- Construction of color tables in which the results are illustrated;
- Setting trends based on the presence of certain key features of training;
- Categorizing (otherwise) the proposed activities;
- Description and discussion of the available quantitative analysis in the selected articles;

In Chapter III:

- Planning a practical study with Bulgarian students (compiling entry/exit tests, final tests, determining a diverse combination of methods, compiling or finding learning materials/exercises, determining the type of study in relation to the forthcoming statistical analysis);
- Conducting the practical study, which includes both teaching in an interactive way and collecting information (input/output tests, impressions, feedback);
- Determination of the final sample, mapping and arrangement of the final results;
- Statistical analysis of the data (distribution of results, α of Cronbach, quantitative analysis of the upgrading of knowledge - conducted in three different ways);
- Comparison of the calculated upgrade with observations from other researchers;
- Analysis of specific questions/concepts from the input/output as well as from the final test;

Chapter I
Comparison of atomic and subatomic physics content in the curricula of different countries

I.1 Comparative education

The discipline *Comparative education* covers differences and correspondences between two or more educational phenomena or quantities, whereby it is also accepted to study foreign education (Bizhkov & Popov, 1994). The historical development of this science has led to rich content, methods, and methodological approaches (Bizhkov & Popov, 1994). No systematic comparison of education in individual countries will be conducted in this work, as this type of analysis is a comprehensive overview of national, historical, sociological, anthropological, economic, statistical, and other aspects. Instead, precisely defined educational elements will be compared in the context of school physics, specifically atomic and subatomic physics in high school. This is followed by a brief contextualization of the planned actions in this work (from the point of view of comparative education) and more specifically in Chapter 1 (comparative analysis).

Like **Advantages** Bizhkov and Popov describe the following aspects, drawing on the works of Joseph Lauwerys and Franz Hilker:

- Clarification (with a more comprehensive scope) of pedagogical problems on the basis of well-prepared, conducted and described comparisons;
- Assessment of the possible nature of pedagogical development over time (trends);
- A useful tool for bodies planning and introducing educational programmes.

The authors list the following two **shortcomings**, again based on reflections by Franz Hilker (Bizhkov & Popov, 1994):

- The comparative method does not allow the extraction of universal regularities (nomothetics) due to the impossibility to achieve empirical repeatability;
- Through comparative research, a generally valid model for the development of education cannot be implemented.

When comparing aspects of education systems, work is done according to a specific model, depending on the purpose of the comparison. Different combinations are possible, mostly in terms of time orientation, the number of educational phenomena examined and the number of countries (Bizhkov&Popov, 1994). According to the classification of types of comparisons of Bizhkov and Popov, the conducted analysis of curricula (Section I.4) appears *Horizontally* comparison. That is, elements of the education systems of several countries are compared at the same time (in this case - in the present). It is also possible to compare one or several phenomena in a single (or more in number) country, but at different times. The comparison is then called *Vertically*. The third type is a combination, that is, *horizontal-vertical* comparison.

The aim is to achieve a comparison of both a given aspect across countries (analysis by aspects) and all aspects for a given country (country analysis). In practice, some of these analyses are dropped due to a lack of data. Finally all the analyses carried out are synthesized. How does curriculum analysis fit into this model?

First, the educational problem should be specified. The need to compare programs partly stems from Bulgaria's low results in the PISA 2018 study (category "Natural Sciences"). On the other hand it is meaningful to compare the structure of (part of) the education system in the context of the recently implemented national education reform. Specifically, it is about the study of atomic/subatomic physics in compulsory training (CMO). It is investigated whether there are fundamental differences between our and selected foreign general secondary curricula? The aspects of the task thus formulated are not many, as they mainly include part of the educational structures, physics curricula and general secondary curricula. In addition, for each country, the share of high school students is clarified, as well as in particular the share of students in general (not vocational or other) high schools. Combining these aspects for each country will clarify which part of atomic/subatomic physics is studied by what proportion of students in which class of general secondary education, and in what format (mandatory/elective). This action is, in practice, a country-by-country analysis. A table should be built in which individual countries can be compared, both by content and by proportion of pupils, availability of electoral subjects. That is, they should be compared by aspects (analysis of aspects). This is illustrated in Table 4. The synthesis of country and aspect analyses presented in sections I.4.3.4 and I.5 is practically oriented. The summary primarily includes such observations and results that could support future educational decision-making in this area.

I.2 Atomic and subatomic physics in the first high school stage

In the dissertation, this section includes a description of the Bulgarian curriculum in atomic and subatomic physics in the first high school stage (CMO). As a result of the content analysis, they were **Certain** Separate **Content indicators**, (Table 1) on which, as a consequence, the curricula of different countries have been compared (Section I.4).

Code	Content indicator (description)
E1	Planck hypothesis (thermal radiation)
E2	Photoelectric effect
E3	De Broglie waves (quantitative)
E4	Corpuscular-wave dualism
E5	Quantized energy levels (spectra)
E6	Interaction between light and matter
E7	Technical annexes
E8	Core characteristics of nuclei/nuclear forces
E9	Bond energy and mass defect
E10	Half-life (no formulae)
E11	Biological action of ionizing radiations
E12	Radioactivity species
E13	Applications of radioactive isotopes (radiocarbon dating, medicine, ...)
E14	Nuclear reactions (fission, fusion)
E15	Nuclear reactor (principle of operation, protection)
E16	Fusion reactor (principle, controllability, prospects)
E17	Electrical particles (leptons, quarks) and antiparticles

E18	Hadrons (baryons and mesons)
E19	Fundamental interactions (comparison; carriers)

Table 1. Content indicators based on the Bulgarian curriculum for X grade (CMO)

I.3 International Studies

I.3.1 The PISA and TIMSS research. Similarities and differences

As mentioned above, both the collection of statistical information and the relationship between the economy and education play an essential role in comparative education. For this reason, the OECD (Organisation for Economic Co-operation and Development) purposefully examines the quality of education in member countries (although other countries, including Bulgaria) and in this context conducts international studies, one of which is PISA (Programme for International Student Assessment) (OECD, 2023). The survey was first launched in 2000 and is organized once every 3 years. PISA also tracks science scores, where the sample covers students as young as 15. For Bulgarian students who participated in PISA 2018 (OECD, 2020), it follows that the majority of them were in 9th grade. It is important to note that since the new curricula for the 9th grade came into force with the beginning of the 2018/2019 school year, and PISA 2018 was held mainly between March and August (NCES, 2020), only the small share of our eighth graders participated in the new curriculum. In 2021, the survey was postponed to 2022 due to the global pandemic and Bulgaria has once again joined (with the exception of only 2003), which is likely to reveal useful and up-to-date information about our education.

PISA Science literacy (natural sciences - literacy) tests not only knowledge of natural sciences, but also whether this knowledge can be applied in order to identify questions, extract new knowledge, and form reasoned conclusions in a scientific context (NCES, 2020). Meaningfully speaking, PISA Science mostly covers the subjects of physics, chemistry, biology and geography. The researchers who build the PISA framework define scientific literacy through the following three skills (OECD, 2019):

- scientific explanation of phenomena;
- evaluation and planning of scientific research;
- scientific interpretation of data and facts,

as a result, they identify and determine the necessary types of knowledge for the successful implementation of these actions - they are not only meaningful; They are also procedural and epistemologica. More information about the PISA Science test framework, technical details around the study, sample test questions and a summary of results/trends over the past 20 years, interested readers can be found on the PISA page (OECD, 2023). It is important to emphasize that the PISA study also uses questionnaire data to extract information on a number of complex interconnections and trends in world education.

The second large-scale study that checks the state of education (in particular - the education in mathematics and science) and examines the factors that may have an impact on it is TIMSS (Trends in International Mathematics and Science Study). The study is organized by the IEA (International Association for the Evaluation of Educational Achievement), which carries out an international collaboration between individual research institutions, including government agencies, scientists and analysts. IAE aims to improve global education (IEA, 2023). TIMSS was first conducted in 1995 and is organized once every 4 years. Bulgaria has participated every time, except for 2011. TIMSS collects test data from students in 4th and 8th grade (as well as from students at the end of high school - TIMSS Advanced), together with survey data from students, parents, teachers and principals of the respective schools. In the context of research hypotheses, it should be emphasized (and thanks expressed to the

IES/NCES - Institute for Educational Sciences of the US Department of Education) that a tool for processing TIMSS data has been made publicly available. This allows the verification of statistically significant relationships. This process will be demonstrated and applied as part of the below described secondary analysis.

Both PISA and TIMSS work with student results in mathematics and science (as well as surveys), but there are also differences. The author (researcher in the field of education) Tom Loveless in 2013 published a report (Loveless, 2013) on this topic and compactly formulated the following three differences:

- TIMSS generally adheres to curriculum content, while PISA checks whether students can apply what they have learned to solve "real" problems;
- PISA tests are completed by students of a certain age (15 years old) while TIMSS selects students according to class (4th and 8th grade or the end of high school in TIMSS Advanced);
- The two studies are organized by different organizations (as described above).

From a research point of view, it can be said that it is because of the existence of differences that the two studies are complementary. The preparation of the comparative analysis in this work revealed a number of countries that rank very well in one of the two studied, but not so well in the other - an observation that the author Loveless has also noticed because he explicitly mentions it in the above-mentioned report. For the purposes of comparative analysis (when selecting countries for comparison), the results of both surveys should be used.

I.3.2 The TIMSS and TIMSS Advanced Study (2015)

A detailed description of the TIMSS Advanced international study, specifically for 2015, can be found in the dissertation. It also presents the results of a secondary data analysis from TIMSS Advanced (2015) using the IDE software. Like SPSS and JASP, IDE is a data processing tool (NCES(IDE), n.d.). Statistically significant links have been established between student results in physics and a number of factors (memorization of facts, role of homework and many others). Two important results that actually motivate the studies in the next two chapters are as follows. It has been established:

- **negative** relationship of the results to the volume of the material (p=0.04);
- **positive** relationship of results with diversification of methods per hour (p=0.01).

I.4 Comparison of curricula (atomic and subatomic physics)

I.4.1 Introduction

In this section, particular similarities and differences of our general education upper secondary physics curriculum compared to other countries will be identified. When it comes to comparison, two important questions arise. What is the purpose of the study and on the basis of which criteria will the countries for comparison be selected?

The main objective of this study is the contextualization of our physics education on a larger scale and in particular - in the identification of useful ideas / opportunities for future changes in the curriculum. The aim is not aimed at criticizing our national program (which is actually extremely extensive and compactly formulated), but rather looking for opportunities for more effective assimilation of the material by present and future generations. The functional purpose of the comparison is tobut finding, collecting and categorizing information. Usually it is not uniform; appears in sources of various kinds; is not (free of charge) publicly available or is provided in a language that the researcher does not know. In connection with most of these difficulties, a solution was found, but the process as a whole takes time and effort. In addition a compact visualisation of the comparison is sought. It is hoped that Table 4 will fulfil this function below.

I.4.2 Selection of countries

Bizhkov and Popov selected countries on the basis of their economic development (Bizhkov & Popov, 1994), and added more countries to the main selection in order to:

- enlargement of the total number of countries and
- insertion of different educational models.

It is important to stress that the aforementioned authors compare different aspects of education systems as a whole, i.e. their national objectives, administration, funding, structure, etc. The present study also has a touch with some of these factors, but the main objective is the comparison of curricula at upper secondary level. A similar meaningful comparison of a specific part of curricula published (Stadermann et al., 2019), in the context of quantum mechanics in schools around the world. Given the specific purpose of their study, they select countries for comparison indirectly. First, they conduct systematic research by entering keywords into a database (Eric, Google Scholar, etc.). In the bibliographies of the publications thus found, the authors find sources that contain information about whether, to what extent and how quantum physics is studied in schools. In this way, they recruit curricula, publications related to teaching methods and comments on a variety of aspects of quantum physics. Once selected, the documents are analysed (and categorised by origin - country or province(s) per country).

In this study, a number of countries were selected, 9 of which were found sufficient amounts of information for comparison with Bulgaria on certain aspects. The countries were selected mainly on the basis of high scores in both PISA and TIMSS surveys (including "TIMSS Advanced"). Here there are a number of subtleties in relation to selection.

First, neither study covers students in recent years of upper secondary school (with the exception of "TIMSS Advanced", which in comparison includes far fewer countries). TIMSS works with results of 8th grade students, and PISA - mainly with 9th/10th grade (for Bulgaria: 9th). For this reason, it cannot be argued that high results from these studies necessarily mean good achievements in atomic/subatomic physics at upper secondary level. On the other hand, it makes sense to look at the programmes of the well-performing countries (PISA/TIMSS) in the higher grades as well, as education in one country nevertheless includes elements of consistency, upgrading, national objectives/priorities, etc. Also aspects such as funding, teaching methods and others are probably carried over to the late upper secondary stage. To what extent this is due to teachers teaching simultaneously in several educational stages (e.g. in 7th, 10th, 11th-12th grades, etc.), to a homogeneous financial distribution from 1st to 12th/13th grades, or to other factors, goes beyond the present study.

In addition, there are a number of countries that have participated in only one of the two above-mentioned large-scale studies. In addition, these studies cover the results of countries that have since undergone curricular reform (e.g. Bulgaria).

As mentioned, PISA and TIMSS test students differently. However, the question of which of the two lists of well-performing countries should be prioritized does not need to be discussed, as here countries are considered at the forefront in both studies separately.

The lists of countries thus selected were shortened as follows. A part of the well-performing countries in PISA 2018 and/or TIMSS 2019 and/or TIMSS Advanced 2015 shall be selected, which also:

- have extremely high national scores and/or
- are comparable to Bulgaria by geographical location and/or
- are comparable to Bulgaria in population and/or
- are economically comparable to Bulgaria (in GDP per capita) and/or

- are located in another continent (in order to diversify and increase the geographical scale of comparison).

Other possible strategies that were ultimately not implemented in the selection include considering the nationality of prospective physics students at certain universities around the world, the annual number of patents in technology, etc.

The countries to be compared in the next section are Bulgaria, Slovenia, Poland, Estonia, Singapore, Lithuania, Norway, Canada (Alberta), Australia (Queensland), Japan. Table 2 contains information on the average scores of students from these countries (OECD, 2019, IEA, 2019, Mullis et al., 2016). These PISA scores are boldly presented, which are significantly higher than the average for OECD Member States (the average score is 489 points). Thus the results of the TIMSS/TIMSS study are also presented Advanced, in which the middle equals 500 points.

State	Result (Mean score: Science) PISA (2018)	Result (Average scale score (Science 8th grade):TIMSS 2019)	Result (TIMSS Advanced 2015: Physics Overall scale)
Australia	**503**	**528**	-
Bulgaria	424	-	-
Canada	**518**	**537** (Quebec); **522** (Ontario)	-
Estonia	**530**	-	-
Japan	**529**	**570**	-
Lithuania	482	**534**	-
Norway	490	495	**507**
Poland	**511**	-	-
Singapore	**551**	**608**	-
Slovenia	**507**	- **551** (Science 8th grade: TIMSS 2015)	**531**

Table 2. Average scores in PISA, TIMSS and TIMSS Advanced

I.4.3 Results

I.4.3.1 Educational structures

The diverse terminology regarding the different educational stages is noteworthy. The International Standard Classification of Education (Eurostat, 2023) aims to facilitate the organisation of educational programmes. School education includes the ISCED 1, ISCED 2 and ISCED 3 stages. In our education system, for example, ISCED 1 corresponds to primary school (grades 1-4), ISCED 2 covers junior high school (grades 5-7) and ISCED 3 the two upper secondary stages (European Commission, 2023). Different countries differ in duration of both upper secondary and compulsory education. In Bulgaria, part of the high school stage (first) is mandatory (grades 8-10). It is the atomic physics at this stage that will be compared with the corresponding foreign curricula. Up to what age education is compulsory and when the upper secondary school begins in the other selected countries is described in the dissertation.

It follows that in many cases the upper secondary stage is not mandatory. Then the following question arises. What proportion of pre-secondary (ISCED 2) graduates continue their education (ISCED 3)? To answer this particular question through the publicly available educational indicators of the statistical structures of UNESCO and the World Bank has proved surprisingly circumstantial. For the purposes of this comparison, it is sufficient to consider what proportion of the population in the specific age range (the beginning and duration of ISCED 3 in the country concerned) is formally trained at ISCED 3. This question is analysed with the aim of approximate (or at least indicative) determining the proportion of pupils actually following physics curricula (ISCED 3). Thus, the analysis covers both the presence (or absence) of a specific content indicator of atomic/subatomic physics in a country's program and the approximate share of students in this age group who study under that program at all.

The second column of Table 3 reveals that over 80% (most often over 90%) of students in the relevant age group are studying at the ISCED 3 stage. The third column indicates the share of students who are educated in "general" high schools. The data are taken from the website of the UNESCO Statistical Institute (UIS, n.d.).

State	Total net enrolment rate, upper secondary (ISCED 3), both sexes (%); (2020)	Share of all students in upper secondary education enrolled in general programmes (%); (2020)
Australia (national)	92.8	48.6
Bulgaria	81.6	48.5
Canada (national)	89.8	91.5
Estonia	95.6	60.1
Japan	98.0	78.0
Lithuania	98.3	75.2
Norway	91.8	48.7
Poland	97.9	46.9
Singapore	98.9	100
Slovenia	98.6	29.2

Table 3. Proportion of pupils in educational stage ISCED 3 and proportion of pupils in general upper secondary schools

I.4.3.2 Variety of curricula

The third column of Table 3 reminds that in ISCED 3 there are in principle several types of high schools, depending on the specific educational structure. Atomic and subatomic physics at ISCED 3 level are predominantly included in the programmes of 'general high schools'. The more academic style of the respective programmes (relative to vocational high schools) is noteworthy, as their main function also involves the preparation of students who will pursue further university education. Professional programs in a country (including Bulgaria) are usually many in number, as there is preparation for a number of professions. It is mainly for these two reasons that the comparison presented here is restricted to physics curricula in a 'general' upper secondary school (ISCED 3) and does not include an overview of vocational (or other by type) programmes.

It follows that the programmes may differ significantly in the scope of both the educational content and the proportion of pupils actually taught under them. Some physics programs (such as Bulgarian) are studied by all students attending general high schools. Others are specialized - they are studied mainly in the upper grades of general high schools and purposefully cover a large number of content elements, i.e. they are preparation for a matriculation exam in physics (or natural sciences) at the end of secondary education. In our general educational structure, this kind of program is also found in profiled training. In some other countries, much of the atomic/subatomic physics is found solely in these specialized (and elective) programs. This will be commented on below.

For pupils studying in the selected countries who have chosen general upper secondary schools (in ISCED 3 stage), there are two options to study physics, depending on the specific education system. One option includes it as a compulsory subject. Other curricula contain physics as an elective subject. In some cases (e.g. in Japan) a certain number of subjects from the field of "Natural Sciences" must be compulsorily covered. In this way, physics and biology, physics and chemistry, etc. can be studied (Web Solutions LLC, 2023). A variety of this type of eligibility is found in the province of Alberta (Canada). There, the training necessarily includes an integrated subject "Natural Sciences" in the 10th grade (Government of Alberta, n.d.). Those students who wish for a high school diploma in Alberta must in the 11th grade cover a certain number of "credits" in the "Natural Sciences" category (Government of Alberta, 2023). That's where physics can choose. Fully selectable is physics in the 12th grade, where in fact all of the above-mentioned indicators in the context of atomic/subatomic physics occur.

In other countries (e.g. in Singapore), upper secondary physics ISCED 3 is fully elective in order to prepare for a final physics examination.

I.4.3.3 Comparison by content indicators

The following is a comparison of our general secondary (OOP) physics programme with corresponding programmes in other countries. Here will be presented and commented on the availability of content indicators from atomic and subatomic physics, which are usually studied in the educational stage ISCED 3. In the dissertation, a short text is formulated for each country (or province) to contextualize the information presented in Table 4.

The columns of Table 4 refer to a specific country and are arranged approximately as follows. Countries that have a resemblance to Bulgaria either in population, economic (GDP per capita) or geographical location are located further to the left. For this reason, the first six countries are European, after which countries from other continents are located. At the far right is the country of Singapore, whose specific education system will be described below. Due to strong decentralisation, Canada and Australia have not been considered on a national scale. Instead, the table includes information about the province of Alberta in Canada and Queensland in Australia.

Compared to Bulgaria, each of the countries in the table has a significantly higher score in the PISA 2018 (Science) survey. Under the name of the country is written the approximate share of students who have contact with the examined curriculum (s) in physics. This share corresponds to the above-mentioned share of participants in general secondary (not vocational or other) programmes, ISCED stage 3.

If a content element is not contained in the considered countryspecific curriculum, then the corresponding box in the table is filled with **black color**. If the content indicator is listed in the program, then as a number it is written in which class (most likely) it is studied. Only some programs explicitly mention which class a topic is intended for. The nature of the area of school physics considered here is, however, such that it is usually covered (and so arranged in the programmes themselves) at the end of the document. However, caution should be exercised because in several countries, for example, elements of nuclear physics are studied well before atomic physics. This complication requires working with curricula, which are sometimes difficult to find. If the cell in the table is filled with color (green/yellow), then the corresponding indicator is not necessarily studied. That is, it appears in a physics program as an elective subject. If there are several levels of election courses (most often "basic" and "advanced"), then green is used for the more basic, and yellow/orange for the more advanced courses.

Four more (E20-E23) - uncertainty principles, atom models (historical), electron microscopes and quantum physics elements have been added to the E1-E19 indicators in Table 1.

Indi-kator	Description	**Bulgaria** (proportion of pupils ≈ *50%*)	**Poland** (proportion of pupils ≈ *50%*)	**Slovenia** (proportion of pupils ≈ *30%*)	**Lithuania** (proportion of pupils ≈ *75%*)	**Estonia** (proportion of pupils ≈ *60%*)	**Norway** (proportion of pupils ≈ *50%*)	**Canada (Alberta)** (proportion of pupils ≈ *90%* national average)	**Australia (Queensland)** (proportion of pupils ≈ *50%* national average)	**Japan** (proportion of pupils ≈ *80%*)	**Singapore** (proportion of pupils ≈ *100%*)
E1	Planck's hypothesis (**explanation** of thermal radiation)					11/12 (elective)		12 (electoral - "Physics")	12 (electoral - "Physics")		
E2	Photoelectric effect	10	11	12	12 (elective)	11/12	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	12 (A2)
E3	De Broglie waves (quantitative)	10	12 (elective)			11/12		12 (electoral - "Physics")			12 (A2)
E4	Corpuscular-wave dualism	10	12 (elective)		12 (elective)	11/12	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	12 (A2)
E5	Quantized energy levels (spectra)	10	11	12	12 (elective)	11/12	11/12? (election - "Physics 1")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	12 (A2)
E6	Interaction between light and matter	10	11	12	12 (elective - advanced course)	11/12 (elective)	11/12? (election - "Physics 1")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	12 (A2)
E7	Technical annexes	10	12 (elective)	12 (elected)	12 (elective - advanced course)	11/12 (elective)	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	12 (A2)

E8	Core characteristics of nuclei/nuclear forces	10	11	12	12 (elective)	11/12	11	12 (electoral - "Physics")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	10/11 (O)
E9	Bond energy and mass defect	10	11	12	12 (elective)	11/12		12 (electoral - "Natural Sciences")	11 (electoral - "Physics")	11/12 (election - "Physics")	12 (A1)
E10	Half-life (no formulae)	10	11	12	12 (elective)	11/12		11 (electoral - "Natural Sciences")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	10/11 (O)
E11	Biological action of ionizing radiations	10	11		12 (elective)	11/12	11	12 (electoral - "Physics")			12 (A1)
E12	Radioactivity species	10	11	12	12 (elective)	11/12	11	12 (electoral - "Natural Sciences")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	10/11 (O)
E13	Applications of radioactive isotopes (radiocarbon dating, medicine, ...)	10	11	12 (elected)	12 (elective)	11/12		11 (electoral - "Natural Sciences")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	10/11 (O)
E14	Nuclear reactions (fission, fusion)	10	11	12	12 (elective)	11/12	11/12? (election - "Physics 1")	12 (electoral - "Natural Sciences")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	12 (A1)
E15	Nuclear reactor (principle of operation, protection)	10	11	12	12 (elective)	11/12		12 (electoral - "Natural Sciences")	11 (electoral - "Physics")	10/11 (election - "Basic physics")	
E16	Fusion reactor (principle, controllability, prospects)	10		12 (elected)	12 (elective)	11/12 (elective)		12 (electoral -			

								"Natural Sciences")			
E17	Electrical particles (leptons, quarks) and antiparticles	10			12 (elective - advanced course)	11/12 (elective)	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	
E18	Hadrons (baryons and mesons)	10			12 (elective - advanced course)	11/12 (elective)	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")	11/12 (election - "Physics")	
E19	Fundamental interactions (comparison; carriers)	10					12/13? (election - "Physics 2")		12 (electoral - "Physics")		
E20	Uncertainty principles					11/12	12/13? (election - "Physics 2")				12 (A2)
E21	Models of the atom (historical)				12 (elective - advanced course)	11/12		10 (Natural Sciences)	12 (electoral - "Physics")		
E22	Electron microscopes					11/12 (elective)		12 (electoral - "Physics")			
E23	Elements of Quantum Physics					11/12	12/13? (election - "Physics 2")	12 (electoral - "Physics")	12 (electoral - "Physics")		

Table 4. Comparative analysis of curricula by content indicators

I.4.3.4 Conclusions

Educational content (atomic/subatomic physics)

Table 4 illustrates which content indicators appear in the physics programmes of each of the selected countries (incl. elective/in-depth courses): photoelectric effect (E2), quantized energy levels/spectra (E5), light-matter interaction (E6), technical applications (of atomic physics) (E7), basic characteristics of nuclei/nuclear forces (E8), types of radioactivity (E12) and nuclear reactions (E14). It follows that 7 of the 18 indicators (not counting E1) in our physics programme (CMO) are also found in each of the other analysed countries.

The remaining 11 indicators can be sorted out, starting with the themes that are least covered in the other programmes:

E19 - Fundamental interactions incl. carriers - only 2 out of 9 countries;
E16 - Fusion energy - 4 from 9 countries;
E3 - De Broglie waves (quantitative) - 4 out of 9 countries;
E11 - Biological action of ionizing radiation - 6 from 9 countries;
E17 - Electrical particles and antiparticles - 6 from 9 countries;
E18 - Hadrons (baryons and mesons) - 6 out of 9 countries;
E15 - Nuclear reactor (principle of operation, protection) - 7 out of 9 countries;
E4 - Corpuscular-wave dualism - 8 out of 9 countries;
E9 - Bond energy and mass defect - 8 out of 9 countries;
E10 - Half-life (without formulas) - 8 out of 9 countries;
E13 - Applications of radioactive isotopes - 8 from 9 countries.

In Bulgaria, both basic and more specific concepts of atomic/subatomic physics are covered as early as the 10th class (CMO). This was not observed in any of the other 9 countries (Table 4). According to the programs in some countries, the 10th class may contain basic elements of nuclear physics or follow-up/enumeration of the various atomic models, but these are exceptions.

In the general high schools of Poland, Slovenia and Estonia physics is compulsorily studied, but in all three countries atomic/subatomic physics is covered in higher classes compared to Bulgaria. The programs of these countries rather resemble our past ("old") physics curriculum.

The upper secondary (physics) programme in Poland mostly comes close to ours. Taking into account also the programmes of the electoral subjects 'physics', the following observation can be made: in terms of coverage of topics, Estonia, Lithuania and the province of Alberta (Canada) almost entirely contain the indicators covered in our curriculum (except only E19 or E19/E3).

In general, the E2-E19 indicators are more often found in physics programmes as an elective subject, including advanced courses at the end of high school, which are preparatory to the matriculation exam in physics.

These observations can be complemented by the analysis of Stadermann, van den Berg and Goedhart (2019), who also compare the presence of given topics (from quantum physics) in foreign high school physics curricula. 7 of their indicators (Q1-Q7) coincide with some of the ones mentioned here. According to their study (which covers many curricula from 15 different countries), elements of atomic physics must be studied in the 10th grade only in the state of Bavaria (Germany).

Curricula (general observations)

The following are comments on certain characteristics of physics curricula. The Bulgarian program (CMO) clearly defines for which class it is intended, includes a short introduction, expected results, annual number of hours incl. percentage distribution of the type of lessons and forms of assessment, recommended lessons for laboratory works, compactly formulated advice on training methods, cross-curricular links. The compact format of the program, including the curriculum, is outlined - the expected competences and new concepts for each of the topics are listed.

The following impressions arose during the examination of foreign physics curricula. Slovenia lists by name the members of the authors' team/committee that has designed/approved the physics curriculum. In addition to the presence of university representatives (fields of mathematics / physics and methodology) in this list is also impressive the large number of teachers. The members of the teams responsible for further changes to the programme are also listed. The availability of this type of information is also observed in the case ofstation curricula (vocational training).

In physics curriculum, specific practical-oriented actions in relation to a topic are sometimes named. The desired outcomes of general secondary education in Slovenia include the following example (Slovenian Ministry of Education, n.d.):

Students are expected to know the structure of an atom, know how to find data on the charge and mass of an electron, and determine the mass of an atomic nucleus using the periodic table.

These are specific skills that more precisely orient teachers which guidelines/sources to include in teaching, what type of exercises to include in their lesson plan, etc. This example also demonstrates the orientation towards skills related to finding information and applying knowledge in a particular context. The program of Estonia (Estonian Ministry of Education and Science, 2014) includes as an expected learning outcome the following example:

to analyse the correlation between the specific energy of the relationship and the mass number on a graph.

It is worth emphasizing that (although less commonly) our curriculum (for 10th grade) also includes similar examples (Ministry of Education and Science, 2018):

Distinguishes radioactive nuclei by their half-life and
determines its value from the ***process graph*** *(without the formula of the law of*
radioactive decay).

It is noteworthy that there are various electoral topics in the physics curricula. Slovenia categorizes the elements in the curriculum - concepts and concepts that are considered basic are included. In *italic* font is written upgrading content, which is optional and included at the discretion of the teacher. It is explicitly mentioned that this choice depends on the group of students in the class, the material base in the school and the professional orientation/competence of the teacher himself. Entirely the selection *material is written in italic* font and marked in a certain way "(I)". This material goes beyond the mandatory and is studied depending on the orientation of the school. It is covered only when there is enough time for deeper study, and not in a purely "informative" way. In addition to classes, these topics are also recommended for science clubs, special school projects or the entirely elective subject "physics". There is also an elective content in the Estonian curriculum, part of which places a serious emphasis on crosscurricular links. An example of an integrated course of this type is "Science, Technology and Society", which addresses specific problems (climate, ozone holes, viruses, food additives, materials in everyday life, electromagnetic radiation from devices, alternative energy sources, sustainable energy at home, etc.) in order to discuss and solve problems that are important to students. Integrated courses are mentioned, which consider robotics, 3D modeling and other directions that students can pursue after completing school education.

The Physics Program of the Province of Queensland (Australia) is organized in a way that allows in each section to stimulate a number of cognitive processes - from the description, understanding and application to the interpretation of scientific observations and results, the analysis of scientific processes and claims, as well as the communication of scientific results, arguments and conclusions (QCAA, 2022). In addition, the program includes a recommended number of hours to cover each topic individually, as well as key issues in some of the sections. Tis can be discussed with students as an introductory / motivational part and are especially useful for beginner teachers. The program ends with a glossary and cited sources.

The Polish physics curriculum reviewed (an elective/in-depth version compiled by Maria Kallas and Karol Jagielski) (Polish Ministry of Education, n.d.) begins with an introduction that reveals how and why the authors laid its foundations. It is about mutual communication and support between two teachers. With regard to physics teaching, mention is also made of the value of student feedback. The authors have set themselves the goal of compiling a program that allows effective teaching andIt grabs students' interest. It is mentioned how important it is for the teacher to master improvisation, in the discussions to be a partner of the students - not to criticize their ideas, but rather to motivate the next question. In terms of specific methodological guidelines for teachers, the authors share how they think one of the best ways to master the material and improve a number of skills is the physical experiment. They encourage teachers to conduct such exercises even when not much material is available in school laboratories. Attention is drawn to the fact that with materials at hand a lot can be achieved. The creativity of the students themselves can be used to enrich the facilities at school. It is proposed that some of the demonstrations be conducted by selected students (with help from the teacher). In general, the authors defend the idea that students should be active participants in the learning process. The main role of the teacher is, through his expertise, to organize meaningful classes and to guide / accompany students in order for them to enrich their own knowledge and skills.

I.5 Conclusion

Atomic, nuclear and particle physics are widely included in the Bulgarian curriculum in physics for 10th grade. Although in a simpler version (compared to the material from profiled training), a number of topics from these areas still figure in the general education of a large number of Bulgarian students. Undoubtedly, the purpose of such an organized program is to enrich the general culture of students before (those who continue education) profile themselves. However, the analysis carried outsignificant differences to the curricula (and strategies) of a number of other countries.

It is noteworthy that our program covers central topics such as photoelectric effect, atoms and their relationship to linear spectra, as well as technical applications, radioactivity and nuclear reactions - content which is found in programmes of other countries. On the other hand, our students as early as the 10th grade study a large number of additional topics, many of which do not appear in other curricula even until the end of high school and even within the framework of electoral or deepening variants of the subject "Physics". An example of a less common content element can be the carriers of (each of) the fundamental interactions in nature, which the program expects students to be able to list. In general, elementary particles are rarely discussed within a compulsory natural science subject at school. Another example is thermonuclear energy, which in none of the other countries appears as a topic of a compulsory physics course. Rather, it can be encountered as a meaningful deepening topic (e.g. in Estonia) for which additional teaching hours are intended. The quantitative description of de Broglie waves is also not included in most of the programmes examined, although only in one country there is no talk of the more general concept of "corpuscular-wave dualism".

It follows that other countries place the burden either on covering topics from other sections and/or on covering fewer topics in order to deepen/upgrade certain concepts, to allow more time for exercise or to consolidate the material. In this context, it is noteworthy how certain countries formulate the expected learning outcomes. Some programs (including the Bulgarian one) name specific actions that students should practice in class - finding a certain type of information, working on the schedule in a given context, working with a specific table, etc. This type of information not only reveals the priorities in relation to specific skills of the students, but also proves useful for drawing up a plan of the particular lesson. Another feature of the curricula is the presence of electoral topics. It is probably worth considering options in which a certain part of the material is not covered necessarily, but according to characteristics of the school, the specific school year, configuration in the class and professional competence/capabilities of the teacher himself.

The inclusion of key (exemplary) questions to some of the topics of the program could facilitate the work of teachers, especially beginners.

Based on these results and observations, it makes sense to revise the format and content of the physics curriculum (CMO), i.e. to constantly seek the balance between the number of different topics in the 10th grade, the level of their deepening and the age of the students. The hope is that the analysis conducted here will support this process specifically by identifying topics that are strongest or least represented in other countries, as well as with additional information that can possibly be included in the program or to help consider other possible configurations in the physics curriculum (election topics/subjects, etc.). If the comparative analysis of atomic/subatomic physics thus conducted proves useful for national educational decision-making, then it is probably worth conducting in the context of any other subject, including physics in general.

Chapter II
Study of teaching methods in atomic and subatomic physics in high school

II.1 (Abbreviated) Introduction/motivation

High school physics encompasses some difficult concepts, especially in relation to microscopic phenomena. There the principles laid down often contradict previous student beliefs. In addition, phenomena are rarely visible to the naked eye. Students should develop an appropriate mental model and relate it to the laws of nature.

Several papers document and analyze students' misconceptions in the fields of atomic, nuclear and particle physics. Tuzón and Solbes (2016), for example, report that some students may have heard of terms such as particle accelerators or the Higgs boson, but sometimes confuse modern concepts with ideas from classical physics. The authors empirically show that students often do not distinguish between fundamental interactions - for example, when they need to identify the force of attraction between the electron and the atomic nucleus. Other difficulties reported relate to the question of how mutually repulsive protons can form stable nuclei and which type of interaction figures in nuclear reactions. It is observed how students confuse the hierarchy of microscopic particles. There are claims that nuclei are composed of atoms, etc. There is a need for classes that build systematic knowledge and thus allow students to identify particles/order as well as the correct contextualization of fundamental interactions.

There are misconceptions that are related to the patterns of the atom and of electromagnetic radiation (photons). Savall-Alemany et al. (2016) report numerous difficulties in relation to atomic spectra and their interpretation. Students do not take into account the quantization of energy levels, perceive each incident photon as absorbed by the atom, confuse the energy of the ground state, mistakenly assume a directly proportional relationship between the intensity and frequency/energy of the radiation. Other misconceptions can be found in the dissertation.

Any single learning activity within high school nuclear physics inevitably runs into the "radiophobia" (Tsuruta et al., 2009) of some students, possibly triggered by the media or by past historical events. Lack of knowledge prevents students from grasping the benefits of radioactivity for society, as well as discovering cross-curricular links, for example with geology, chemistry and biology (De Cicco et al., 2017).

Recently, STEM education has gained popularity in research. It aims to prepare students for real, complex problems by increasing their activity in the classroom. The idea is to deepen students' thinking, thereby driving them to higher cognitive levels. In this context, the question also emerges whether diversifying the methods applied helps students to cope with more difficult problems.

A statistically significant relationship of this type was found among the TIMSS Advanced 2015 data. Analysis of TIMSS data also revealed a positive relationship between the diversification of methods and the minutes allocated weekly to off-hour physics (which is probably related to student motivation).

II.2 Research questions

In view of the above mentioned findings, the following questions arise:
1) Which **teaching methods** are offered in the papers on atomic and subatomic physics at high school level?
2) Specifically, **how do students engage** in the proposed activities?
(3) Which of the methods examined are there quantitative **indications** that they are 'effective'?

II.3 Method of study

The Scopus, ERIC (and Google Scholar*) databases were selected* with the aim of compiling an overview of articles related to the research issues. This section describes (very condensedly) the steps that led to a set of 32 included publications.

First, the articles were filtered using the following combination:

("secondary education" OR "high schools") AND (instruction OR teaching) AND (atom* OR nuclear OR particle)

It was checked whether up-to-date reviews related to the study existed and, as a consequence, it was decided not to include the key term 'quantum'. Scopus covered **312** hits and ERIC **364**.

II.3.1 Inclusion criteria

The following criteria were then selected for inclusion of publications:

The documents must...
C1) ... are written in English;
C2) ... are articles or reviews of articles;
C3) ... have been published since 2002;
C4) ... cover methods/activities at upper secondary level;
C5) ... include a description of the method;
C6) ... cover at least one topic of atomic or subatomic physics and
They should not be limited to the teaching of quantum physics.

Criteria 1-3 are easily applicable because both Scopus and ERIC enable filtering by language, publication date and document type. Scopus covered **33 publications** (after limiting papers to "Physics and Astronomy") and ERIC 53 papers (after limiting to "Physics ").

However, criteria 4-6 require a detailed examination of the abstract (and usually the entire text) of the other articles. Some of the papers were excluded, for reasons which are described in the dissertation.

Total included were 10 (+2 additional) = 12 articles from Scopus and 16 documents from ERIC. 4 articles from Google Scholar were added, resulting in a total of 32 **articles for analysis.**

It is important to emphasize that the two additional articles by Scopus were discovered during a previous search involving the keyword "quantum". It was decided to add them anyway because one is related to experimental activity (photoelectric effect) and the other describes an interesting research task for students (nanotechnology). Four articles from Google Scholar were also included. which really adds subjectivity in the selection (the so-called. *selection bias*). Given the research questions, these publications were added because they either further diversify the proposed activities or provide more quantitative information on effectiveness. The articles included are listed in Table 5 and can be found in the cited literature at the end of this work.

II.3.2 Key traits

After the selection of articles, the following decision was taken on the analysis: the documents will be carefully checked for the description of teaching methods/preparation of activity, quantitative assessment and specific engagement of students. By 'specific engagement' are meant separate ways in which pupils can participate in the learning process. One possibility is to classify learning practices: modelling, problem-based learning, design, etc. Another possibility is to implement an idea highlighted by Geis as early as 1984. The author suggests instead of categorizing methods ("lecture" or "computer-based learning"...), to look for the "key signs" of an activity – characteristics that lead to success and can be incorporated into different methods (Geis, 1984). The signs of "links with everyday life" or "receiving feedback" for example may or may not be included in a lecture, problem-based learning, collaborative learning, etc.

In the present review, it was decided to look for 17 separate ways in which students could become involved during an exercise. These signs were extracted from the TIMSS Advanced 2015 and 2019 surveys. It was also checked whether an article offered a description of the activities (lesson plan) and whether it included a quantitative assessment. More information on the type of quantitative assessment provided can be found in the dissertation.

II.4 Results and discussion

The results of the analysis are summarized in Table 5, which is arranged chronologically (atomic, nuclear, FETCH, combined). It is important to stress here that the identification of a key attribute in an article (marked with an "X" in the table) means that it is either explicitly mentioned by the authors or implied by the context.

II.4.1 Key features of proposed activities

Table 5 can be used in two ways. On the one hand, articles can be quickly found that describe the specific student participation sought. For example, one can look for group activities in nuclear physics or select ideas for experiments. It is not recommended to compare articles (i.e., on the lines) because some publications are quite naturally longer than others. One can describe long-term projects that engage students in a variety of ways. Others focus only on specific aspects of an activity, thus providing a more detailed description. On the other hand the columns of Table 6 can be compared. Table 6 shows how often a character occurs among all articles. Even if an element of subjectivity is involved, Table 6 nevertheless reveals trends. The dissertation includes **another way** to categorize activities.

Article (yr) / description	Coll. analysis?	Lesson description/plan?	Discussion	Connection with everyday life	Relationship with previous knowledge	Explain answers	They express ideas	Group work	They work with a computer	Plan exp./creation	They're conducting exp.	Interpret data	Present data	Observe phenomenon	They use facts to prove	Watching demo on exp.	Field work	Difficult/atypical tasks	Feedback
ATOMIC:																			
Savall-Alemany, F. et al. **(2019) PBL atomic spectr.**	Y	Y	X	X	X	X	X	X		X	X	X		X	X	X			X
Rodriguez, L. V. et al. **(2020)Inquiry quantum.**	Y	Y	X	X	X	X	X	X	X			X	X	X	X	X			X
Kontomaris, S. V. et al. **(2020) Ionizing vs. non-ion. rad.**	N	N		X	X														
Cziprok, C. et al. **(2016) Vee heuristic, photoel. eff.**	N	Y		X	X			X	X		X	X	X		X				
Cai, S. et al. **(2020) AR, photoel. eff.**	Y	Y						X	X		X	X		X					X
Woo, Y. et al. **(2019)Constr. spectrometer**	N	N							X	X			X						
Maftei, G. et al. **(2011) Mosaic method, atom. spectra**	N	Y	X		X	X		X				X	X	X	X				X
Salazar, R. et al.**(2019) Modeling**	Y	Y	X	X	X	X	X	X	X				X						X

Article (yr) / description	Coll. analysis?	Lesson description/plan?	Discussion	Connection with everyday life	Relationship with previous knowledge	Explain in answers	They express ideas	Group work	They work with a computer	Plan exp./ creation	They're conducting exp.	Interpret data	Present data	Observe phenomenon	They use facts to prove	Watching demo on exp.	Field work	Difficult /atypical tasks	Feedback
NUCLEAR:																			
Bastos, R. O. et al. **(2016) Experiments, low-cost.**	N	N		**X**							**X**	**X**						**X**	
Tsuruta, T. et al. **(2009) Exp., track detection**	N	N		**X**								**X**		**X**		**X**	**X**		
De Cicco, F. et al. **(2017) Radon exp., School-uni collab.**	N	**Y**		**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**
Schibuk, E. **(2015) Activities (Manhattan project)**	N	**Y**	**X**	**X**	**X**	**X**	**X**	**X**	**X**										**X**
Sengdala, P. et al. **(2014) <u>NOS teaching</u>, Nucl./peace.**	N	**Y**	**X**	**X**	**X**	**X**	**X**	**X**					**X**						**X**
Shastri, A. **(2007) <u>Constr.</u> Slide-rule comp., nuclear eff.**	N	**Y**	**X**	**X**	**X**	**X**	**X**		**X**	**X**		**X**	**X**		**X**			**X**	
Brown, T. **(2014) Exp., radioactive dating**	N	**Y**		**X**	**X**				**X**		**X**	**X**		**X**					**X**
Kapon, S. **(2013)**	N	**Y**	**X**	**X**	**X**	**X**	**X**	**X**							**X**			**X**	**X**

Article (yr) / description	Coll. analysis?	Lesson description/plan?	Discussion	Connection with everyday life	Relationship with previous knowledge	Explain answers	They express ideas	Group work	They work with a computer	Plan exp./creation	They're conducting exp.	Interpret data	Present data	Observe phenomenon	They use facts to prove	Watching demo on exp.	Field work	Difficult/atypical tasks	Feedback
Scientific text for students (Einst. E=mc^2)																			
KRIŠŤÁK, Ľ. et al. **(2013)** **Multimedia/ DVD activity**	Y	Y	X	X	X	X		X	X		X	X			X	X			X
Elbanowska-Ciemuchowska, S. et al. **(2011)** ***Many activities***	N	Y	X	X	X		X	X	X		X	X	X		X		X	X	X
ELEM.PART.:																			
Schramek, A. et al. **(2019)** **Research-based teaching, Uni-school. Detectors**	N	Y		X	X	X	X	X		X	X	X	X		X	X	X	X	X
Bressan, E. **(2011)** **Research-based teaching, Uni-school, CR detection**	N	Y		X					X	X	X	X	X		X		X	X	X
Bardeen, M. et al. **(2018)** **Online tools, *QuarkNet***	Y	Y	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
van den Berg, E. et al.	N	Y	X		X	X		X										X	X

(2006) Fast feedback, symmetries etc.																			
Kourkoumelis, C. et al. **(2014) Online tool, *HYPATIA***	N	**Y**	**X**		**X**				**X**			**X**	**X**	**X**	**X**			**X**	**X**
Goldader, J. D. et al. **(2010) Constr. cheap CR detec.**	N	N							**X**	**X**	**X**		**X**					**X**	
Brouwer, W. et al. **(2009) Research-based. *ALTA* proj.**	N	**Y**		**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**		**X**		**X**	**X**	
de Souza, V. et al. **(2013) (re-) Constr. CR Impact point**	N	**Y**			**X**					**X**		**X**	**X**		**X**			**X**	**X**
Badalà, A. et al. **(2007) Data analysis, Simul. CR data**	N	**Y**	**X**		**X**			**X**	**X**			**X**	**X**					**X**	

Article (yr) / description	**Coll. anal ysis?**	**Lesson descrip tion/pl an?**	**Discus sion**	**Conn ectio n with ever yday life**	**Relatio nship with previou s knowle dge**	**Expla in answ ers**	**They expre ss ideas**	**Group work**	**They work with a comp uter**	**Plan exp./ creati on**	**They're conduct ing exp.**	**Interp ret data**	**Present data**	**Observe phenome non**	**They use facts to prove**	**Watch ing demo on exp.**	**Field work**	**Difficult /atypic al tasks**	**Feedb ack**
COMBINED/ OTHER:																			
Bussani, A. **(2020) Dice game, microsc.sys.**	N	**Y**	**X**		**X**			**X**	**X**			**X**			**X**			**X**	
Kvita, J. et al. **(2018) Particle camera for exp.**	N	**Y**		**X**	**X**				**X**		**X**	**X**	**X**	**X**		**X**	**X**	**X**	

Keegans, J. D. et al. **(2021), <u>Outreach</u>, Python, Nucleosynth.**	**Y**	**Y**			**X**			**X**	**X**			**X**	**X**		**X**			**X**	**X**
Planinšič, G. et al. **(2008), <u>Constr</u>. AF microscope model, Nano.**	N	**Y**		**X**	**X**			**X**		**X**	**X**	**X**	**X**		**X**	**X**		**X**	
Laubach, T. A. et al. **(2010), <u>Quided inquiry</u>, Nano.**	N	**Y**		**X**	**X**	**X**			**X**		**X**	**X**	**X**		**X**			**X**	

Table 5. Key Signs in Articles

II.4.2 Trends

According to Table 6, most articles (84%) include a lesson plan. The presented activities encourage students to connect the concepts of atomic and subatomic physics with previous knowledge of physics, as well as with everyday life. Many of the articles (63%) focus on group work and presentation of information (66%). More than half (59%) authors mentioned feedback. Interestingly, 11 of the articles did not involve computer work. Despite the modern tendency to use simulations, many authors illustrate particular learning activities that visualize microscopic phenomena in other ways. Also, computer use does not play a central role in the exercises described in some of the other articles. 50% of the papers cover experimental activities and 31% describe design/construction of appliances. Less than half of the articles describe discussions between students, argumentation of answers and expression of opinion. Fieldwork (which is understandable, since these articles usually describe long-term or international projects) and quantitative assessments are mentioned most rarely.

Sign	Frequency (total:32 articles)	Sign	Frequency (total:32 articles)
Description/Lesson plan	84%	Running an experiment	50%
Relationship with prior knowledge	81%	Discussion, Explaining answers	47%
Data interpretation	75%	Expression of ideas	34%
Relationship with everyday life	69%	Planning an experiment/creating a device, Observing a phenomenon	31%
Data Presentation, Computer Work	66%	Watching a demo. of experiment	25%
Group work	63%	Quantitative analysis, Fieldwork	22%
Difficult/atypical tasks, Feedback, Using facts to prove	59%		

Table 6. Trends

II.5 Conclusion

Scopus, Eric and Google Scholar cover articles that cover a variety of learning activities. Reviewing articles allows both the identification (and rapid detection) of specific student participation (Table 5) and the disclosure of trends (Table 6). In general, the presented methods aim to relate the topic to everyday life and to enrich/systematize the knowledge of students. Some authors put emphasis on scientific literacy, ethics and society. The articles provide original ideas for constructing and using classroom devices, educational games, working with scientific texts, research assignments, collaborating with students and scientists from other cities/countries, including participation in long-term scientific projects. Only some of the practices require working with a computer. The papers generally describe how to apply the particular method in the classroom, but the authors rarely (less than 25%) evaluate the proposed method quantitatively. The relevant publications provide quantitative information on student achievement, attitudes/attitudes, scientific literacy, and identify misconceptions. The result of the methods evaluated was mostly positive (see dissertation).

Chapter III
Importance of diversifying teaching methods for the assimilation of nuclear and atomic physics concepts in high school

III.1 Introduction/motivation

Secondary analysis of TIMSS Advanced 2015 data reveals statistically significant links between student success at the end of high school and a number of factors. It turns out that there is a significant positive relationship between success in physics and the variety of methods applied in class (Ilchev, 2021).

Following this analysis, the above-described review of articles (Chapter II) describing methods of high school atomic and subatomic physics was conducted in 2021 (Ilchev&Kotseva, 2022). Based on the observed trends, it was concluded that the least likely to find articles that include a quantitative analysis of the impact (success, attitudes, etc.) of the proposed activities (Ilchev&Kotseva, 2022).

Thus, the idea developed in 2022 to conduct a survey with Bulgarian students who *do not* study physics at the second level (PP), unlike the participants in the aforementioned TIMSS 2015 study. The aim was to collect information on the ground, and then to conduct a quantitative analysis of the upgrade of student knowledge as a result of diversification of the methods used in class. Some of the selected learning activities in this study were found precisely during the review of articles of Chapter II. The following is a compact description of the objectives of the study - in the form of questions to be answered in Section III.6.

III.2 Research questions

The questions which motivated the present study are as follows:

C1) Diversifying methods in class to what extent does it help our students to master basic concepts in atomic and nuclear physics?
C2) Is there a sustainability of the acquired knowledge (within 1-1.5 months)?
C3) Do the various methods help those students who have scored equal to or lower than "Good (4)" in the previous term?
C4) Which concepts continue to hinder students, even after conducting a variety of lessons? Do students distinguish between physical phenomena?
C5) Is it reasonable for a teacher to compare, on the basis of quantitative analysis, the input and output knowledge in physics classes?
C6) What are the key signs of the proposed methods (specifically how students engage)?
B7) What main conclusions emerge?

Questions B1)-B3) were formulated with the aim of establishing the effect of diversifying the methods applied at hour from both methodical and practical (teacher) point of view. It tracks not only how the methods affect students immediately after each lesson, but also whether this knowledge is sustainable in the short term and whether the activities help students who have struggled in the past.

The question C4) aims at the identification of concepts that are problematic for students in the context of difficulties already identified by other authors (section II.1).

Question B5) is aimed at clarifying the advantages and disadvantages of input/output tests as a teaching tool, and question B6) is an example of how a teacher can independently gain insight into how and in what way he engages students (self-assessment), as well as a basis for comparison with the methods analyzed in Chapter II.

The last question is posed in order to draw general conclusions on the application of various methods in an atomic / subatomic physics class in the 10th grade.

III.3 General description of the study

The research was conducted independently and included preparation (III.2, III.4), teaching and data set (III.4), statistical analysis (III.5) and conclusion (III.6, III.7). The survey covers students from four classes 10th grade in a private English high school (2 hours per week, CMO). With the exception of the lesson on "Nuclear Energy", English was used in class. The students and the teacher have known each other for two years. The total number of participants at the beginning of the study was 74. No control group appears for the following reasons:

- The strategy of subjecting the control group to a "traditional" approach, in which the active participant in the class is mainly the teacher, is avoided. This decision is in the interest of students, as the goal is to use every opportunity to increase their engagement and thus develop their skills.
- The idea is to monitor the weekly upgrade of *all* participants, i.e. to subsequently analyze how the diversification of methods affects the largest possible number of students (maximum *sample size*). This solution leads to a set of student results, the distribution of which is approximately Gaussian/normal (III.5).

Instead of the comparison with a control group, the results of the present study will be quantitatively correlated to conclusions from larger scale studies (in Section III.6.1.1). This type of contextualization and comparison of results is also found in other studies (Choudhary et al., 2018) in the field of physics education, again in the context of applying a variety of interactive methods.

The survey is divided into two main parts. The first part consists of four lessons. It is important to emphasize that for a given topic the *same combination* of methods was used for all four classes (Table 7). For each lesson, six test questions with **5** possible answers were developed (in order to reduce the number of random hits). The participants filled in the tests (on paper) before the lesson and immediately after the end of the lesson. This allows *the quantitative comparison* of their input and output knowledge. The students knew that the aim was to check whether the method would help them and participated actively. This stage was *not evaluated.* The questions for a specific topic were the same for all four classes.

The second part consists of a final test, covering the material from the previous four lessons*, with an assessment*. There were 4 *different* versions with 18 questions, again with 5 elective answers. On the part of the teacher, efforts were made to avoid copying, to give feedback in class and out of class, as well as to encourage group work. The aim was for the students themselves to take much of the responsibility for their own knowledge.

By the end of the study, the total number of participants decreased to 48. This is due to the large number of absent students at the end of the term (due to illness, external assessments in 2 compulsory subjects and 2 subjects at will).

III.4 Description of teaching methods

(**To readers:** A detailed statement of the methods used, along with practical comments on their impact, unfortunately cannot be entered here, but can be found in the dissertation. There are a number of important specifics of the questions asked in detail and analyzed, including which of the concepts remain problematic for students - even after diversifying and illustrating the topics.) The impact on knowledge upgrading is addressed quantitatively in section III.5.

III.5 Data analysis

Many of the details in connection with the statistical analysis are not mentioned here, but are commented in detail in the dissertation. This includes the quality of input/output tests as a tool for measuring knowledge, the type of distribution of test results (discrete instead of continuous), comments on the application of parametric tests in this case, etc.

Normal data distribution

How are the results distributed? Despite the small sample size, no significant deviations from the normal distribution were observed - values of P (Shapiro-Wilk) respectively equal to 0.083; 0.393; 0.057 for the sum results of all input/output tests and for the final test visualized in Figure 1. The condition $P > 0.05$ is necessary, for example, for the conduct of the so-called. *parametric paired samples t-test* for the purpose of calculating the *Cohen coefficient* d below. Figure 1 presents the frequency of results **from 0 to 100 percent**. The maximum number of points for the total entry/exit tests is 24, and on the final test students can score a maximum of 18 points. The figures (distributions, histograms and tables of statistics) are compiled within the JASP software (n.d.).

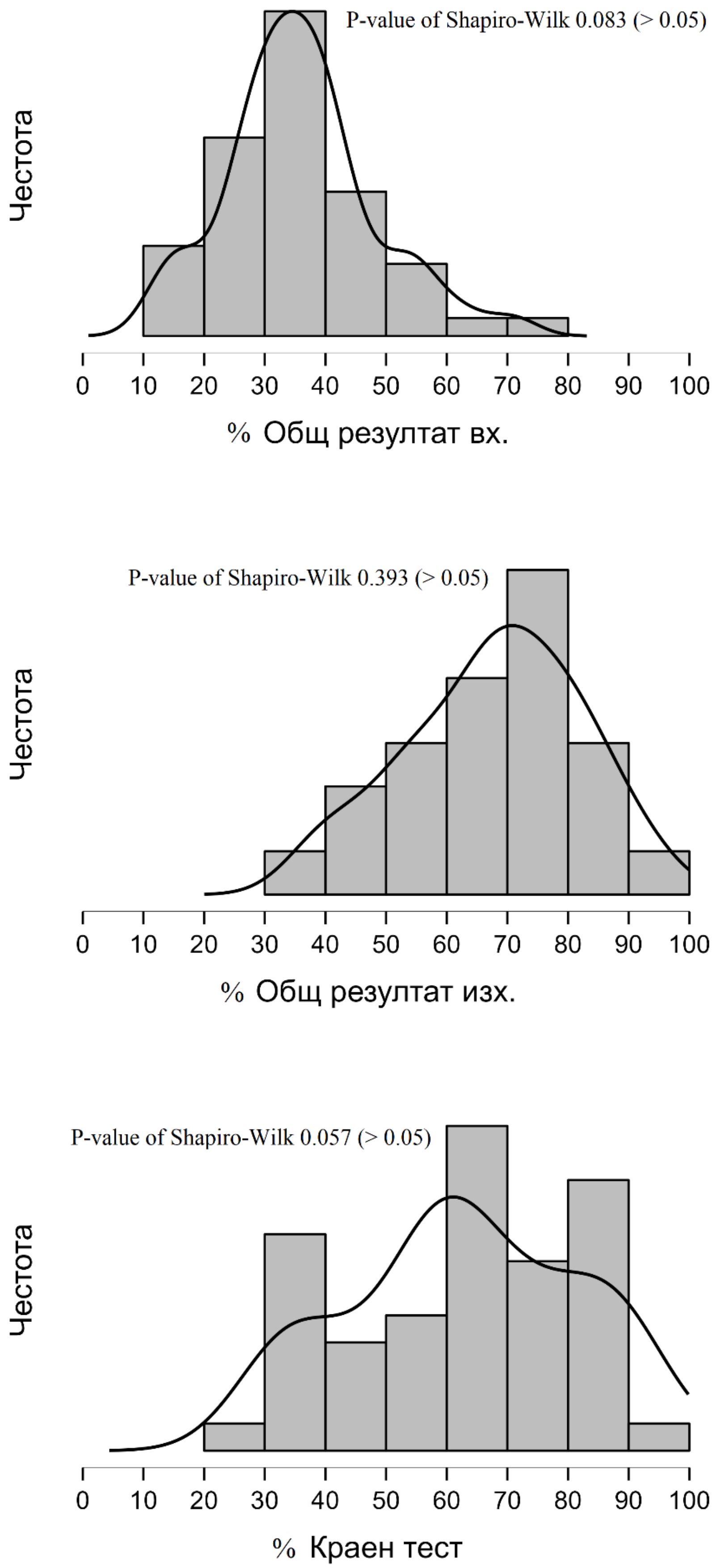

Figure 1. Distribution of results

Descriptive Statistics

Descriptive Statistics

	pre	post	final
Valid	48	48	48
Missing	0	0	0
Mean	8.583	16.250	11.354
Std. Deviation	2.960	3.473	3.411
Skewness	0.524	-0.302	-0.082
Std. Error of Skewness	0.343	0.343	0.343
Kurtosis	0.728	-0.488	-0.886
Std. Error of Kurtosis	0.674	0.674	0.674
Shapiro-Wilk	0.958	0.975	0.954
P-value of Shapiro-Wilk	0.083	0.393	0.057
Minimum	3.000	9.000	5.000
Maximum	17.000	23.000	18.000

Figure 2. Additional information on distributions

It is interesting to consider in which way the distributions deviate from normal. Figure 2 gives additional information, including on whether the distribution is drawn further to the left or further right stopped normal (*Skewness*). It follows from the figure that the results of the entrance tests of the *students who attended and during the 4 weeks (48 in number) were drawn to the left (with a value of 0.524). The sum results of* the output tests They are drawn to the right (-0.302). This is interpreted in the dissertation.

Quantitative assessment of acquired knowledge

This is followed by a quantitative assessment of the upgrading of student knowledge during the individual classes, as well as the general upgrade through a comparison of the total input-output results. In the dissertation, this assessment is obtained in two main ways, which in the literature often compete for various reasons (Nissen et al., 2018, Coletta & Steinert, 2020). The two strategies are the calculation of a certain coefficient introduced by Richard Hake (Hake, 1998) and the application of (two types) of statistical tests (parametric and nonparametric). In the present study, they actually lead to the same results. Only an analysis through the Hake coefficient and the nonparametric test will be presented here.

Hake coefficient *g*

The first of these methods applied to obtain a quantitative assessment of the upgrade of student knowledge consists in calculating Hake 's gain score (Hake, 1998) according to the formula

$$g = \frac{posttest\% - pretest\%}{100\% - pretest\%} \qquad (1)$$

, in which *posttest% and* pretest% *are respectively the output and input averaged results of a class for a given topic. Hake emphasizes that formula (1) represents a ratio between the realized average upgrade (numerator) and the maximum possible upgrade (denominator).*

The meaning of formula (1) becomes clearer when an exemplary comparison is made between two different classes A and B with equally realized upgrade *posttest*% - *pretest% = 30%, but different input results* (pretest%), equal to 20% and 50% respectively for class A and class B. It follows that class A had more opportunities to improve its score. This is reflected in the coefficients according to formula (1), which equals respectively and . The coefficient for class B is higher because, despite the available previous knowledge, students have managed to upgrade them significantly during the lesson. $g_A = 0,38 g_Б = 0,6$

For values g < 0.3, the upgrade is assumed to be small, and the *result g* > 0.7 is interpreted as a particularly large upgrade (Hake, 1998). Values that are located around are assigned to the range of interactive engagement-methods range, as Hake (Hake, 1998) shows. $g = 0{,}5$

Formula (1) can calculate for a given topic (e.g. the photoelectric effect), ... , representing the coefficient for the first of the four classes. The arithmetic mean values of , ... for each of the individual subject-method combinations are plotted in Table 7 of Section III.6.1 . The total upgrade for the 4 weeks will be displayed as the arithmetic average of the results for the individual lessons.$g_1 g_4 g_1 \underline{g} g_1 g_4 \underline{g}$

The Hake coefficient (1) can also be calculated using *Individual* responses (percentages) of each of the 48 participants. In this way, an estimate for the individual upgrade is similarly generated (Hake, 2002, Coletta&Steinert, 2020):

$$g_{ind} = \frac{posttest\% - pretest\%}{100\% - pretest\%} \qquad (2)$$

The mean mean value value of of g_{ind} for the whole sample is distinguished from g by less than 5% (Hake, 2002, Coletta & Steinert, 2020). allows to track the progress of individual (e.g. difficult) students over a longer period of time. g_{ind}

Other authors (Salazar et al., 2019) calculate Hake's coefficient not for individual students, but for individual questions on entry/exit tests:

$$g_q = \frac{posttest\% - pretest\%}{100\% - pretest\%} \qquad (3)$$

The percentages in formula (3) are formed on the basis of all answers to a question. In this way, concepts that still make it difficult for students to be identified relatively quickly. The above section (III.4) discusses all the questions with < 0.3 regarding the physical concepts at stake, trends in the selection of specific distractors (wrong answers) and thus conclusions can be drawn about the course of the lesson itself, as well as in which direction to seek improvement. g_q

Wilcoxon nonparametric test

As a next step, a nonparametric paired samples *test was conducted* (Goss-Sampson, 2019), specifically Wilcoxon's signed rank test, *without removing* participants from the sample whose total test results showed significant outliers (as recommended in (Bakker&Wicherts, 2014)). The results are presented in Figure 3.

Paired Samples T-Test

Paired Samples T-Test

Measure 1		Measure 2	W	z	df	p	Hodges-Lehmann Estimate	Rank-Biserial Correlation
post	-	pre	1176.000	6.031		< .001	7.500	1.000

Note. Wilcoxon signed-rank test.

Descriptive Statistics

	pre	post
Valid	48	48
Missing	0	0
Median	8.000	16.500
Std. Deviation	2.960	3.473
MAD	1.500	2.500

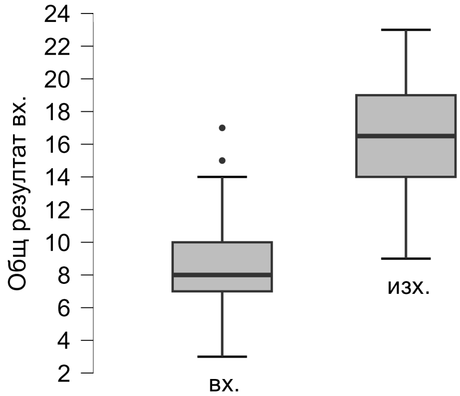

Figure 3. Nonparametric test (total results - total for all topics)

Input to output results for the whole sample have been compared (48). Wilcoxon's W-statistic is significant (), with a value equal to W = 1176 ($p < 0{,}001$Figure 3). The Hodges-Lehmann estimate, *which corresponds to the average difference between the results (*Goss-Sampson, 2019), equals 7.5 points. The rank-biseries correlation can be interpreted as the size of the change (Goss-Sampson, 2019) and for the present data occupies a value . This has been interpreted as a major change (> 0.5) ($r_b = 1{,}00$Goss-Sampson, 2019).

Correlations

The relationships between the results of Figure 1 can also be analyzed. Again, there is an analysis of correlations between continuous data (which provides *a Pearson coefficient r). For correlation analysis between discontinuous (but ordered) data, methods are applied that rank the data and thus* calculate coefficients ρ *of* Spearman and τ of Kendall (Goss-Sampson, 2019). Three pairs of correlations were considered, the most closely related of which were the sum result of the output tests and the result of the final test (Pearson's). This is interpreted as strong $r = 0{,}659, \rho = 0{,}693, \tau = 0{,}547$; $p < 0{,}001$(Goss-Sampson, 2019) and statistically significant correlation - depicted in Figure 4. Whether the information from this correlation provides an answer to the research question B2) will be commented on in the next section.

Correlation Table

				Pearson		Spearman		Kendall	
			n	r	p	rho	p	tau B	p
post	-	final	48	0.659***	< .001	0.693***	< .001	0.547***	< .001

* p < .05, ** p < .01, *** p < .001

Shapiro-Wilk Test for Bivariate Normality

			Shapiro-Wilk	p
post	-	final	0.975	0.405

Scatter plots

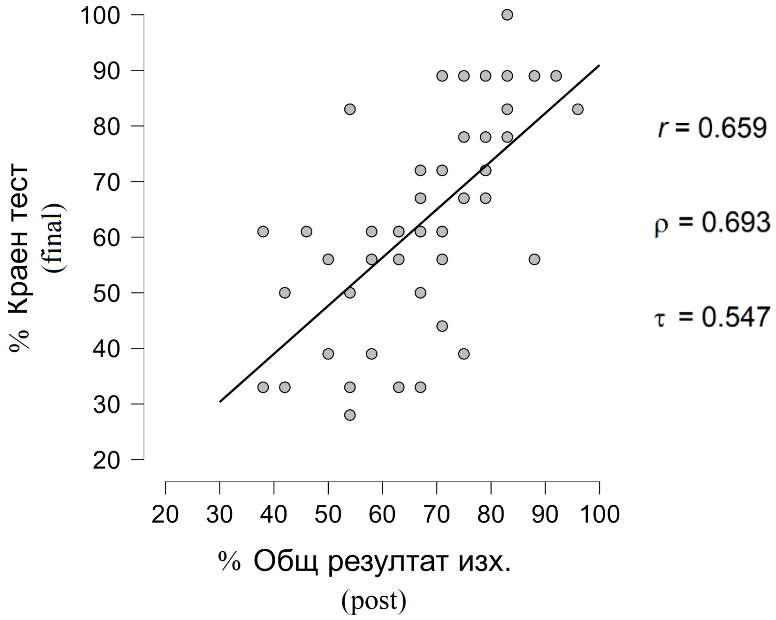

Figure 4. Relationship between the results of the output tests and the final test

III.6 Discussion of results

In this section, the research questions B1)-B6) will be discussed, based on the processed data presented in the previous section (III.5).

III.6.1 Upgrading knowledge (B1)

Table 7 shows the Hake coefficient for the four themes. **A significant upgrade** of the results was observed after each of the lessons (the average for the 4 weeks equals **0.51**), except for the atom/spectra lesson ()$\underline{g} = 0,28$.The biggest upgrade (the core/radioactivity lesson:) is obtained by $\underline{g} = 0,71$**combining** interactive and visualizing methods with systematic generalization of the board. The **Cohen's *d* *value*** > **2** (see dissertation) confirms the good impact of the diverse methods chosen. The average result of the final test is 63%, which can be assumed to be a successful average sample result given the existence of five elective responses Instead of four. One student earned a maximum number of points (18).

Lesson	Combination of methods (same for each class)	Hake's $\underline{g}$
Photoelectric effect	Virtual simulation; "Peer instruction" (students explain of peers); Visualization (with student-actors) of the equation Einstein's.	**0,51**
Hydrogen atom. Spectra	Working and expert groups (mosaic exercise)	**0,28**

Atomic nucleus. Radioactivity	Construction and discussion of light cores (virtual simulation); Student Visualization of Nuclear Forces and the mass defect; Group exercise (decay of uranium-235).	**0,71**
Nuclear reactions and energy	Reading and discussion by teams; Discussion between teams.	**0,53**
Ultimate test	40 minutes for 18 questions [A) to E)]	Mean: 63%

Table 7. Lesson-methods-degree of upgrade

The question arises what was the upgrade of those students (26 in number) who are not included in the here analyzed final sample (48 in number) due to at least one absence during the 4-week period of the study. Their average $Hake$ coefficient (calculated by averaging the individual average values according to formula (2) for those lessons in which the respective student/girl was present) equals 0.56 g_{ind}. On the final test, these students earned an average of 51%, among which there is a maximum score (18 points) despite an absence.

These two results suggest that the exclusion of absent students from the sample probably did not contribute to a significant change in the final results in the present study, since the Hake averaged coefficient for the participants in question ($0,56$) is comparable to the above presented value ($0,51$). On the other hand, the fact that students absent for between one and three weeks (out of a total of four) received on average lower scores on the final test is not surprising.

III.6.1.1 Comparison with Hake's (1998) analysis

Hake's 1998 large-scale analysis (Hake) aims to compare "traditional" and "interactive" methods in the field of mechanics, based on average values of the respective upgrade. The averaging is carried out simultaneously in different educational institutions and in different stages of education (high school students, students). In connection with the schools, Hake came to the conclusion (Hake, 1998, Fig.3(a)) that schools with 'traditional' teaching, where students are rather passive (Hake, 1998), reach values of $N = 6542$ g less than 0.3, i.e. the upgrade is small. Schools that often apply 'interactive' methods reach an average . The corresponding average $g = 0{,}55of\ g$ for universities is slightly lower but comparable. Hake notes that for schools with more advanced courses (*honors classes*) are reported higher values of g compared to regular *classes.* Bulgarian students from the current study are rather assigned to the second category of "regular" courses, as the 10th grades are not profiled and most of them do not want to profile with physics. Also, the high school is a language (in the 8th grade it includes one year of language training **without** natural sciences).

It follows from Hake's analysis that the average upgrade in mechanics of regular students whose teachers use interactive methods is of the order of . This corresponds to the results that emerge in the present study (although the topics are different). On average, students demonstrate an upgrade far beyond what is typical (according to Hake) of "traditional methods." $g = 0{,}5$

Hake summarized in 1998 (Hake, 1998) that in order to achieve large-scale physics education through engaging and interactive methods, it is necessary to work together between all participants in the management of educational activities (teachers at school / universities, departments, institutions, professional organizations, etc.), as well as long-term implementation, scientific research (feedback, analysis of the upgrade, etc.) and modification/improvement of the methods in question. In this context, it makes sense to conduct research on a variety of methods with Bulgarian students.

III.6.2 Sustainability of knowledge (B2)

In connection with the upcoming discussion in this section, it is important to emphasize that before the final test (taken 30-40 days after the first lesson of the study) the students received additional exercises, revision (and optional consultation) - especially for the problematic lesson "Atoms".

Figure 4 illustrates the relationship between the sum results of the initial tests and the performance of the final test. On the right side of this graph there is less variation than on the left side, i.e. there is a tendency for students with higher scores immediately after the lessons to score higher on a final test. From a teacher's point of view, this is not surprising. On the left, a wider distribution of final test results is observed for a given number of points from the output tests. The question arises as to what exactly Figure 4 says in the present context.

The graph summarizes the relationship between two distributions of scores laid by the same students, but at different times. Pearson's coefficient *r* points out that there is a significant correlation. It does not depend only on the specific actions that the students have taken in class (that is, on the various assignments assigned by the teacher). A number of 'hidden variables' are also at stake here (Hake, 2002) that characterise both students' skills to calculate, model, etc., and responsibility/motivation to learn after classes/before the final test.

From the teacher's point of view, the assumption arises that the sustainability of knowledge in atomic/nuclear physics depends to a large extent on the personal qualities of individual students, for example:

- *the responsibility* to *negotiate qualitatively before the* final test - independently or with classmates;
- *the desire* to attend a group consultation in order to learn concepts difficult for them and to consolidate the learning material;
- *the ability* to successfully complete a test *with an assessment* and *limited time*.

From the point of view of some authors in the field of physics education, including Hake himself (Hake, 2002), the following factors (but in relation to higher education) are mentioned and analysed:

- *skills*/knowledge of *mathematics*;
- *the ability* to *visualize* concepts - spatial, patterns, etc.;

Hake found modest but significant correlations between these factors and the upgrading of students g_{ind} in his study, as well as significant differences (in terms of upgrading) between girls and boys.

It follows that Figure 4 generally shows the presence of short-term knowledge resilience for those students who score relatively high after each lesson. The degree of resilience decreases significantly for the other participants, given the variation of their final test scores. This observation leads to the conclusion that in the current study it is likely that other personal factors (beyond the scope of the study) of the students play a greater role than the specific choice of methods during the physics classes. However, students generally increased their motivation to *participate in the class*. This is probably due to the diversification of methods.

What actions can be taken to increase the sustainability of the knowledge of the *all* Students, including those who are struggling? In particular, the question arises as to how the positive effect of diversification of methods can be reinforced for this group of students, which is difficult with the learning material and with self-study.

III.6.3 Struggling pupils (B3)

The coefficients according to formula (3) can be calculated for each of the themes, then averaged over topics. The coefficient thus obtained illustrates the overall upgrade of individual students. It follows that of the 13 participants most hampered in the past, 4 obtained values above the average for the whole sample (0.51). $g_{ind} < g_{ind} >< g_{ind} >$

The average of for here considered part of the sample (13) equals 0.39. It is therefore less than the average over the whole sample (48). That is $< g_{ind} > 0{,}51 Generally$ The population of students with tendentiously lower grades still have difficulties with the absorption of the material in class, despite the diversification of methods. The difference between the two results is less than 25%.

The distribution of the results of these students, as well as additional statistical conclusions can be found in the dissertation.

III.6.4 Concepts making it difficult for students. Differentiation of individual physical phenomena (B4)

Within the present study, questions/concepts emerge that remain problematic for students after the first phase of the research (i.e. immediately after school hours). In relation to these questions, the often selected distractors and other factors in the section on the respective lesson were commented (see dissertation). Of the 24 input/output questions, the 4 most problematic questions - those that for which both the smallest upgrade coefficient () and a relatively small share of correct answers to the outcome of the lesson (< 50%) are outlined. These are the questions $g_q < 0{,}3$**F4** and **A3**, **A4**, **A5**.

Question **F4** checks to what extent students have understood the role of intensity in the photoelectric effect. 48% correctly determined that an increase in intensity will lead to an increase in the number of photoelectrons (but not to an increase in their kinetic energy). The questions from the different versions of the final test that are related to the intensity of the light are 4 in number (TA4, TB3, TC3, TD3) and 52% of the students answer them correctly. That is **Improvement** based on a summary, individual review (and group consultation for those students who wished to visit it) **is minimal**.

Question **A4** checks how students interpret a scheme showing atomic transitions (spectral series of hydrogen). 46% of students correctly indicate that *for a given series* electron transitions from different excited levels to the same lower energy level are shown. The related questions from the final test versions are TA8 and TC8, which 79% of students answer correctly. Question **A3** proved to be the most difficult for students (only 12.5% correct) - primarily because of the exquisite consistency in deriving the answer. The questions TA9, TB9, TC9 and TD9 examine whether students understood the relationship between wavelength/frequency and energy of the respective photon, as well as the relationship between this energy and atomic transitions. The questions cover the entire sample and 50% of the students answer these questions correctly. In general it follows that in connection with the interpretation of a scheme with atomic transitions as well as with the indication of the correct energies of the respective photon there is **significant improvement** (compared to the results of the output of the lesson itself).

Question **A5** is mixed and includes distractors that are related to several concepts - the discretion (mathematically) of the energy levels of the atom, the quantum nature of photons (indivisible), as well as the relationship between their energy and frequency/wavelength. 38% of students respond correctly to the outcome of the lesson.

The questions from the final test, which by presenting specific numerical values check whether the students have understood the relationship between energy and frequency or frequency and wavelength are the first questions from the tests - TA1, TB1, TC1, TD1 (therefore covering the entire sample). 81% of students answer these questions correctly. The final test questions that link to the discretion of the colors/wavelengths/photons emitted by atomic gases are TA6, TB8 and TD8. 53% of students answer these questions correctly. It follows that there is a **slight improvement** in the results.

It turns out that 72% of 18 students correctly answered question TD4, which is related to the historical significance of the photoelectric effect. A large number of these students realized that he had revealed unexpected properties of light (against the background of the conclusions of Jung's experience). This historical aspect was discussed immediately after the virtual experiment exercise.

The last question of each version checks the **overall understanding**, as in its distractors it includes elements of all (or almost all) covered topics during the study. These are questions TA18, TB18, TC18 and TC19, for which students should either decide in which of the already discussed processes the most energy is released (TA18) or correctly recognize the visual phenomenon (TB18 - photo effect; TC18 - nuclear fusion; TD18 - atomic transitions based on a shown linear spectrum). On average, students answered these questions with 52% accuracy, whereby the TD18 question (atoms/spectra) made it most difficult for the respective class (11%, i.e. 2 correct answers out of 18). If one does not consider that part of the sample which worked on the test version D, then 77% correct answers are observed. It should be noted that this difference is indeed large (despite the always available differences between classes/students). Again, it follows that students seriously struggle with the relationship between atoms and their spectra. The good presentation of the other three questions shows that a large number of students correctly identify a phenomenon by picture and define nuclear reactions as the most energetic compared to other examples.

III.6.5 Is it worth it for a teacher to analyse input/output tests in this way? (B5)

It is probably worth a teacher to analyze the result of his own teaching, but not for absolutely every lesson. This type of activity takes time from the school class, and efforts are required for the preparation of the questions itself. However, Hake's formula (1) is simple enough to be understood and even applied by the students themselves. This may prove to be a useful crosscurricular relationship with mathematics. The teacher learns what helps the students, which questions remain problematic, how individual students cope. In this way, the progress of difficult students can be periodically monitored. The effect of a particular method-topic combination can be considered (especially when the teacher undertakes to look for alternative methods for problematic lessons, which for years obviously make it difficult for students to be taught in a specific way). Without further verification immediately after the lesson, it is not always clear how the new idea/combination of methods has impacted.

It is noteworthy that students fill the tests with interest. In relation to the present study, the suspicion arises that this results from the perception of input/output tests as an exercise/challenge without the presence of stress (evaluation). Students notice that the teacher indirectly communicates the desire to help them, and thus the work is perceived as collaborative.

The students knew they would get the same test after class. This further directs their attention, because during the class itself they in one way or another try to extract the answers from what is happening in the classroom.

III.6.6 Key signs of activities in individual lessons (B6)

As mentioned in Chapter II, the individual methods/proposed activities in the articles can be characterised by key features that determine the *how exactly* Students are engaged during class. In Chapter II, the analysis of the 32 selected articles was presented compactly (Table 5) in order to illustrate which of these signs are directly (or indirectly - from the context) mentioned by the authors. What does the table look like for the 4 lessons described here if they are mapped on 4 rows? Table 8 reveals that *each one* of the four lessons motivated:

- group work and discussion between students;
- the establishment of a link with previous knowledge and with everyday life;
- the interpretation of data presented in a variety of ways;
- seeking an explanation of specific issues.

The table also indicates key activities that *are not embedded in any* of the lessons (bottom line):

- conducting/planning an experiment or creating a device;
- fieldwork.

Тема на урока	Колич. анализ?	Описание/план на урока?	Дискусия	Връзка с ежедневие	Връзка с предходни знания	Обясняват отговори	Изразяват идеи	Групова работа	Работят с компютър	План експ./създаване	Провеждат експ.	Тълкуват данни	Презентират дании	Наблюдават явление	Използват факти, за да докажат	Гледат демо на експ.	Работа на терен	Трудни/нетипични задачи	Обратна връзка
АТОМНА:																			
Фотоефект	Y	Y	X	X	X	X		X	X			X		X	X				X
Атоми/спектри	Y	Y	X	X	X	X		X				X			X			X	X
ЯДРЕНА:																			
Ядро/радио-активност	Y	Y	X	X	X	X	X	X				X				X			X
Ядрена енергетика/реакции	Y	Y	X	X	X	X	X	X				X	X		X				X
ОБЩО:																			
4 седмици разнообразни подходи	Y	Y	X	X	X	X	X	X	X			X	X	X	X	X		X	X

Table 8. Key Signs in Physics Classes

The field work probably includes participation in the Master Class organized by CERN (in collaboration with the Faculty of Physics at Sofia University), which is held every year and introduces students to the scientific approach through real experimentals data from the detectors of the Large Hadron Collider (LHC).

A qualitative experiment in the 10th grade is not impossible. More time per class is needed, given the type of high school (linguistic). As a conclusion, it can be confirmed that the variety of methods successfully leads to diversification of the specific activities of students, in which the use of computers is central to only one of the four lessons. The nuclear energy lesson motivates students to express opinions and seek crosscurricular connections. Field work is offered at All students and it takes place *optional*. The current study does not include the conduct and planning of an experiment, although an experiment on atoms/spectra was conducted with students from another school (Kunis et al., 2022).

It follows that within a few weeks (*at least* 5 instead of 4) the complete filling of the columns of the table is possible only if the teachers have several hours to include additional exercises. Based on the data from the study, the assumption similarly emerges that if the students themselves have more time to understand the relationship between atoms and their spectra, then the upgrading of their knowledge on this topic will be dramatically improved.

In addition, some authors have suggested that in order to observe a significant increase in student motivation, **long-term** application of interactive methods is needed in order to meet the needs of students (Azizoglu et al., 2022). The authors add that it is desirable that the method they consider be practically applied by teachers during their studies.

III.7 Conclusions of the study (B7)

In connection with the 2022 survey with tenth graders (CMO) from a private English language school in Bulgaria, the following main conclusions are outlined:

- **Diversification of methods helps students develop diverse skills (III.6.6) and** build on their knowledge of atomic and nuclear physics (III.5, III.6.1). Upgrading falls into the category of **interactive methods** and is comparable to the average results of a larger analysis of schools in another country (III.6.1.1);
- Short-term **robustness of knowledge** was observed only in students with coefficients of greater upgrading/scores from the aggregate output tests (III.5, III6.2). The results of the final test of those students who already during the lessons failed to master key concepts **vary more** and are generally **lower** than those of their aforementioned peers.

The reasons for this have been commented, on the basis of personal assumptions and of judgments formed by other authors (III.6.2);

- **Problematic** remain the concepts of:
  - the role of light intensity in the photoelectric effect;
  - the atomic transitions and their relationship to the observed linear spectra, although students show a significant improvement in the final test (after additional work in class and out of time);
  - the quantization of the energy levels of the atom and the quantum character of the photons, although a slight improvement of the final test was observed.

  It turns out that these problems do not only occur in our students (III.6.4);
- Pupils **are aware** of the historical significance of the photoelectric effect and **successfully distinguish** covered phenomena by picture, with the exception of spectra and their relationship to atomic transitions (III.6.4);
- The main problem (including the lesson "Atoms/Spectra") is related to the fact that in practice **there is no time to** apply more different methods in relation to a specific topic (see dissertation). The question (A3) is difficult for students because it requires deeper thinking and the establishment of a connection between several concepts. We are talking about a cognitive level, which for a large number of students is reached only through additional time for exercise. **The experimental** method (which does not appear in the present study, but was conducted separately) shows (see dissertation) that the relevant group of students more successfully assimilates the concepts in question;
- The comparison of lessons with respectively the highest/lowest upgrade coefficient g leads to the hypothesis that the use of **different interactive methods *within a lesson,*** combined with a summary and writing a plan on the board, provokes the interest and keeps the attention of the students. The fact that this leads to better end results should not be ignored (despite the differences in the relative difficulty of the two lessons - for the atom and for the core).
- Some of the students who have struggled in the past demonstrate an upgrade higher than the average for the entire sample. However, some students score poorly on the final test. That is, the diversification of methods in the current format (in terms of choice of methods, duration, etc.)**has not helped all students** to successfully upgrade their knowledge of atomic and nuclear physics.
- **Yes**, it is worth a teacher to apply (and analyze through Hake's coefficients (1), (2), (3) $g g_{ind} g_q$**inputs/output tests** (especially when unevaluated) - or periodically to track students' progress and/or in relation to topics that are problematic for students in order to precisely identify their misconceptions, as well as to check the impact of a new learning method.

In summary, it follows that the intuitive assumption of a number of teachers/parents/students/methodologists **is confirmed** by quantitative analysis - the diversification of methods helps Bulgarian students to develop knowledge and skills **if** the relevant tasks can be covered within the limited time. Some topics require more time than other topics. This is not clear from the physics and astronomy curriculum for X grade (Ministry of Education and Science, 2018), but can be supplemented with help from teachers.

Problem concepts can be worked on by applying additional methods for which publicly available information from authors in this field exists. Incorporating activities that engage students in different ways (and degrees) shows good results. The teacher himself can periodically analyze the effect of the methods used, as well as track the progress of difficult students. They need further consultation despite their increased interest during classes. The problem is probably related to their ability to learn periodically and independently - a quality that, if they want to apply successfully in the future, must be built up at school - with the help of teachers, parents and classmates.

Conclusion

The diversification of methods in general secondary education in atomic/subatomic physics in Bulgaria leads to good academic achievements of students in general, including some of the students struggling with the subject. In attempting to cover the basic concepts of atomic transitions and their relation to linear spectra in an interactive way, the teacher encounters difficulties, due to the limited time per hour. There are many opportunities to diversify activities. The implementation of intriguing methods in physics classes can be facilitated if some of the topics merge into mandatory-election content. On the one hand, the comparison of curricula in a number of other countries reveals that in Bulgarian general high schools atomic and subatomic physics is very well covered. On the other hand, the question arises as to whether this programme should be reviewed. Bulgarian students study some relatively abstract and partly conceptually difficult to understand topics as early as tenth grade, regardless of their focus (choosing a profile in the second high school) and without the possibility within regular classes some of these topics to be elective for them. This conclusion is reached as a result of an analysis of curricula from a number of countries around the world, each of which has significantly high results in the PISA 2018 (Science) study, as well as empirical observations and processed data from a survey with Bulgarian students at a Sofia language school.

It follows that there are many possible directions in which one can look for ways to support Bulgarian school physics. Comparison of curricula (in any subject) takes time, but reveals useful information and contextualizes national decisions in a given field. The physics curriculum in some other countries includes interesting details that are useful for teachers. For example, good guiding questions are listed that can motivate discussion with students on a given topic or determine approximately how many teaching hours it is meaningful to allocate to the assimilation of a concept. The present work (as well as a number of other articles) clearly reveals that some topics (hydrogen atom) take significantly more effort and time to assimilate. The question of the volume of material studied is topical. It is worth considering a national approach that prioritizes the deeper absorption of fewer topics. The content does not need to be significantly reduced. In practice, it turns out that the annual number of physics classes 10th grade in some high schools does not reach 72 hours for various reasons (national holidays, external assessment, etc., including related to the particular school).

The availability of elective cross-curricular "modules" within the physics curriculum at first upper secondary level would encourage the implementation of the integrated approach on a national scale. Some group methods (problem-oriented tasks, presentations, projects, experiments, etc.) find extremely good application precisely within this type of integrated content and are not limited by one specific topic (physical, chemical, historical, ...). For example, a configuration is possible in which students group develop a product or illustrate a current/interesting phenomenon. With the help of the teacher, they conduct the necessary research/research, learn to present and defend information/results to a jury, liaise with entrepreneurship and/or history, etc.

The conducted review of articles can also be expanded and categorized interesting/useful for students methods in the field of physics in general. The identification of key features contained in the articles can be further improved. On the one hand, additional signs can be selected. On the other hand, the analysis of articles can be conducted by several scientists/teachers who can then compare how they filled out tables such as Table 5. This process probably cannot be automated in the near future and the expert assessment of several people will lead to an accurate and compact description of an article in the field of training methods. This can be useful for all participants in education.

The study with Bulgarian students allowed to find answers to several research questions. The formation of more teams that purposefully conduct this type of research can certainly reveal a lot about the learners, about the teaching style of their teachers, as well as about the results of changes in the education system. It seems that this way a good idea is gained about the "micro-effects" in education, i.e. - about the results after one hour / block of teaching or based on one particular method, etc. Analyses of the results of national external evaluations reveal the state of education on a crude, albeit significantly larger, scale. A combination of the two types of analysis would give an even more comprehensive picture of the state of physics education in Bulgaria.

Here, the study with students described is limited as it does not include a control group. The reasons for this are given in Chapter III. However, the study can be improved if conducted with more participants, for a longer time (several months or a whole year), and in order to identify effective method-topic combinations. In this way, one can verify the assumption expressed in the dissertation (not in the autoreference) that the merging (within a lesson about new knowledge) of interactive methods with generalization and systematization by the teacher in general represents the optimal strategy for achieving good success and motivation.

Based on the results of secondary analysis (see dissertation), another potential topic for discussion and analysis arises - career guidance. In practice, there are students in general high schools who, even at the end of the first high school stage (the end of the 10th grade), do not know what they want to do. This probably makes it difficult to choose a specific profile. Career guidance can be inspiring and useful for students (especially if people with experience in a particular field are visiting the class). There is an opportunity to integrate career guidance into the curriculum - in class hours, in the curricula in specific subjects, even in the form of internships after a preliminary indicative determination of the interests of the child.

Author's contributions

1. Development and approbation of a methodology for comparative analysis within the world training in atomic and subatomic (high school) physics, based on predetermined content indicators in curricula;
2. Creation and implementation of a methodology for characterizing, through key features, the content of publications in the field of training methods;
3. Extracting a number of links between factors in education and physics outcomes through secondary analysis, based on data from the TIMSS Advanced 2015 study;
4. Creation of a methodology for quantitative measurement (in three ways) of upgrading knowledge as a result of learning through various interactive methods in the field of school atomic and subatomic physics, within the framework of a practical study conducted with Bulgarian students from a language school.
5. Development of recommendations based on the results obtained.

Publications of the author and participation in conferences

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49th NATIONAL CONFERENCE ON PHYSICS EDUCATION on the topic: "Physics in STEM Education in Secondary and Higher Schools" 4 – 6 June 2021, Vidin
National Conference with International Participation "EDUCATIONAL TECHNOLOGIES 2021" 06.09. – 09.09.2021, gr. Kavarna
Ninth International Conference "Modern Trends in Science" – FMNS-2021 15 - 19.09.2021, Blagoevgrad, Bulgaria
50th NATIONAL CONFERENCE ON PHYSICS EDUCATION on the topic: "Climate Change and Physics Education" 2 – 5 June 2022, Varna
11th Conference of the Balkan Physical Union (BPU11 Congress) Belgrade, Serbia, from 28 August to 1 September 2022.
EDUCATIONAL TECHNOLOGIES 2022 International Science Conference September 7-8, 2022 Kavarna, Bulgaria
3RD NATIONAL FORUM FOR ADVANCED SPACE RESEARCH SOFIA TECH PARK, 10-12 NOVEMBER 2022

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