Matematicko-fyzikální fakulta Univerzity Karlovy v Praze

Výuka astronomie na středních školách

Petr Pudivítr

Školitel: Doc. RNDr. Marek Wolf, CSc.
Obor: F12 Obecné otázky fyziky
Praha, červen 2004

Faculty of Mathematics and Physics, Charles University, Prague

Teaching Astronomy at High Schools

Petr Pudivítr

Supervisor: Doc. RNDr. Marek Wolf, CSc.
Branch: F12 General Questions of Physics
Prague, June 2004

Tato disertační práce byla vypracována v rámci doktorského studia na Matematicko-fyzikální fakultě Univerzity Karlovy v letech 2001 - 2004.

Doktorand:
Mgr. Petr Pudivítr

Školitel:
Doc. RNDr. Marek Wolf, CSc.

Školicí pracoviště:
Astronomický ústav Univerzity Karlovy
V Holešovičkách 2
180 00 Praha 8

Oponenti:

Doc. RNDr. Zdeněk Pokorný, CSc.
Hvězdárna a planetárium Mikuláše Koperníka v Brně
Kraví hora 2
616 00 Brno

RNDr. Martin Macháček, CSc.
soukromník
Ondřejov 219
251 65 Ondřejov

Autoreferát byl rozeslán dne

Obhajoba se koná dne . .2004 v hodin před komisí pro obhajoby disertačních prací v oboru F12 Obecné otázky fyziky na Matematicko-fyzikální fakultě Univerzity Karlovy, Ke Karlovu 3, Praha 2 v místnosti č. 105.

S disertací je možno se seznámit na studijním oddělení Matematicko-fyzikální fakulty Univerzity Karlovy, Ke Karlovu 3, Praha 2.

Předseda rady doktorského studijního oboru F12:
Doc. RNDr. Jiří Langer, CSc.

Contents

1 Introduction

Teaching astronomy in a class at Czech high school depends on a teacher that teaches physics in the class. On one hand astronomy is taught by teachers that practise amateur astronomy, on the other hand it is taught by teachers that have never heard about astronomy before.

In spite of this, astronomy is valued as a very useful subject that is suitable for teaching natural sciences. Extraordinary images of distant galaxies attract students, astronomical exercises connect physical principles together with geographical view, biological aspects, or chemical laws. We can use parts of astronomy in curricula of all these subjects, where application is serving a purpose.

According to changes that are happening not only in curricula in the Czech Republic, there lies a question of usage of astronomy for students' motivation. Can we let it be just only an extra-part of our subjects? Is it necessary to teach astronomy in non-science classes? What kind of teaching should it be?

2 Teaching Astronomy

There are many articles on teaching astronomy at schools, but Pasachoff and Percy's (1990) remains the most useful publication. The situation of teaching astronomy at high schools is rapidly changing, along with changing of school curricula or school systems. According to Stavinschi (2003), astronomy has not been in curricula of many countries, yet pseudo-sciences and astrology are still taught in schools all over the world.

International Astronomical Union tries to cover the situation, especially in its Commission 46 named *Astronomical Education and Development*. In 2003 the commission brought out its *Resolution on the Value of Astronomy Education*, that reflects a global necessity of astronomical teaching for all, who want to live in a modern society. As one of the points, the resolution recommends educational systems to include astronomy as an integral part of curriculum. On the other hand approximately 50 % of children can attend no school (it makes up about 130 million children aged 6 to 11 without basic education) - for these kinds of countries it is very complicated to involve astronomy there.

Children in the **Czech Republic** get to know their first astronomical facts in their first five grades of basic schools. In the ninth (the last) grade astronomy can form a topic in physics, taught for half a year. Many teachers do not teach it because pupils lose interest at the end of the year. Some astronomy may also be covered as examples of theories in physics.

At high schools the only formal astronomy teaching is in the gymnasia, where astronomy is a part of physics. Unfortunately, there are many other topics to teach, and with physics getting an average of just two lessons per week for three

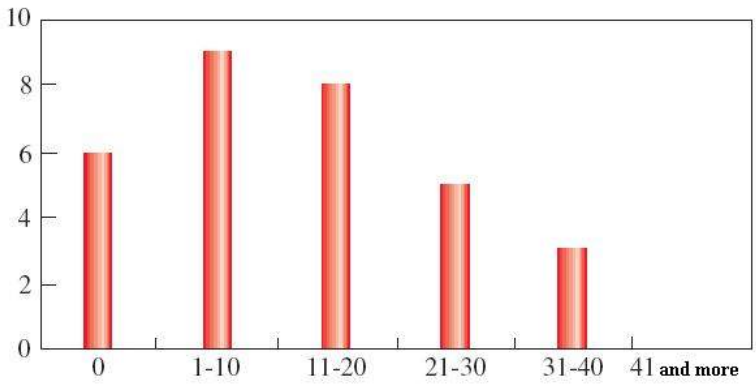

Figure 1: In how many lessons do your children study astronomy at school?

or four years, the pressure of time tends to squeeze out much of the astronomy.

About 5 % of all the physics lessons appear to the astronomy (see figure 1), but we need to remember that these data were obtained from a questionnaire that was answered by teachers who taught astronomy as well. Astronomy is taught predominantly by lecturing facts about the solar system, stars, galaxies and the universe in the last grade (the recommended textbook is Macháček 1998). Only gravitation problems (moving of objects in homogeneous and central gravity fields) are discussed in the first grade in physics (Bednařík and Široká 2000). Our students can use these facts, but do not see the relevance of them to solving real-life problems.

In **Europe** there are three types of countries with different astronomical teaching at high schools (see table 1). Countries of the first type teach astronomy only as examples in other subjects, or have no astronomy involved at high schools. The most frequent way of teaching astronomy is seen in the second type - astronomy is a part of another subject (like physics or science). This type is used in the Czech Republic too. Astronomy as a separated subject is taught in the last type of countries. Teaching of astronomy in European countries is on high level. Astronomy is taught with more mathematical background, so it is in its difficulty similar to American freshman astronomical courses.

North America countries have different way of teaching astronomy. While US high schools have got *Earth & Space Science* chapter included in a subject called *Science* (for all grades K9–K12), Canadian provinces create their own curricula. Most Canadian schools use *Pan-Canadian Science Project*, where astronomy takes place in grades K9 and K11 (or K12). Very poor knowledge of astronomy among high school teachers is the biggest problem in these countries.

Kantor (2001) mapped the situation in Brazil (very similar situation is in other **Ibero-American countries**). There is no astronomy in high school curriculum

astronomical examples in nature sciences	Belgium, Germany
astronomy as a part of another subject	Austria, Croatia, England, France, Hungary, Lithuania, Poland, Russia, Slovakia
astronomy subject or seminar	Finland, Greece, Romania

Table 1: Categorization of some European countries according to their astronomical teaching at high schools.

except of gravitation in physics. This is caused by no astronomical preparation of future teachers. Very valuable teaching of astronomy exists in Cuba: students learn about the universe in the first grade and astrophysics in the last grade of high schools.

There are two different countries in **Asia**. In Japan the school system was renovated, Isobe (1993) wrote on a problem of Japanese teachers that are not able to understand astronomy themselves. Many students find astronomy as a very difficult subject. In 2003 there were used new curricula of subjects in Thailand. Astronomy is taught with the same importance as mathematics or physics.

The situation in other countries (more detailed), also in **Africa** and **Australia region** is discussed in the thesis.

3 New trends

Astronomy at high schools in the Czech Republic is still lectured as a collection of facts. Facts about our solar system thematically dominate (especially in the only Czech high school textbook Macháček 1998). However, there are new trends growing in the world: new astronomical topics, new methods of teaching, new programmes for non-science students, or dominant progress of using computers in lessons.

Štefl (2002) alerted on the necessity to revise the whole structure and range of astronomical topics for teaching at high schools. He correctly reasones that it is not possible to cover all new fields of modern astronomy, and that attractive problems are still missing. He suggests to use astrophysics, strongly connected to physics, to attract students. I propose to use another (more interesting) subjects for students, as biology, geography, arts... Astronomy as the last part of physics loses its unique property: it is very interesting subject that can be used to motivate students in all subjects.

Activities in lessons (which frequently do not have the noticeable astronomical background) can help students to learn astronomical data by the way. It always depends on atmosphere in a class: one group of students can deal with real as-

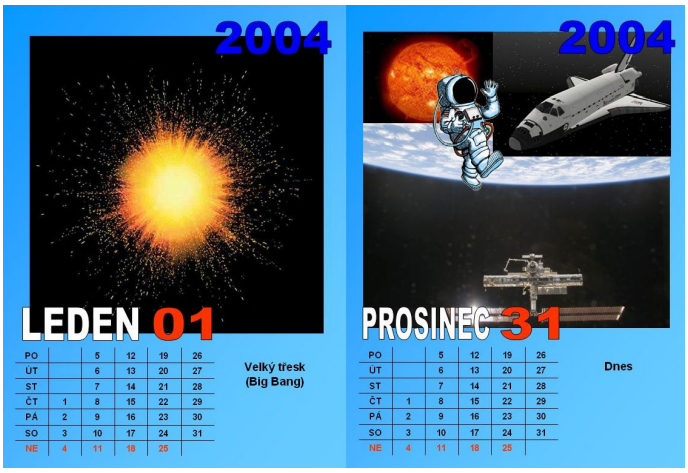

Figure 2: The first and the last page of a cosmic calendar. Students have to make a calendar where all important historical events of our universe are showed. The Big Bang started on January 1st, our presence is at midnight of December 31th.

tronomical data, while non-science students can solve life-based exercises. One kind of activities are **projects**. Project is a task that is handled by students, who should evolve a certain effort (Petty 1996). It is often useful to built up a team of students to work out the project. Projects can take one lesson (like a cosmic calendar project, see figure 2), or can take all school students a week or more. Very popular project is called *Voyage to Mars*, where students are divided into groups of engineers, astronauts, biologists, physicists, politicians... The goal is to prepare a voyage to Mars: engineers built up plastic rockets, astronauts practise space-walk in a swimming pool, biologists grow hydroponics...

Very popular are **games** or **life-based problems**. Explanation of HR diagram can be introduced by height vs. weight diagram (see figure 3). The chapter on galaxies can be introduced by the classification of images of galaxies by their shape. Kirchhoff's laws can be demonstrated by group of students that pitch multicolored tennis balls (they represent multicolored photons).

Practical measurements are neglected at high schools, because teachers consider astronomy a night-science. There are many daily-experiments (observing the sun, moon, optical phenomena in atmosphere), students can make their night-experiments at home (moon drawing, watching constellations). With contribution of computers students can measure computer exercises (ESO/ESA Astronomy Exercises Series, CLEA). Computers become very important component of astronomical teaching: astronomical information on web, finding astronomical pictures, or multimedia encyclopaedias are some of possible usage of them.

Astronomy for non-science students is the useful way for making astronomy more interesting for these students. Fraknoi (2002) prepared a list of stories

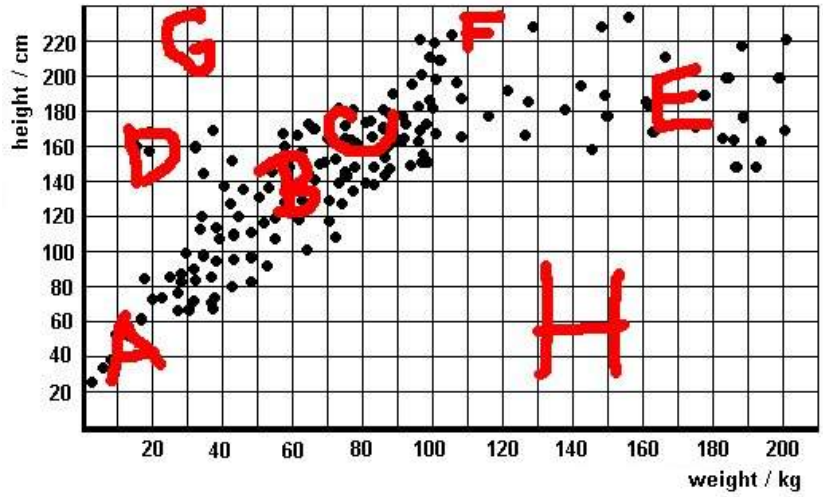

Figure 3: HR diagram of height vs. weight. Students are asked to collect data of height and weight of some group of people (parents, teachers, football players). There can be seen at least eight areas of people: A - early born, B - growing up, C - adults, D - malnourished, E - overweight, F - extra-high; areas G (undernourished tall) and H (underweight) are improbable for humans.

with astronomical background, Czech teachers can use translations of these works or can use works by Czech authors (Čapek, Neruda, Neff). They can use history of astronomy to introduce astronomical topics (Giordano Bruno's story, Stonehenge and other ancient observatories, enlarging of our solar system, philosophic view of the universe). Music of composers that was sent with our probes (e.g. Viking) can be great accompaniment of lessons. Students can draw astronomical topics in art lessons.

4 High school astronomy topics

Making new astronomical tools for teaching has to be the new task for methodological and didactic experts. Teachers are waiting for exercises that attract students, that can expand their interest in natural sciences. Although we can use all students' knowledge in their last grade of high school for solving astrophysical problems, there are more students that are bored of that. Students with the interest of astronomy can study independently, they can attend a special astronomical seminar (there are many good textbooks for teaching this, e.g. Šolc, M. a kol. 1983).

I suggest to use astronomy in all four grades of high schools to motivate students for natural sciences. My plan relates with all subjects (natural and art ones), so astronomy connects all other subjects), teachers can use the appropriate topic in

their lessons (whereever it is possible). Physics has still got the most important role in teaching astronomy, but astronomy appears in chemistry, biology and other subjects too (Pokorný 2001).

The topics should be taught in an easier way, following present topics in all subjects. Nowadays there is a chapter on our place in the universe in geography, planets and their moons are discussed in physics in chapter on gravitation. The origin and evolution of the solar system is taught in biology, the genesis of chemical elements (in the sun) in chemistry. Teachers of mathematics suggest to teach more astronomy in their subject (using logarithms in astronomical equations - e.g. Pogson's law, or conics in planet motions).

The most discussed issue is the preparation of future teachers that would teach astronomy in their lessons. I agree with Pokorný (2001) that academically educated teacher is able to understand basic astronomical concepts and to use methodical tools in lessons[1]. Ideas of high school astronomy do not need to be very scientific ones, it is more important to use astronomy to motivate students, to guide them into the problems of natural sciences.

To define new high school astronomical topics I firstly rewrote topics by Mackowiak (2003) and used those of Fraknoi (1996) and Pokorný (2001). Basic concept of the approach is summarized in this overview:

> We are living in the universe that is approx. thirteen billion years old. During the time systems of stars were gravitationally created, energy of thermonuclear reactions in these stars counteract against gravitation. We can observe other objects in the universe (straight or indirectly): black holes, pulsars, quasars, neutron stars... Exploring the origin and evolving of the universe are some of the fundamental questions of astronomy. Astronomers know features of these object mostly by observing the electromagnetic radiation of these objects.
>
> Our solar system is a part of a spiral galaxy that contains billions of stars, planetary nebulas, star clusters, and central black hole. The sun is our nearest star - rotating sphere of hot gas. Thanks to its energy (that has been emitted for about five billion years) good conditions for life were created. All planets are orbiting the sun and only reflect the sun light.
>
> Astronomy is no more just night job, it is no more science of optical and radio telescopes. It is science of all kinds of electromagnetic spectrum, and can be practise during day. Not only do terrestrial telescopes (VLT, Kecks) and telescopes in the universe (Hubble) help, but space probes, computers or CCD cameras help too. Astronomical observations can

[1] The thesis contains samples of these tools (exercises), some of them can be obtained through the web page *Výukový AstroWeb* (`http://puda.matfyz.cz`).

help to discovering various new facts from secrets of our universe to secrets of the ecosystem of our planet Earth.

Astronomy affects our culture and history by its practical applications, by philosophical and religious ideas. It reflects in calendars, mythology, works of art, navigation, time measuring, climate... Astronomy is no more just the spherical astronomy, it is the science that connects all other sciences (physics, chemistry, mathematics, geology, meteorology, or biology). There is the great difference between astronomy and astrology.

Following topics that are suitable for Czech high schools are in correspondence with Fiero (2000), who put together required astronomical skills of high school students.

4.1 Universe - Its origin and our place in it I

This chapter has to be taught in the first grade of high schools. Students learn our location in the universe, and get to know all common astronomical events. In physics teachers should start their lessons with the matter, space and time (using coordinates for specification of the location, periodical astronomical events for better understanding of measuring the time). There should be briefly discussed forces and universal constants too. Chapter on galaxies is included for better and more attractive teaching about the universe. Deep insight to the universe is not needed.

Geography can present the location of our Earth in the solar system, more detailed information on motions of our planet (moon and solar eclipses included). Geographical coordinates for description of location of all objects is needed (see an example of exercise in figure 4).

The topics are:

Structure of the universe (matter, space, time, forces, universal constants)
Galaxies and their formation (*Hubble Deep Field* included)
Measuring distances in the universe (astronomical unit, parallax, parsec, light year)
Time measuring (clocks, time intervals, calendar)
Earth location in the universe (the universe, our Galaxy, the solar system)
Astronomical coordinates (sky view, motions of planets, moon and the sun)

Students should measure some astronomical events (observing the night sky, sundial building, measuring the sun height or the angular diameter of the moon). As basic knowledge students should understand the implementation of coordinate systems, the important role of universal constants, and be able to recognize the main constellations.

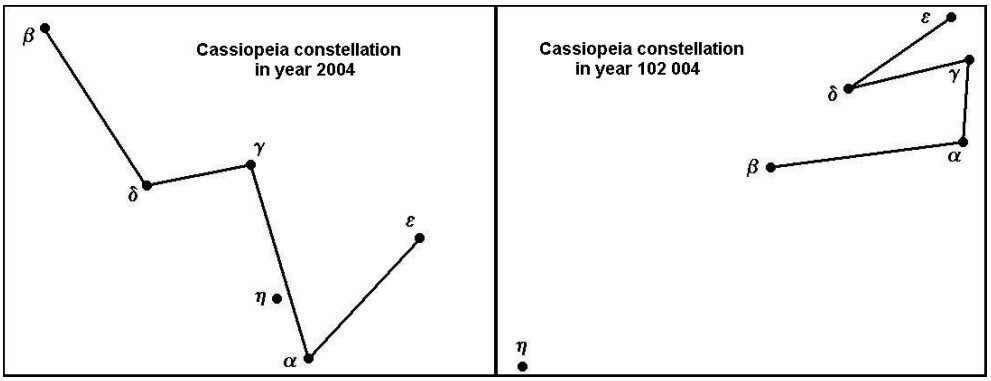

Figure 4: A shift of Cassiopeia constellation stars in next 100 000 years. Students find the information of changing constellations during time and draw the future positions of stars. They use astronomical coordinates (right ascension and declination).

4.2 Understanding of our solar system

Astronomy starts again at the end of the first or at the beginning of the second grade of Czech high schools in physics (the chapter about the gravitation). Students already know elementary mathematical functions and they are able to solve equations and inequations. This time the understanding of the solar system should be completed. Connections are in chemistry (the structure of objects in the solar system), in biology (exploration of the solar system, possibility of life on other planets), in geography (cartography of other planets).

Students should use more mathematical knowledge into astronomy (circular motion, goniometry, conics - see figure 5).

Topics are:

Origin and evolution of our solar system
Geocentric and heliocentric concept (history of astronomy)
Planets (wandering stars, planet loops, visibility of planets)
Structure of objects in the solar system
Exploration of the solar system (probes, rockets, Moon conquest...)
Structure of our sun

As practical exercises students can draw the surface of the moon, make projects on geocentric or heliocentric view of the solar system, can observe sun spots (this connects the topic to the following topic of physics - electricity and magnetism). Basic laws are Kepler's laws of planets' motion and Newton's gravitational law.

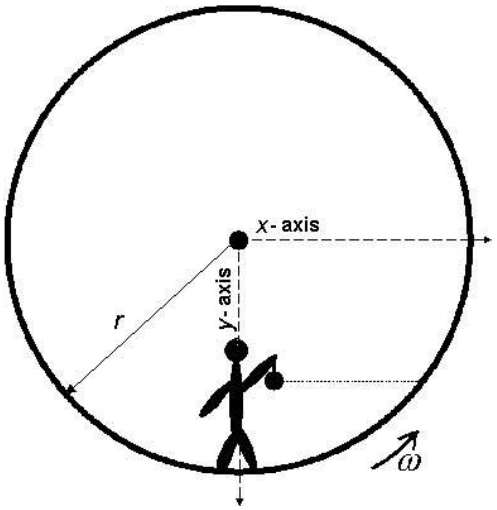

Figure 5: The situation of space station with the artificial gravitation caused by its rotation. Students discuss "free fall" of an apple. This exercise requires better mathematical understanding of the situation. (Fisher 2001)

4.3 Objects in the universe and how we know about them

At the beginning of the third year most schools start their last year of physics and other natural sciences too (except of biology where there are many topics to teach). That is why I suggest to teach the following topics in the last year of these natural sciences (if it is possible). The topics are:

Stars (characteristics, spectrum, star classification)
Star systems
HR diagram (evolution of stars)
Galaxies, galactic nuclei
Relativist astrophysics (quasars, black holes, gamma ray bursts...)

All the topics are closely connected with optics (see figure 6), unfortunately electricity and magnetism take place before the optics. I suggest to teach optics before the electricity and magnetism - so optics (especially the geometrical one) can be taught closer to the plane geometry in mathematics (where problems of Huygens' principle, refraction and reflection, mirrors and lenses can be mentioned).

The estimation of magnitudes of stars using searching maps can be one of the practical measurements. Basic laws of this chapter are Kirchhoff and Stefan-Boltzmann radiation laws, Wien displacement law, Pogson's equation and Doppler's effect.

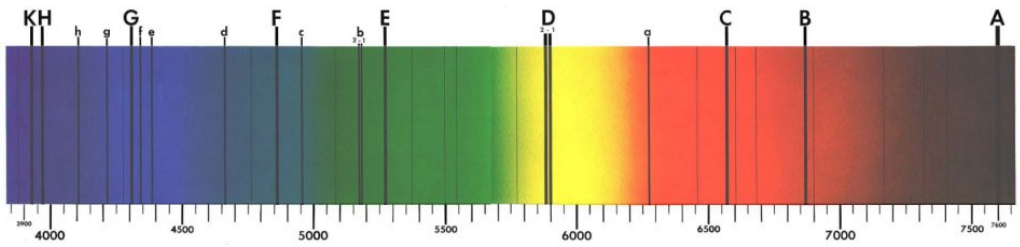

Figure 6: The spectrum of our sun. By classification of missing lines of the spectrum students find chemical elements existing on the sun.

4.4 Universe - Its origin and our place in it II

In the last grade of high schools students that are interested in astronomy and have no astronomical seminar should be showed what is concrete astronomy about. Astronomy should be ended with these topics:

> **Other methods of measuring distances** (using radio astronomy, supernovas, cepheids)
> **Measuring velocities**
> **Hubble law, the age of the universe**
> **Cosmology** (dark matter, dark energy, evolution and the end of the universe)
> **General questions of astrophysical sciences**
> **Life in the universe** (Drake equation)

Students have to solve astronomical "undying" questions (How old is the universe?), and seek the interdisciplinary connections (Are there another life forms in the universe?). They can use all their knowledge that was given to them in all grades of high school.

As practical problems for measuring, students can use simulations of real astronomical measurements, or they can participate international projects and competitions.

COMMENTS TO THE NEW TOPICS:

Questions of new way of teaching natural sciences come regularly, but nowadays also deeply. With the future reorganization of curricula (all natural sciences will be in one topic called *Human and nature*) there is possibility to change the order of topics in these subjects too.

I see astronomical topics to be very suitable for making natural sciences more attractive for students - that is the main reason for the shift of astronomy from the end of physics (where there is no time to teach so attractive topic because

of close state exams). Teachers should use the interconnection of astronomy with mathematics (where historical astronomical examples are very motivating). Some countries in the world tried to connect astronomy with al natural sciences (US project STAR[2], where the level of content is very low according to the Czech Republic standards), or with mathematics (England).

Teachers of different subjects should more co-operate with each other in making their subjects more interdisciplinary. More methodological materials are needed (sets of exercises, worksheets, series of commented pictures...). The co-operation is mentioned in the new conception of Czech school system, the methodological materials are available for free in English on internet. The next step should be using astronomical examples in textbooks of other subjects, or to bring out an astronomical textbook where all subjects will be used (as a teacher's manual).

The modern, and the complex, very difficult astronomical topics should be taught in the last two grades of high school. These topics are very hard for non-science students (although they are fascinating for them). Schools should differentiate their students into the special seminars (where astronomy can be taught).

5 Conclusion

The thesis maps teaching astronomy in the Czech Republic, and other selected countries around the world. It shows that teaching astronomy at Czech gymnasia is at high level, especially in the theoretical way. On the other hand, there is no astronomy taught or just a small amount of it at most high schools. Some teachers go to a planetarium or an observatory with a class instead of teaching astronomy in their lessons. That is caused by untimely placing of the topic as the last one in physics (close before the state exams). Teachers do not take advantage of astronomy as an interdisciplinary and a good motivating subject.

Astronomical knowledge of Czech students is excellent. Talented students do not worry to write their seminar or scientific works on astronomy (one third of all SOČ[3] works in last five years were astronomical ones), astronomical olympiad became very popular[4].

The situation in the world is very complicated, because there are many ways astronomy is taught there. Problems in teaching astronomy are caused by need of using modern technologies like computers too (many third world countries cannot afford to spend money this way[5]). The most similar situation (according to the Czech Republic) is in other European countries, astronomical teaching is growing in east Asia and Ibero-American countries.

Development of astronomy causes changes in teaching high school astronomy

[2] `http://www.starlab.com`

[3] Středoškolská odborná činnost

[4] This was prepared only for basic school children - high school version will be prepared.

[5] One half of children could not attend any school!

- but new topics and new ways of teaching (instead of lecturing) are missing in the Czech Republic. Astronomy is strictly connected with computer sciences: astronomical information acquisition, working with astronomical data, compiling results - the role of computers is irretrievable.

By presenting the new astronomical topics I want to take astronomical teaching out of the edge of physics into a new, interdisciplinary subject at our high schools, that connects all natural sciences, especially as a motivating factor. Other astronomical topics (with deeper view) can be taught for talented students in special seminars in last two years of high schools. I agree with the idea that astronomy should be presented in all subjects of all grades, in a form of projects, games and interesting problems (instead of lecturing facts). Production of new methodological materials is needed - they can be created not only by teachers but by talented students and future teachers at universities too.

Making new projects, games or other materials is the only way teachers of other subjects can be involved. Astronomical teaching can be another part of life-long education of teachers. Interdisciplinary education becomes more important - new Czech curricula reflects this situation.

The question of internal differentiation of schools remains open - internal differentiation of special subjects or special topics for selected students must be discussed. Astronomical seminar should be one of the special seminars that make this internal differentiation.

References

Bednařík, M., Široká, M. (2000): *Fyzika pro gymnázia - Mechanika*. Prometheus, Praha.

Fiero, J. (2000): *International Astronomical Union Commission on Education in Astronomy*. Teaching of Astronomy in Asian-Pacific Region **16**, 1 – 5.

Fisher, N. (2001): *Space science 2001: some problems with artificial gravity*. Physics Education **3**, 193 – 201.

Fraknoi, A. (1996): *Astronomy Education: Current Developments, Future Coordination*. ASP Conf. Series, Vol 89.

Fraknoi, A. (2002): *Science Fiction Stories with Good Astronomy & Physics*. Version 4.3, `www.astrosociety.org/education/resources/scifiprint.html`.

Isobe, S. (1993): *A Flower and a Star - An Important Aspect of Human Being*. Teaching of Astronomy in Asian-Pacific Region **7**, 1 – 8.

Kantor, C.A. (2001): *A ciência do céu: Uma proposta para o ensino médio*. Doctoral thesis. Universidade de Sao Paulo, Instituto de física, Faculdade de Educaao, Sao Paulo.

Macháček, M. (1998): *Fyzika pro gymnázia - Astrofyzika*. Prometheus, Praha.

Mackowiak, B. (2003): *The Important Role of Public Astronomy Education for Society*. Teaching of Astronomy in Asian-Pacific Region **19**, 5 – 14.

Pasachoff, J.M., Percy, J.R. (1990): *The Teaching of Astronomy*. Proceedings of the 105th colloquium of the International Astronomical Union. Williamstown, Massachusetts, 26 - 30 July 1988. Cambridge University Press, Cambridge.

Petty, G. (1996): *Moderní vyučování*. Portl, Praha.

Pokorný, Z. (2001): *Astronomické vzdělávání*. Hvězdárna a planetárium M. Koperníka, Brno.

Stavinschi, M. (2003): *Astronomy Education in Europe*. Preface of a special issue of Teaching of Astronomy in Asian-Pacific Region **19**.

Šolc, M. a kol. (1983): *Fyzika hvězd a vesmíru*. Státní pedagogické nakladatelství, Praha.

Štefl, V. (2002): *Výuka astrofyziky na gymnáziích v České republice*. Contribution at international conference DIDFYZ (Contents Innovation of Physics Teaching), Račkova dolina.

List of publications

- Pudivítr, P. (2001a): *Hloubka měsíčních kráterů.* Matematika - Fyzika - Informatika **3**, 151 – 157.
- Pudivítr, P. (2001b): *Praktické úlohy z astronomie.* Diploma thesis. Matematicko-fyzikální fakulta UK, Praha.
- Pudivítr, P. (2003a): *High School Astronomy in the Czech Republic.* Physics Education **6**, 472 – 473.
- Pudivítr, P. (2003b): *Výuka astronomie na středních školách v USA.* Pokroky matematiky, fyziky a astronomie **3**, 251 – 255.
- Pudivítr, P. (2004): *Jak vyučovat astronomii?* Matematika - Fyzika - Informatika **6**, 352 – 357.