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Active Learning in Advanced Undergraduate Course of Thermodynamic and Statistical Physics

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Abstract

In the field of physics education, the last two decades have seen a shift from teacher-centred traditional approach towards student-centred active learning approaches. This contribution describes such a shift within the scope of a compulsory undergraduate course of advanced Thermodynamics and Statistical Physics tailored for future physics teachers.

Our goals were to verify the applicability of active learning methods under the conditions of our faculty, to improve students' habits of regular work during the term and to inspire them as future teachers. The redesigned course was inspired mainly by the Peer Instruction method, enriched by Just-in-Time Teaching technique. While majority of studies published so far describe these methods when being used in large courses, in this case the whole study group included up to ten students. All the components of the course had been designed according to the active learning approach, i.e. not only the instruction itself, but also targeted work with students' motivation, students' preparation for lessons, homework projects and assessment. The redesigned course has been run three times so far.

Despite increased time demands, placed both on students and lecturers, we consider our realization of the course successful—all students were active during lessons, worked within their current capacities and enhanced their attitudes towards learning. They appreciated the opportunity to get a deep conceptual insight into the issue at hand, displaying an increasingly positive attitude to the broad variety in instruction and the collaborative spirit of the lessons.

Key words: active learning, student-centred learning, advanced undergraduate course, thermodynamics and statistical physics.

Výuka pomocí metod aktivního učení v kurzu pokročilé termodynamiky a statistické fyziky

Abstrakt

V posledních dvou desetiletích lze ve fyzikálním vzdělávání pozorovat postupný přechod od tradičního přístupu, kterému dominuje učitel, k aktivnímu učení, pro které je ústřední postavou vzdělávacího procesu student. Tento článek popisuje takovýto přechod v případě pokročilého univerzitního kurzu termodynamiky a statistické fyziky určeného budoucím středoškolským učitelům fyziky.

Hlavními cíli, které motivovaly náš příklon k metodám aktivního učení, bylo ověřit jejich použitelnost v podmínkách naší fakulty, zlepšit průběžnou práci studentů v průběhu semestru a inspirovat je coby budoucí učitele. Metodami, které jsme k dosažení těchto cílů zvolili, byly zejména Peer Instruction a Just-In-Time Teaching, jejichž použití popisuje většina publikovaných studií na příkladech velkých studijních skupin; oproti tomu jsme měli v našich kurzech vždy nejvýše 10 studentů. Aktivní metody učení byly určující nejen pro podobu samotné výuky, ale pro celý design kurzu včetně cílené práce s motivací studentů, jejich domácí přípravy, zápočtových testů či vlastní zkoušky. Prezentované výsledky jsou založeny na tříleté zkušenosti s výukou takto koncipovaného kurzu.

I přes zvýšené časové nároky (kladené jak na studenty, tak na vyučující) považujeme průběh kurzu za úspěšný – zvolené metody umožnily všem studentům, aby se do výuky aktivně zapojili na jejich aktuální úrovni porozumění dané látce. Kromě značného prohloubení konceptuálního vhledu do tématu jsme také zaznamenali pozitivní změnu postojů studentů ve vztahu k vlastní výuce.

Klíčová slova: aktivní učení, výuka orientovaná na studenta, pokročilý univerzitní kurz, termodynamika a statistická fyzika, peer instruction, just-in-time teaching.

1 Introduction

Educators and educational researchers are still looking for appropriate ways how to improve students' learning and learning outcomes. In the recent few decades, student-centred ways of learning have attracted most attention and are gradually moving from scientific papers and educational conferences to real lessons and lectures. These diverse methods are commonly labelled as active learning (AL) and as their starting point can be considered the monograph *Active Learning: Creating Excitement in the Classroom* (Bonwell & Eison, 1991).

1.1 What is active learning

Up to the present, most educators still rely more on intuitive understanding than exact definitions of AL. Despite the absence of explicit formulation, there is a wide range of generally accepted descriptions of characteristics typical for AL. In the following text AL is understood as

- "...anything that involves students in doing things and thinking about the things they are doing." (Bonwell & Eison, 1991)

This description can be broadened by giving an explicit list of what students do:

- Active learning "involves providing opportunities for students to meaningfully talk and listen, write, read, and reflect on the content, ideas, issues, and concerns of an academic subject." (Meyers & Jones, 1993)

Sometimes, the definition involves the purpose that inclusion of AL follows:

- Active learning aims at "increasing of student participation, or 'interactivity', for the purpose of positively affecting student learning and attitudes." (Georgiou & Sharma, 2015)

Alternatively, some authors stated which students' activities are insufficient to be called active:

- "Active learning is anything course related that all students in a class session are called upon to do other than simply watching, listening and taking notes." (Felder & Brent, 2009: p. 2)

According to this definition, rhetorical questions asked during the lecture or questions answered by several students in first line could not be considered as AL.

1.2 Current state

The shift from teacher-centred approach to student-centred learning is apparently caused by various reasons. Burgan (2006) states two reasons—the increasing of the students' diversity (age, social-cultural context, high-school preparation) and rapid development of ICT—using digital technologies from childhood significantly changes students' thinking (Spitzer, 2014), information is easily reachable and there is no need to memorize.

Bonwell and Eison (1991) summarized the literature on AL and concluded that it leads to better student attitudes and improvements in students' thinking and writing. Hake's (1998) huge survey confirms this result and uncovers that significant improvements in students' performance may occur if AL methods are used in all components of a course (motivation, lessons, exams, ...) with tight integration.

When using AL methods which require students' home study, it is essential that students really follow the materials intended for it (Burgan, 2006). This is certainly important when using traditional methods as well—with unprepared students lecture turns into something what Mazur (2009) aptly described as "...process whereby the lecture notes of the instructor get transferred to the notebooks of the students without passing through the brains of either."

The aim of AL, i.e. to increase students' level of engagement during the lessons, results in a wide range of techniques; let's mention here only a few well-established approaches and those that have influenced us. These are Peer Instruction (Mazur, 1997), Just-in-Time Teaching (Novak et al., 1999), Inquiry-Based Learning (McDermott, 1996; Levy et al., 2011), Interactive Lecture Demonstrations (Sokoloff & Thornton, 2004), Investigative Science Learning Environment (Etkina & van Heuvelen, 2007) etc.

2 Motivation and goals

In the previous years we used some of AL methods as a complement to the traditional lecture based university lessons. In agreement with researches (Prince, 2004; Felder & Brent, 2009: p. 4; Zhang, Ding & Mazur, 2017) we observed that even short episodes of AL incorporated into lectures had noticeable impact on students' attitude, attention and could influence their performance in final exam.

This experience motivated us to prepare and conduct a course based fully on AL methods. We formulated our two basic principles for designing the course:

- Students have to be as active as possible during lessons because in the classroom they can benefit from the presence of their classmates and teacher.
- Somebody who understood a new concept/principle quite recently (e.g. classmate) is very well capable of explaining it to someone else, because he/she still remembers what it means not to understand and chooses wording comprehensible for the learner.

The main reason why we decided to use AL methods was a challenge to put them in practice at advanced undergraduate level. Extensive meta-analyses (Hake, 1998; Prince, 2004; Freeman et al., 2014) showed higher effectiveness of AL methods in comparison with traditional instruction; former studies (Specht & Sandlin, 1991) have confirmed their stronger long-term effect on students' comprehension. As well as thousands of educators we have already heard a lot about these benefits of such approach, however, overwhelming majority of university courses in our country is still led traditionally[1].

Besides more active students' attitude, we aimed also at more continuous students' work not only in lessons but also at home during the whole term. There is a long (although weakening) tradition of regular homework in Czech high schools; conversely, in many courses at university level students' engagement is almost never required during the semester. This approach weakens students' previously hard-gained work habits—in these circumstances, the simplest way is to study intensively for a short time before the final exam which leads to the storage of knowledge in a short-time semantic memory that is inclinable to forgetting (Tulving & Donaldson, 1972). If AL course design keeps the recommendation to include assessment of conceptual understanding into final exams (Hake, 1998), it prevents the typical abuse of university exams where students only mechanically repeat memorized facts which many lecturers find unfortunate but sufficient to pass the exam.

Furthermore, it is also important to take into account that our students are future physics teachers, so we felt a unique chance to let them experience the complex use of AL approach in order to inspire them for their future practice.

3 Course design

In this part we describe the design of the advanced university course of Thermodynamics and Statistical Physics based on AL approach. Our experience with such a course is specific mainly due to the low number of students in the studying group (up to ten students, see Table 1). We have not found any previous study focusing on teaching under these conditions, when the students and their teachers know each other quite well. For this reason, our description of applied methods and procedures as well as our experience with them can serve as an inspiration for lecturers who consider introducing AL methods into their smaller courses.

Tab. 1: Number of students attending the Thermodynamics and Statistical Physics course

Academic year	Designation	Students	Men	Women	Students passed the course[2]
2013/2014[3]		10	4	6	8
2014/2015	2014 course	7	5	2	6
2015/2016	2015 course	9	4	5	9
2016/2017	2016 course	6	3	3	4

[1] Generally, published studies showed that science educational research influences undergraduate teaching only insignificantly (Hattie & Marsh, 1996; Prince, Felder & Brent, 2007).

[2] The passing rate was similar as in years before the introduction of the active learning methods. However, the comparison might be inadequate since not only the method but also the assessment has been changed.

[3] In 2013/2014 course active learning methods were used only as a supplement of traditional lecturing.

3.1 Specifics of the Course

The Thermodynamics and Statistical Physics course is aimed at third year university students as a part of study programme for prospective physics teachers. The syllabus of the course consists of more advanced concepts of thermodynamics including entropy, thermodynamic potentials and basics of statistical physics—statistical ensemble, classical and quantum distribution function, statistical definition of entropy etc.

There are usually 12 weeks of instruction in a semester, the course includes two sessions per week (135 and 90 minutes). In lecture-based courses the longer sessions are lectures and the shorter ones seminars dedicated to solving problems; we cancelled this strict separation of "theory and practice" and all sessions (in the following text called lectures, even though they are not based on lecturing) have similar design.

3.2 How did we motivate students

In agreement with others (Mazur, 1997; Hake, 1998) we believe that proper familiarization of students with new methods and their motivation to change their study habits is crucial. Therefore, we spent about 40 minutes of the first lecture discussing the new course design, explaining its goals and gaining students' enthusiasm. To keep it, we repeated similar but shorter discussion several times during the term.

3.3 Instruction

The instruction itself was designed as a mixture of lecturing periods (e.g. formulations of fundamental principles, mathematical derivations etc.) and AL periods. The time structure of the whole course (based on detailed observation of more than 80 % of lessons by the second lecturer) is showed in Figure 1.

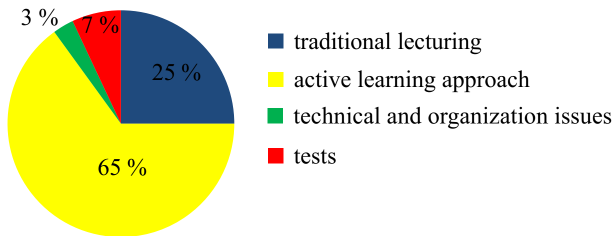

Fig. 1: Time ratio of particular activities during instruction – averaged data (2014–2016)

- *Active learning methods:* The time devoted to AL methods includes mainly small group discussion and whole class discussion[4], collaborative solving of both quantitative and qualitative tasks and dealing with ConcepTests using the Peer Instruction method (Mazur, 1997). In the 2014 course all these activities were focused mainly on exploring and practicing new concepts using ConcepTests mainly, whereas in the 2015 and 2016 courses almost one third of AL periods was connected with students' homework (see part Just-in-Time teaching home assignments).
- *Active Learning Kit:* To support AL in class we prepared for each student the so-called "Active Learning Kit"—a small plastic bag with paper flashcards,

[4]We find it necessary to remind, that in our case the "whole class" means typically 7–9 students.

Fig. 2: Left – Active Learning Kit, Right – flashcards (10 × 10 cm, printed on thick paper and laminated)

A5-sized white board, wipe-off markers and a piece of cloth (Figure 2 left). Based on our experience, we modified our flashcards by adding frequently used answers (e.g. yes/no, increase/decrease etc., Figure 2 right). Students used them to answer multiple-choice questions and to solve ranking tasks (O'Kuma, Maloney & Hieggelke , 2000). Small whiteboards—similar to a tool described in Whitney (2011)—were used for individual solving of open-ended tasks like drawing a graph, deriving a formula, simple calculation etc. Furthermore in group discussions A3-sized white boards were used.

All these simple means persuaded all students to be active and gave us an immediate feedback how students deal with their tasks and enabled us to spontaneously react on the class discussions or unexpectedly occurring learning difficulties—e.g. by simplifying the question, using analogies etc.

- *Materials for AL methods:* For the purposes of our course we prepared a set of nearly 130 ConcepTests inspired by several sources such as course-related collection of solved problems (Obdržálek, 1996, 2015), collection of ConcepTests developed at University of Colorado Boulder (Pollock et al., n.d.) and other supplementary textbooks (e.g. Halliday, Resnick, & Walker, 2013). Moreover, we adopted some conceptual questions used when identifying typical students' misconceptions (Yeo & Zadnik, 2001; Mandíková & Trna, 2011).
- *Lecturing periods:* As lecturing periods we consider longer, typically 20 to 40-minute long stretches of time intended mainly for complicated mathematical derivations. We integrated lecturing with AL because there are topics difficult for students to understand when using AL methods only, but we did not want to discard them from the syllabus (general polytrophic equation, derivation of the canonical distribution etc.).

However, we tried to keep high level of students' attention during the lecturing period as well. By simple questions we continuously verified that students understood the main points and kept the line of thought; simpler steps were executed by students independently or in small groups (according to their own preference). Shortly after the start of the semester students spontaneously stopped the lecturing if they felt that they did not fully understand.

3.4 Home preparation for lectures

Home preparation consisted of two components. In all courses, one of them was a set of individual projects. Home reading assignments were the second part in the 2014 course, but we were not confident about the benefits of reading, so we replaced it by Just-in-Time teaching assignments in 2015 and 2016 courses.

- *Individual home projects:* During the semester students had to work out five (2014 course) or four (2015 and 2016 courses) extensive individual home projects; below we shortly describe each of them:
  1. Awkward questions about temperature and its measurements: The project was a starting point of the whole class discussion about empirical temperature, temperature measurement in uncommon situations and selected temperature-related misconceptions.
  2. Working with graphs and plots: This activity involved making charts by hand as well as preparing more complicated graphs on a computer.
  3. High school problems and their proper explanation: The project simply verified the ability to deal with high school tasks.
  4. Harmonic oscillator in statistical physics in various settings (2014 course only): Students were supposed to describe various systems of harmonic oscillators mathematically in both classical and quantum case.
  5. How to understand entropy: While we consider entropy as a central concept of the course, the aim of the last home assignment was to promote students' metacognition. In an essay, they were supposed to describe their own way how they dealt with this concept and how they had approached it, then to highlight the most interesting idea in their classmates' texts and finally to form the "concept map" of entropy as a group work during a lesson.

Students had always two weeks to solve each project.

- *Home reading:* In 2014 course we incorporated compulsory home reading used mainly for familiarization with new terminology and revision/extension of topics learned in preceding courses. It consisted of six excerpts from textbooks, 10 to 20 pages long each (Obdržálek, 1996, 2015). Students used the annotation taking tool NB[5] which enables them as well as lecturers to discuss the text outside the classroom (see Figure 3). The texts were published online at least two weeks before the lecture dedicated to the particular topic. Students were supposed to read the texts before the lecture, to label those parts they found difficult, to ask questions that ran in their minds or to mark ideas they found interesting. Posting notes to the NB system was one of the conditions to get the credit for the course.
- *Just-in-Time teaching home assignments:* Following the recommendations in (Simkins & Maier, 2010) and in (Watkins & Mazur, 2010), in 2015 and 2016 course we replaced compulsory home reading with Just-in-Time Teaching assignments (JiTT) (Novak et al., 1999). Two days before each lecture we published electronically three questions in the course management system (Moodle was used). Two problems were aimed at course content (revision of dis-

[5] It is prepared by Haystack Group at MIT and available on http://nb.mit.edu/welcome. More elaborated annotating system is Perusall (http://perusall.com/) run on Harvard University; the main difference is that Perusall is able to assess students' comments automatically.

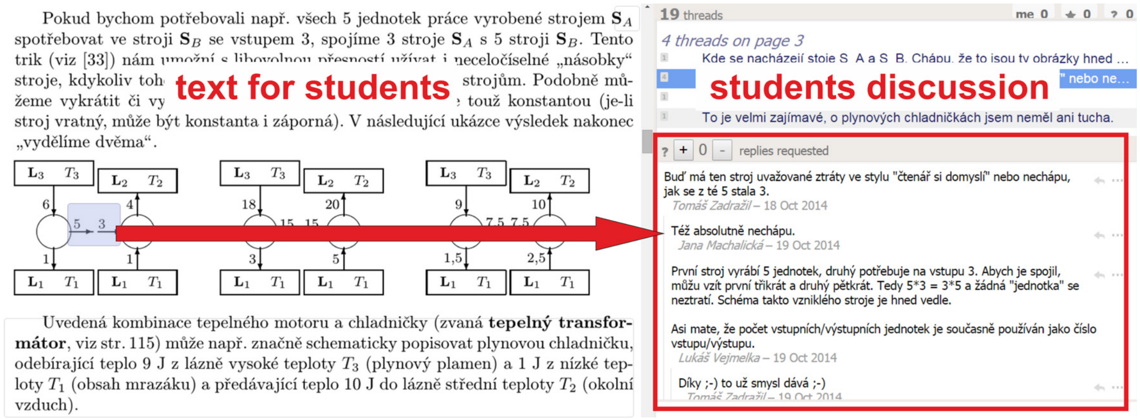

Fig. 3: Screenshot of NB annotation taking tool with example of students' discussion

cussed topics, students' conceptual understanding development or motivation for next topics—typically ConcepTests with open answers), the third question was metacognitive: "What was the hardest or least understandable thing in the last lecture?" Students were supposed to answer these questions electronically no later than the evening before the lecture. The lecturer corrected and commented students' answers and adjusted the lecture according to them.

3.5 Tests

Students wrote two tests—in the middle and at the end of the term. Both tests consisted of multiple-choice as well as productive tasks (doing simple calculation, drawing a graph, writing an explanation) with easily checkable answers. All test items were inspired by ConcepTests or JiTT problems solved previously during lessons.

Both tests were administrated as two-staged (Rieger & Heiner, 2014) as showed in the Figure 4. The first part lasted 40 minutes, students worked individually and at the end they handed in a filled-in answer sheet with their answers; they did not hand over their notes and calculations done during this part, because they needed them in the second part. This second part lasted 30 minutes and students worked in groups of three people[6], solved the same tasks as in the first part. They were allowed to correct their wrong answers and gain partial credit.

Fig. 4: The individual part (left photo) and the group part of the test (right photo)

[6]It was impossible to form groups of three students only once, so one group was a pair. However, Rieger and Heiner (2014) and Mazur (1997) suggest for similar purposes groups of four or five students.

3.6 Oral exam

For the oral exam following the term we prepared 12 summarizing or cross-chapter questions (see Table 2) and 6 assignments of mathematical derivations (e.g. equation of general adiabatic process) which students knew in advance. At the beginning of the exam, each student drew two questions and had 15 minutes for preparation, during which use of his/her own notes was allowed. Then students one by one opened discussion with a 5 minute-long speech about main aspects of their topic; after that, a chosen classmate could ask a couple of questions, add some facts or correct inaccuracies followed by a discussion of the entire group. Both teachers as well as other students could ask questions and all students could answer.

Tab. 2: Examples of oral exam questions

Oral exam questions (selection)
• A brief summary of the four laws of thermodynamics and the relationships between each other.
• What does thermodynamics tell us about the law of energy conservation and the energy itself?
• Carnot cycle for both reversible and irreversible processes and its implications.
• Different formulations of the second law of thermodynamics and their equivalence.
• An introduction to statistical physics—methods of statistical physics, phase space, ergodic hypothesis, Liouville's theorem and their implications.
• Distribution function, partition function, differences between classical and quantum statistical physics.
• Ideal gas from the perspective of both thermodynamics and statistical physics.
• Entropy—inducing in thermodynamics and statistical physics, importance, measurement.

4 Methodology

The sample consisted of all students of 2014, 2015 and 2016 courses. They were informed about the research at the beginning of the term and agreed with their participation in it. All data was anonymized. We asked for special permission for using photographs taken during the class.

Data collection: We collected data about our AL course and its impact on students by several methods:

- In 2015 and 2016 courses, more than 80 % of the sessions and oral exams were observed by a second teacher who recorded the chronology of instruction as well as authentic quotations of students.
- Students completed several short open-ended questionnaires—the first one about their expectations and fears at the beginning of the term, the second one about their immediate opinion at the end of the term and the third one half a year after they had completed the course.
- As a supplementary feedback, we performed several unstructured group discussions with students during the term as well as after their oral exam.

Data analysis: Session observation records were bases of the analysis of time distribution of the particular lessons/course components. Questionnaire answers, discussions' records and records about student behaviour during the lessons and exams were analysed together.

5 Results and discussion

5.1 Experience with teaching such a course: Lecturers' perspective

- *Time demands:* It is not surprising that preparing the course with AL components was demanding and time consuming; these high demands did not decrease significantly even while repeating the course the following year as is common in standard lecture based teaching. Especially challenging was processing and assessing students' homework and answering to JiTT problems (twice a week in 2015 and 2016 course).
- *Conceptual understanding:* We experienced that this type of teaching requires teachers' deeper conceptual understanding of topics, an overview of common misconceptions and students' learning difficulties as well as knowledge of cross-chapters connections to provide immediate reactions[7]. However, high conceptual demands were put on students as well—instead of learning isolated facts or ways how to solve typical problems, students were directed to build the holistic picture, they were pushed to explore problems from various points of view, to practise how to discuss them and how to explain them to their classmates.
- *Peer Instruction:* Using Peer instruction method enabled us to activate all students—those who had not understood the problems completely tried to formulate their point of view and deepened their understanding, more advanced students helped them to find errors in their solution or explained how to solve the problem. Because our students are future teachers we consider it important to teach them how to formulate ideas on various levels – using formulas, rigorous textbook formulations, simple models, analogies or examples from everyday life.

We repeatedly observed that Peer Instruction approach was more convenient (especially at the beginning of the term) for extroverted students, who were able to discuss anything without fear of making mistakes, further for students who are not so mathematically skilled and students with lower understanding in previous physics courses.

- *Home reading (2014 course only):* Students' discussions in the NB annotating tool were quite rare, which was one of the reasons why we left out this approach in the following years. Our class was too small and students met on lectures almost every day, so the majority of discussions took place during their face-to-face meetings outside the NB system.
- *Just in Time Teaching (2015, 2016 courses):* Due to the small number of students in our courses we were able to assign not only credits to all students' answers to JiTT problems (as described by Novak, 1999), but also individualized comments (how to improve the solution, what was not taken into account, what more can be thought over). These comments didn't usually uncover the

[7] On the other hand, with respect to the size of our group we found it quite difficult not to be drawn into students' peer discussions and not to point out correct solutions prematurely.

solution and were intended to provoke students to work with the problem more. Students in their feedbacks appreciated (and later even required) this approach, that was also confirmed by the fact that none of them stopped answering JiTT problems at the moment of having a sufficient number of credits.

- *Atmosphere:* We intentionally worked on building a safe environment for discussions by supportive lecturers' behaviour, supressing unwelcome reactions of students and in a few cases by individual talks with student about the course approach aims.
- *Students' attitudes:* We could observe how students changed their attitude towards the course during the term. At the beginning, some of them were motivated to fulfil somehow the course requirements with high effort to conceal anything they don't understand from teachers. As time went on, students gradually understood more and more the importance of their active participation and presentation of their own views and ideas. They also fulfilled all tasks without paying much attention to the passing limits, because—in their words—they felt it helped them to understand the concepts and to build the overall picture of discussed topics. This change of students' approach was so powerful that it persisted even till the oral exam, when one student spontaneously said: "Please wait a minute. I am not sure if I have fully grasped the idea how to solve this. Can we go through it once more?"
  Immediately, another student informally started to explain the problem from another point of view.
  As written above, one of our aims was also to inspire future teachers for their own practice. We were very pleased to hear from some students that they were so keen on the approach that they used it immediately during the term in their teacher-training lessons.

5.2 Students' perspective

Being aware of the fact that students react positively to quite every novel intervention regardless of its merit (Prince, 2004), in this part we summarize their opinion based on interviews and free-answers from questionnaires. Generally speaking, the lessons were perceived as very useful by students; their subjective assessment of the course impact was sometimes even higher than ours:

"I have never experienced anything like this and I enjoyed it."

"I like variety in instruction—tasks, flashcards, discussions, lecturing, ..."

Students independently confirmed our expectations and observations and in several cases we were delighted to hear how aptly they described our intentions using their own words. As a very positive sign we consider students' attendance in lessons (approx. 95 %) which was significantly higher in comparison with other courses (attendance 50–80 %) even though it didn't bring any credits.

- *Expectations and fears:* Immediately after the presentation of the new course approach, students expressed their expectation and fears in a short survey. They anticipated deepening their knowledge in thermodynamics, experiencing a new way how to learn and teach ("the more teaching/learning styles I get to know the better") or training of appropriate expressing of opinions; on the other hand, they also expected difficulties in managing of continuous work during the term and participation in discussions ("...it will be hard for me not to be afraid of expressing my opinion publicly, especially when I assume it is wrong...").

- *Time demands during the term:* Students found fulfilling all duties more demanding than in other courses:

  "I think that it might be possible to have two courses with such high demands in the same term at most."

  "The work during the semester always pays off, now I finally utilized it when preparing for the test—I knew where to search in my notes, I had such a general overview."

- *Peer Instruction:* Students declared peer discussions as the most beneficial part of the course:

  "During explaining to each other I understood a lot of things, even though it was me who explained."

  "Many times I found the explanation from classmates more understandable."

  They repeatedly expressed their impression that they understood more if they could discuss the problems together compared to listening traditional lectures and solving typical textbook problems. As a weakness students considered that the teaching form did not guide them to take systematic and coherent notes.

- *Just in Time Teaching, home projects:* We have received very positive students' feedback on JiTT problems. They felt that these questions kept them continuously prepared for each lesson and helped them to uncover topics that were not understood enough:

  "Thanks to those problems, I was prepared for every lesson and it was easier to find out what I didn't understand."

  As negative aspects students stated time demands which they estimated as 1-2 hours on average by solving each set of JiTT questions. Generally, intensive home preparation was perceived as a quite unusual part of the course, because it is not customary to force students to work regularly during the term. Because they were able to see the purpose of all home assignments and their link to the course goals, they felt that it is worth of the higher effort:

  "I was forced to work hard, which I liked."

  "I liked the diversity in homework—they differed not only in the content, but also in the form."

  "As the greatest benefit I consider the homework about entropy! To walk along the coast of such an extensive concept, at first alone and then to invite other helpless castaways to discuss together on a beach party…"

  Students stated that they would solve the problems even if it would be voluntary but probably not so regularly; therefore, after the end of the course they recommended keeping JiTT assignments compulsory.

- *Tests:* The overall impression of both midterm tests could be documented by survey answers:

  "It was a change and it fitted in a general context of the session."

  "I learned much from my mistakes in the test which doesn't happen often."

  "Thanks to the second, group part of the exam I learned how others think to reach the correct result."

  The atmosphere was quite relaxed, not stressful, sometimes similar to a game, but working very well:

  "It is not so bad, almost everything is correct. Let's have a closer look at mistakes." (One student after the corrected group answer sheet were returned.)

"I wrote the tests knowing that when I don't pass them with the required score, at least I will find out what I don't understand and how to solve it."

Students appreciated that the tests emphasized less mathematical apparatus and more the underlying concepts and understanding of physics phenomena. Because the test design was new for them, they perceived as a disadvantage the fact that they did not know how to prepare for them. As other negative aspects some students mentioned the lack of time and the influence of others who were in their group (groups were put together by lecturers to ensure similar performance). Group part was also viewed as an advantage for weak students:

"I find it quite silly that those who don't know almost anything pass the test thanks to the group part where they get the correct answers dictated by their two other mates."

- *Oral exam:* Despite the fact that it is common that courses in our faculty are ended by an oral exam, its design in our course was quite unusual. Students described their preparation for the exam in these words:

  "I read my notes and put individual pieces to particular questions. I understood everything from lessons, so I focused at putting particular pieces in order and searching for connections."

  "Because I knew I could use my notes, I did not deal with remembering difficult mathematical derivations, but I focused on understanding of each step and ability to explain them meaningfully."

  The preparation for the final exam was not so time consuming for students:

  "We were little ashamed and surprised that we needed only three afternoons to prepare for the exam perceived as a difficult one."

  We managed to prepare the cross-chapter questions with emphasis on understanding:

  "The questions were not of the type that I can say—well, we went through this in the thirteenth lecture and all was done. It was necessary to connect various pieces spread out through the entire course."

  "It was sufficient to read my notes and link particular pieces to individual questions. I actually understood everything, so I just needed to sort out and organize my knowledge and to find connections between these pieces of knowledge."

  "I think the final exam showed whether you memorize or you understand the problematics."

  Students appreciated the pleasant, non-stressful atmosphere during the exam.

  "I didn't feel like taking an exam at all, it was more like in a discussion club, it was superb. I liked that emphasis was put on understanding particular topics as the parts of the whole."

  Negative aspects mentioned by students were longer duration in comparison to other courses exams.

- *Generally:* To conclude this section we stated students' opinions on the overall impression of the course and its benefits. Opinions below were collected one month after the end of the course:

  "Firstly, it was a great experience—different course design attracted attention, but more importantly, it didn't decrease in time."

  "I think the majority of information anchored in my memory, if not forever, then at least for a long time."

"I must admit that I didn't like the amount of homework during the semester. But it really helped me to prepare for the exam, so it was useful after all."

Half a year after the course end, when students passed their final bachelor state exam, they wrote:

"It was a great benefit that I discovered another method of teaching/learning which I used even later during studying for final [state bachelor] exam. Moreover, I got rid of the fear of 'being a fool', when I answered given questions wrong."

"The best is to express it without words by the following graph (see Figure 5)."

"It was very inspiring for me: Lessons don't have to be boring and kept the way I am accustomed to from high school."

On the basis of the last quotation we conclude that the course fulfilled also the goal to inspire our students—pre-service physics teachers—for their future carrier.

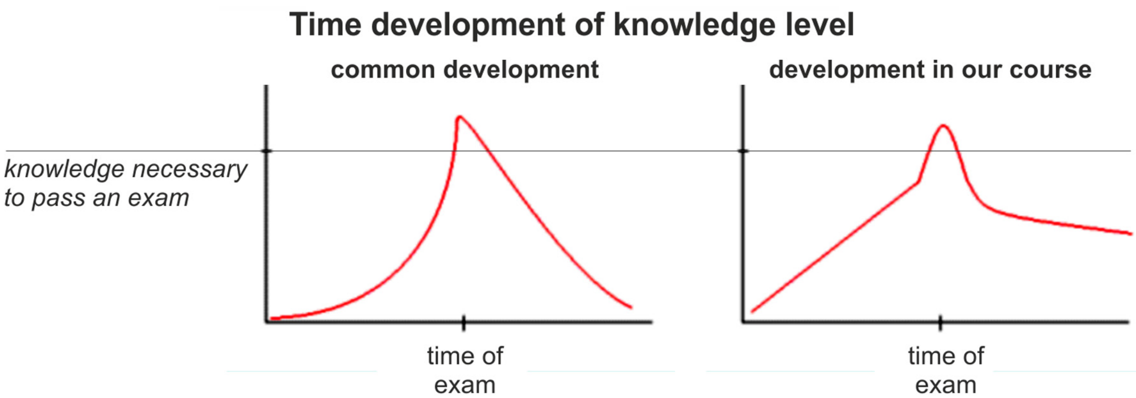

Fig. 5: Example of student's feedback (redrawn and translated)

6 Conclusion

The contribution describes a shift from traditional approach to active learning (AL) approach in obligatory advanced undergraduate course of Thermodynamics and Statistical Physics in the case of small study groups (up to 10 students) in academic years 2014/2015, 2015/2016 and 2016/2017. We found the decision to convert the whole course into the AL style as very beneficial and even if we consider Hawthorne/John Henry effects (Hake, 1998), we are convinced that implementation of AL methods was successful.

All students were active during the lessons; each of them could work at his/her current level of understanding. Students were confronted with concepts and problems from different perspectives, so they had the opportunity to understand the context of discussed topics more deeply and to fix it in their long-term memory.

Students have changed their attitudes towards learning; they wanted to understand instead of to pass the exam no matter how. We supported these findings by students' own opinions stated above. We also succeeded in creating safe atmosphere where students were not afraid of making mistakes and became engaged in their learning process.

Teaching based on AL methods proved to meet its aims in the conditions of our faculty. We fulfilled the goal to persuade students to work regularly during the term, students' answers in feedback questionnaire as well as reports from their concurrently running training classes convinced us that they were inspired by using AL and some of them expressed their willingness to incorporate such an approach into their future teaching.

We plan to teach the course in this way in the future again (probably with minor adjustments) and to conduct a research to proof if there is any positive effect on students' long-term conceptual understanding and if such an isolated experience with AL can influence approach to teaching.

Supplementary material to this paper with examples of ConcepTests and class activities used in the course is available on the authors' web page: http://kdf.mff.cuni.cz/∼koupilova/thermodynamics.

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