Measurement skills of medical students

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Abstract. Measurement is an everyday part of medical praxis and research. Development of measurement skills of medical students is one of the objectives of a Medical Biophysics course. Since students come from different countries, they have different backgrounds and experiences with measurement. This paper presents results of pedagogical research focused on monitoring measurement skills of first-year medical students and on identifying possible factors influencing their initial level. A personal questionnaire, an introductory test focused on factual knowledge, and continuous short tests were used in academic year 2016/17. Approximately 28% of respondents studying in English language and 6% of respondents studying in Slovak language declared their experience in laboratory measurements. Continuous monitoring of measurement skills in a sample of 66 students showed insufficient ability to read a measured value and discuss its uncertainty, and students’ low awareness of controlling measurement conditions. Development and validation of context-relevant tasks and cases developing measurement skills in medical biophysics is required.

1. Introduction
Measurements form the basis of diagnosis, prognosis and evaluation of the results of medical intervention [1]. Efficient, safe and accurate medical care is based on collection, evaluation and interpretation of data. Furthermore, evidence-based medicine requires understanding and utilising scientific research in medical praxis. A medical doctor has to know to select the appropriate measurement method, proceed with the measurement correctly, read the measured value, evaluate the measurement and interpret the result.

Essentials of measurements are provided to medical students at the Faculty of Medicine Comenius University in Bratislava (FM CU) at the beginning of their study within the Medical Biophysics course. In the study program General Medicine, the course consists of 24 hours of lectures and 36 hours of practical training. In the study program Dentistry, there are 24 hours of lectures and 24 hours of practical training.

The main objectives of practical training are:
- to understand basic principles of scientific investigation – hypothesising, testing, modelling, measuring, processing collected data (including graphs and basic statistical elaboration), interpreting results, concluding;
- to develop application of the principles mentioned above in a medical context;
- to familiarize the students with selected physical methods used in medicine;
- and thereby understand the practical role of physics in medicine.
Though there is no admission test in Physics at FM CU (only in Chemistry and Biology), content and methods used in Medical Biophysics course are built on the assumption that students have already acquired some physics knowledge and skills during their education. Especially students studying general medicine or dentistry in the English language come from different countries. They graduated in different types of high schools. The great variety in students’ experiences, knowledge and skills often causes discrepancies in their educational needs and learning objectives.

2. Subject and methods
The unsatisfactory level of science process skills of pre-medical and pre-dental students has been the subject of research since the 1970s [2]. Educational reforms realised in many countries at the beginning of the new century gave rise to the need for new evidence.

Pedagogical research focused on monitoring and development of selected science process skills among medical students at FM CU was realised in academic year 2016/17. The research consisted of four parts (table 1):

- Characteristics of previous physics education were collected using the electronic questionnaire with short open-ended questions and questions with yes/no answers. Students answered the questionnaire voluntarily at the very beginning of their study. In total 366 students (67% of all first-year-students) answered the questionnaire.
- The initial level of selected factual knowledge was investigated using an introductory test containing 6 open-ended tasks and 6 multiple-choice questions. Students answered the test voluntarily. Evaluation of the test was not included in individual student assessment. Results of the test were used to adapt the educational content to the students’ needs. One multiple-choice question was focused directly on measurement. In total 433 students (74 %) answered this question.
- Two groups of general medicine students took part in further research - 31 students studying in the English language (mainly from Germany and Poland) and 35 students studying in the Slovak language. Students were asked to answer short written tests related to current practical training tasks each week of semester. Particular tasks focused on science process skills were answered by different numbers of students. In total 11 questions related to measurement skills were used: 5 questions related to reading the measured value, 2 questions related to measurement uncertainty, 2 questions related to measurement conditions and 2 questions related to measuring range.
- Measurement and results processing reports written by 153 students were collected after the final exam in medical biophysics. Analysis of these materials is still in progress.

| Method                                         | Students studying in the English language | Students studying in the Slovak language |
|------------------------------------------------|------------------------------------------|-----------------------------------------|
| Personal questionnaire                         |                                          |                                         |
| – characteristics of previous physics education| 124                                      | 242                                     |
| Introductory test                              |                                          |                                         |
| – initial knowledge (one question directly related to measurement) | 178                                      | 257                                     |
| Set of short tests during the semester         |                                          |                                         |
| – monitoring of science process skills         | 31                                       | 35                                      |
| Analysis of students’ reports of their measurement and results processing | 50                                       | 103                                     |
3. Results

3.1. Characteristics of previous Physics Education

Responses to the personal questionnaire showed that 48% of students studying in the English language studied upper secondary school in Germany, 20% in Poland, 15% in Austria and 12% in Greece. A small number of students studied in Iran, Spain, Japan, Canada and Slovakia (less than 3% in particular country). Among students studying in the Slovak language there were only four who did not graduate upper secondary school in Slovakia; these students did not participate in further research.

Only 12% of foreign students and 2% of students studying in Slovak language graduated in Physics. Approximately half of respondents in both groups did not study Physics during the last year of upper secondary school. Moreover, 84% of foreign and 46% of Slovak respondents started their study at FM CU one year after graduation at upper secondary school or even after a longer break.

In total 28% of respondents studying in the English language and 67% of respondents studying in the Slovak language did laboratory measurements as a part of their previous physics education. At the same time, 21% of students studying in the English language and 65% of the Slovak students performed their own measurement reports or at least some parts of a measurement report (for example, principles of measurement, procedure, recorded values, statistical and/or graphical evaluation of results, discussion and/or conclusion). An additional 14% of foreign students wrote reports using data given by teacher, video data or data obtained from computer simulations.

3.2. Initial Knowledge

One of the multiple-choice items in the introductory test focused directly on measurement. Students were asked to choose all possible options to increase the accuracy of a measurement. The options and a summary of students’ answers are shown in table 2. Only 22% of non-Slovak students and 51% of Slovak students selected the correct answer only.

| One can increase the accuracy of a measurement by...                          | Students studying in the English language (N = 143) | Students studying in the Slovak language (N = 290) |
|--------------------------------------------------------------------------------|----------------------------------------------------|---------------------------------------------------|
| … repeating on different objects                                             | 13%                                                | 8%                                                |
| … repeating under the same conditions                                       | 71%                                                | 82%                                               |
| … repeating under changed conditions                                         | 21%                                                | 6%                                                |
| … dividing the smallest division of the scale into smaller sections          | 27%                                                | 20%                                               |
| … statistical treatment of the results                                       | 47%                                                | 29%                                               |
| Only the correct answer (= repeating under the same conditions)              | 22%                                                | 51%                                               |
3.3. Monitoring measurement skills

Practical measurement skills of students were observed and monitored continuously during the semester. Particular test questions were related to current tasks of practical training. Students answered them before their own measurements. Though students feel satisfied with their measurement skills, research results show significant deficiencies.

In total five questions were focused on reading the measured value from the device. Each question was entered by an image (sketch or photo) and the task “Read the measured value.” While reading the measured value from analogue or digital device (table 3) students do not think spontaneously about measurement uncertainty in case of a single measurement. They are not used to expressing measured values as an interval and prefer an estimation of single value.

| Task / week of semester | Answer categories                                                                 | Students studying in English language | Students studying in Slovak language |
|------------------------|----------------------------------------------------------------------------------|---------------------------------------|-------------------------------------|
| 1st week               | Estimated single value from the correct interval                                 | 78%                                   | 80%                                 |
|                        | Neglecting the size of smallest unit of the scale                               | 17%                                   | 14%                                 |
|                        | Measurement uncertainty                                                         | none                                  | none                                |
|                        | Mentioned unit of quantity                                                       | 97%                                   | 91%                                 |
| 2nd week               | Estimated single value from the correct interval                                 | 83%                                   | 79%                                 |
|                        | Measurement uncertainty - mentioned                                             | 3%                                    | 35%                                 |
|                        | Measurement uncertainty - correct                                               | none                                  | 6%                                  |
|                        | Mentioned unit of quantity                                                       | 87%                                   | 94%                                 |
| 6th week               | Value of the meniscus - lowest point                                            | 87%                                   | 67%                                 |
|                        | Measurement uncertainty - mentioned                                             | none                                  | 22%                                 |
|                        | Mentioned unit of quantity                                                       | 100%                                  | 100%                                |
| 7th week               | Correct value                                                                    | none                                  | 11%                                 |
|                        | Estimated single value from the interval determined by outer scale (without using the Vernier scale) | 73%                                   | 50%                                 |
|                        | Single value out of the interval determined by outer scale                       | 20%                                   | 28%                                 |
|                        | Measurement uncertainty - correct                                               | none                                  | 6%                                  |
|                        | No answer                                                                        | 7%                                    | 11%                                 |
| 3rd training           | Correct reading (value and unit)                                                | 7%                                    | 53%                                 |
|                        | Value with incorrect or missing unit                                             | 33%                                   | 28%                                 |
|                        | Incorrect value                                                                  | 57%                                   | 17%                                 |
|                        | No answer                                                                        | 3%                                    | 0%                                  |
Most difficulties were observed when students were asked to read the Vernier scale. None of the respondents used such type of scale in the past. An explanatory example in study materials was considered by the students to be incomprehensible. While reading the measured value displayed by digital multimeter, the most frequent mistake was calculating the measured value as the product of the displayed value and the magnitude of selected range, or sometimes the sum of these values. Only two foreign and three Slovak students declared that they had used any digital ammeter in the past.

Understanding how to use a digital ammeter was tested once more using two alternative tasks: “Draw the best position of the switch to measure electric current 0.19 mA / 0.12 mA.” (Fig. 1) The correct position was drawn by 27% of students studying in English language foreign and 28% of Slovak students.

**Figure 1.** Image to the question: “Draw the correct position of the switch to measure electric current 0.19 mA / 0.12 mA.”

Two more questions were focused on understanding the measurement uncertainty. One task was entered verbally and one task by a figure. Results can be seen in tables 4 and 5, the correct answer is written in the first row.

| Table 4. Understanding measurement absolute and relative errors. |
|---------------------------------------------------------------|
| Which of following measurement has the lowest uncertainty?   | English $(N=30)$ | Slovak $(N=36)$ |
| Measurement of 8 m distance with absolute error 8 cm.         | 30%            | 64%            |
| Measurement of 2 m distance with absolute error 4 cm.         | 0%             | 5%             |
| Measurement of 1 meter with relative error 3%.                | 70%            | 31%            |
Table 5. Understanding measurement uncertainty.

| What figure represents the measurement with the smallest uncertainty? | English (N=30) | Slovak (N=36) |
|---------------------------------------------------------------|----------------|---------------|
| B and C                                                        | 27%            | 0%            |
| Only B or only C                                              | 53%            | 97%           |
| Other answers                                                 | 20%            | 3%            |

Two tasks were focused on control of measurement conditions. Students were asked to write the main rules that should be fulfilled for correct measurement of peak expiratory flow (in the first in-class test) and indirect blood pressure measurement (3 weeks later). In the first test, 83% of students studying in the English language and 50% of the Slovak students were not able to give any relevant answer. The majority of the other students focused on the necessity to repeat the measurement, a specific way of breathing during the measurement (mainly Slovak students) and preparation of the patient - no food intake, drinking and smoking before the measurement (mainly students studying in English language). While describing measurement conditions necessary for correct measurement of blood pressure both subgroups of students focused mainly on preparation of the patient before the measurement (63% of foreign and 72% of Slovak students) and the correct position of the patient’s arm and/or correct position of the cuff (93% foreign and 72% of Slovak students). Only two students, one in each subgroup, mentioned the necessity to choose suitable a method of measurement (students used two methods in their practical training).

4. Discussion

Comparison of medical students’ previous physics studies and the results of introductory test shows a high heterogeneity, but the number of students who considered the value as well as the unit of physical quantity increased in both subgroups during the semester.

In general, we can see lack of personal experience with physical measurement and reporting it. Monitoring students’ measurement skills showed significant differences (chi-square test, $p < 0.05$) between the two subgroups in all tasks except reading the value measured with a ruler and choosing the appropriate range for a digital ammeter. Foreign students were more successful when reading measured values from a graduated cylinder, while Slovak students achieved significantly better scores when reading the measured value from the digital ammeter. This is influenced by the fact that foreign students preferred to work in pairs during the practical training, whereas Slovak students had more experience with measurement from previous education and more often worked individually during the semester. Slovak students also mentioned measurement uncertainty more frequently when reading the measured value.

Slovak students were more successful in tasks entered verbally (first question focused on measurement uncertainty and both questions focused on measurement conditions). This can be also influenced by language barrier, because students studying in English did not learn physics in their native language.
The results presented here align with our previous findings of significant differences in initial factual knowledge between students studying in the English and Slovak languages [4]. However, we must take into account that students at FM CU are not representative of upper secondary graduates in particular countries. Furthermore, studying physics in a non-native language can be considered as important factor influencing students’ ability to express their knowledge and to discuss their ideas.

5. Conclusion
Their initial measurement skills do not allow of first-year medical students at FM CU to successfully carry out practical tasks and thereby understand the phenomena under investigation. Development of measurement skills should therefore be an explicit goal of practical training in Medical Biophysics. Lack of experience, unawareness of particular components of measurement processes, and variety of starting points should be taken into account. It is extremely important to design and validate context-relevant tasks and cases developing measurement skills in context of Medical Biophysics and to identify factors that influence the transfer of acquired skills into new contexts.

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