Students’ Misconception of Accuracy

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Abstract

As has been shown in previous studies, students misperceive important engineering concepts such as accuracy. The present research investigated students' understanding of the concepts of accuracy and error, and their achievements in solving simple problems focusing on measurement accuracy and error. A quantitative research methodology was applied. A multiple choice questionnaire, including two questions involving the concepts of accuracy and error and four practical problems, was developed. More than three hundred engineering students from three study programs—mechanical engineering, electrical and electronic engineering, and industrial engineering and management—participated in the study. The results indicate that the students were able to successfully solve simple practical problems, in which they were asked to find a range of measured physical parameters and evaluate measurement accuracy. They, however, demonstrated insufficient understanding of the concept of accuracy and the relationship between accuracy and error in measurement. Only about half of the study participants chose the correct answer: that accuracy is a measure of the degree of closeness of a measured value to its actual value. The remainder believed that accuracy is defined by the number of digits to the right of the decimal point in the measurement result and some thought that accuracy is the smallest measured value that can be presented by a measurement instrument. The results show that engineering educators do not pay adequate attention to the theoretical foundation of the concept and practical calculation of accuracy values.

Keywords: *Misconception, Accuracy, Error.*

1. Introduction

Accuracy and uncertainty are basic engineering concepts widely used in engineering practice. From an engineering point of view, measurement accuracy is the “closeness of agreement between a measured quantity value and a true quantity value of a measurand” [1, p. 21], whereas measurement uncertainty is a “non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand [1, p. 25].

Accuracy can be characterized by error. Absolute error is a difference between true value and measured value, and relative error represents the ratio of absolute error to true value. Uncertainty is quantification of the doubt about the measurement result, and can be represented by different statistical parameters such as standard deviation or the half-width of an interval [ibid.].

Professional organizations of engineers and engineering researchers recognize the importance of these two concepts in engineering practice. Thus, [2, p. 6] explains: “accuracy and attention to detail ensures better engineering solutions, just as inaccuracies and carelessness in engineering can mean failure of engineering projects, which can in many cases mean financial failures, accidents, injuries and deaths”; [3] points out that an engineer in his practice “applies a wide range of engineering tools for analysis, simulation, visualization, synthesis and design, including assessing the accuracy and limitations of such tools”. Frank investigated competences of experienced systems engineers with high capacity for engineering systems thinking (CECT) and found a set of ten general cognitive abilities that are characterized by high CECT. One of these abilities is having a tolerance for ambiguity and uncertainty, namely, to feel comfortable and continue acting without understanding fully all of a system's details in unclear conditions and in an uncertain environment [4].

Students' misconceptions about accuracy and uncertainty are poorly investigated in engineering educational literature. The researchers [5] claim that engineering students never think about measurement uncertainty. The paper [6] asserts that the misconception that accuracy and uncertainty are dichotomous in engineering practice exists among engineering students. [7] reveals misconception about the accuracy concept by engineering students taking basic electricity and electronics courses while using engineering models. Some students perceive accuracy as the number of digits right of the point in the result they reach; namely, they misunderstand the concept of accuracy. It is a great interest to continue the research of students' misconceptions about accuracy.

The purpose of the current study is to investigate students' understanding of the concepts of accuracy and error, and their achievements in solving simple problems focusing on measurement accuracy and error.

2. Method

A quantitative methodology was applied in the research. The main research tool—a multiple-choice questionnaire including two questions involving the concepts of accuracy and error and four practical problems—was developed for the study. The questionnaire is given in the Appendix.

More than three hundred students from an engineering college participated in the study. In the first stage, in October 2013, 98 students from two engineering courses—1st year, Digital Logic Design and third year, Digital Electronics, both given by the Electricity and Electronics Department—participated in the research. The results of the first stage were analysed, and thereafter the research population was broadened. In the second stage of research, December 2013 – January 2014, 208 engineering students from three study programs—mechanical engineering, electrical and electronic engineering, and industrial engineering and management—participated in the study. The students, who participated in the first stage, did not take part in the second stage of the study.

The independent variable in the first research stage was the course taken by the student. The independent variables in the second stage were the student's learning experience (the semester, beginning from the student's freshman year) and the learning program—mechanical (ME), electrical and electronic (EEE), and industrial engineering and management (IEM). The dependent variable was the percentage of correct and incorrect answers in every questionnaire problem.

A descriptive analysis of the students' answers according to course, learning experience and study program was implemented.

3. Results

The first problem in the questionnaire (Q1) relies on students' understanding the definition of the concept of measurement accuracy. It can be seen from Table 1 that only about 50% of students from either course understand the concept correctly.

Table 1. What is measurement accuracy? The first research stage – distribution of student answers to Q1

Course	Number of students	Answers		
		Degree of closeness	**Number of digits**	**Smallest measured value**
Digital Logic Design	46	53.33%	15.56%	31.11%
Digital Electronics	52	53.85%	26.92%	19.23%

Q1 received the fewest correct answers in the questionnaire. Table 2 presents all results of the first research stage—percentage of students' correct answers to all the questions.

Table 2. Percentage of students' correct answers to all the questions in the first research stage

Course	Number of students	Q1	Q2	Q3	Q4	Q5	Q6
Digital Logic Design	46	53.33%	91.30%	97.83%	71.74%	65.22%	89.13%
Digital Electronics	52	53.85%	65.38%	96.15%	65.38%	63.46%	84.62%

It can be seen that the percentages of correct answers from students in both courses to the questions 1, 3 and 5 (Q1, Q3, Q5) are almost equal. The percentages of correct answers to the questions 2, 4 and 6 (Q2, Q4, Q6) were higher for freshmen students who took the Digital Logic Design course than for their sophomore colleagues who took the Digital Electronics course. These results contradict standard expectations that the achievements of experienced students would be higher than the achievements of freshmen.

With the aim of getting a broader picture of students' understanding of the concept of accuracy, it was decided in the second stage of the research to expand the research population and include students from additional engineering programs.

In the second stage too, Q1 received the fewest correct answers. Table 3 shows the distribution of students' answers for the first problem by study program.

Table 3. What is measurement accuracy? The second research stage – distribution of students' answers to Q1 by study program

Study program	Number of students	Answers		
		Degree of closeness	Number of digits	Smallest measured value
ME	94	41.49%	25.53%	32.98%
EEE	59	42.37%	30.57%	27.06%
IEM	55	50.91%	25.45%	23.64%

In an effort to examine the relationship between learning experience and student achievements, it was decided to divide the study population into three groups. The first group—freshmen—included students in their first and second semesters of study; the second group—sophomores—included students in semesters 4, 5 and 6; the third group—experienced students—included students in semesters 7 and 8. Table 4 presents the second research stage's distribution of students' answers to Q1 by study level.

Table 4. What is measurement accuracy? The second research stage – distribution of students' answers to Q1 by learning experience

Learning experience	Number of students	Answers		
		Degree of closeness	Number of digits	Smallest measured value
Freshmen	35	51.43%	22.86%	25.71%
Sophomores	87	41.38%	29.89%	28.73%
Experienced students	86	44.19%	28.73%	30.23%

Table 5 presents the all results of the second research stage by study program, and Table 6 shows all the results according to learning experience.

Table 5. Percentage of students' correct answers to all the questions by study program in the second research stage

Study program	Number of students	Q1	Q2	Q3	Q4	Q5	Q6
ME	94	41.49%	72.34%	93.62%	59.57%	68.09%	90.43%
EEE	59	42.37%	81.36%	98.31%	64.41%	69.49%	86.44%
IEM	55	50.91%	67.27%	90.91%	56.36%	45.45%	92.73%

Table 6. Percentage of students' correct answers to all the questions by learning experience in the second research stage

Learning experience	Number of students	Q1	Q2	Q3	Q4	Q5	Q6
Freshmen	35	51.43%	77.14%	100%	54.29%	48.57%	85.75%
Sophomores	87	41.38%	71.26%	91.95%	59.77%	63.22%	89.66%
Experienced students	86	44.19%	74.42%	94.19%	62.79%	67.44%	91.86%

Table 7 presents the total results of both research stages.

Table 7. Percentage of students' correct answers to all the questions by research stage

Research stage	Number of students	Q1	Q2	Q3	Q4	Q5	Q6
First stage	98	53.06%	77.55%	96.94%	68.37%	64.29%	86.73%
Second stage	208	44.23%	73.56%	94.23%	60.10%	62.50%	89.90%

Conclusions

The questionnaire included two questions involving the concepts of accuracy and error (Q1, Q2) and four simple practical problems (Q3-Q6). It can be recognized that the results of both research stages are very consistent, and the percentages of the correct answers in all the tables are relatively close.

As noted above, in both research stages Q1, which referred to the definition of measurement accuracy, received the fewest correct answers. Only 53.06% of students in the first research stage and 44.23% in the second research stage chose the correct definition of the concept (Table 7). A significant number of students (from 15% up to 30%, Tables 1, 3, 4) thought that measurement accuracy is presented as the number of digits after the point in the measured value. This misconception came to light in [7]. According to the remaining students (from 19% up to 33%, Tables 1, 3, 4), measurement accuracy is the smallest measured value that can be presented by a measuring instrument. This group of students confused the concepts of accuracy and resolution.

The second question (Q2) referred to the relationship between two concepts—accuracy and error. The results show that about quarter of the students (Table 6, Q2) misperceived the relationship between them.

The results presented in Tables 1, 3, 4 and 6 (Q2) enable us to summarize that a significant number of engineering students misunderstand the concept of accuracy.

The results of four simple practical problems (Q3-Q6) can be divided into two groups: one group that provided a very high percentage of correct answers (Q3, Q6, Tables 2, 5, 6, 7) and another group that provided relatively low proportions of the correct answers (Q4, Q5, Tables 2, 5, 6, 7).

The meaning of Q3 and Q4 is similar, but in the questionnaire they are represented differently. Q3 was presented as a written statement, whereas Q4 was presented visually. Apparently, the students we polled are more comfortable with the written form. Students today have less experience with measurement instruments that have a needle, because a majority of modern measurement instruments present measured values in a digital form as a number. Q5 operates with the same concepts as Q3 and Q4, but it involves higher thinking skills. According to the taxonomy of problem-solving activities or PST [8], Q3 can be classified as a routine problem, in which the problem solving is well-known to the student, whereas Q4 and Q5 refer to the interpretation taxonomic level, which requires implementation of the students' knowledge of the real world. Therefore, student achievements in Q4, Q5 are lower than in Q3. It is interesting to point out the percentage of students who chose the incorrect answer in Q5—that the accuracy of voltmeter and milliampermeter is not comparable because they measure different parameters—is relatively high: 28.57% in the first stage and 32.69% in the second stage. This fact supports the assertion that a significant number of engineering students misunderstand the accuracy concept.

As can be seen from Table 6, the answers given by students in the different academic programs are close. According to Table 7, the achievements of freshmen in Q1, Q2 and Q3 are higher than their sophomore and experienced peers, but in Q4, Q5 and Q6 they demonstrate lower achievements. The fact that student achievements do not go up with their experience can be explained by insufficient learning of the accuracy issue during the course of their studies. Freshmen engineering students encounter the issue of measurement accuracy in their first physics laboratory course in their first academic year. The engineering courses that they take afterword, mainly, laboratory courses and projects, do not pay abundant attention to this issue, student knowledge is not refreshed, and therefore, student achievements do not improve.

It can be concluded that engineering educators, mainly teachers of practical laboratory courses and project supervisors, must confront the issue of teaching the concept of accuracy, explain its theoretical foundations and require students calculate the accuracy of measured parameters and explain their results.

Appendix – The Questionnaire

1. Measurement accuracy is
   1) Degree of closeness between a measured value of a specific parameter and its true value.
   2) The number of digits after the point in the measured value.
   3) The smallest measured value that can be presented by the measuring instrument.

2. What is the correct assertion?
   1) If the measurement error goes up, then the measurement accuracy goes up.
   2) If the measurement error goes up, then the measurement accuracy goes down.
   3) Measurement error and measurement accuracy are independent of each other.

3. The room temperature is measured using a thermometer with accuracy of $\pm 10\%$. The instrument shows 20°. What is the temperature in the room?
   1) 20°
   2) 22°
   3) 18°
   4) $18^\circ \le T^\circ \le 22^\circ$

4. The car speed is measured using a speedometer whose needle is as shown in the followed picture:

The needle thickness is about half the graduation (the interval between two adjacent stripes). The speed scale is graduated in km/h. What is the car's speed?

1) $180 km/h$
2) $182.5 km/h$
3) $175 km/h \le v \le 185 km/h$
4) $178.5 km/h$.

5. The voltmeter measures the voltage on the resistor in an electrical circuit and shows $5V$. It is known that its measurement deviation is $\Delta_V = 0.5V$. The milliampermeter measures the current in an electrical circuit and shows $10mA$. It is known that its measurement deviation is $\Delta_I = 0.5mA$. What instrument has the higher measurement accuracy?
   1) Milliampermeter
   2) Voltmeter
   3) Not comparable, because the measurements are of different parameters.

6. There is the need to measure the thickness of a matchbox. Three bars in length of $50cm, 20cm, 10cm$ are available. Every bar is divided into 100 graduations. What bar must be used for the greatest measurement accuracy?
   1) $50cm$
   2) $20cm$
   3) $10cm$.

References

[1] JCGM 200:2008 International vocabulary of metrology – Basic and general concepts and associated terms. http://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2008.pdfhttp://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2008.pdf, Last accessed 2 February 2014.

[2] Engineering ethics in practice: A guide for engineers. The Royal Academy of Engineering, 2011, https://www.raeng.org.uk/societygov/engineeringethics/pdf/Engineering_ethics_in_practice_short.pdf, Last accessed 25 January 2014.

[3] Competency Standard for Professional Engineer. Engineers Australia, 2010, http://www.engineersaustralia.org.au/sites/default/files/shado/Education/Program%20Accreditation/110318%20Stage%201%20Professional%20Engineer.pdf, Last accessed 20 January 2014.

[4] M. Frank, "Knowledge, abilities, cognitive characteristics and behavioural competences of engineers with high capacity for engineering systems thinking (CEST)", Systems Engineering, Vol. 9, No. 2, pp. 161-174, 2006.

[5] M. F. Chimeno, M. A. Gonzalez, and J. R. Castro, "Teaching measurement uncertainty to undergraduate electronic instrumentation students", International Journal of Engineering Education, Vol. 21, No. 3, pp. 525-533, 2005.

[6] A. Elshorbagy, "Accuracy and uncertainty: A false dichotomy in engineering education. A case study from civil engineering", International Journal of Engineering Education, Vol. 24, No. 1, pp. 137-143, 2008.

[7] E. Trotskovsky, N. Sabag, S. Waks, and O. Hazzan, "Students' Achievements in Solving Problems Using Models in Electronics", IEEE Transactions on Education, Submitted for publication.

[8] H. L. Plants, R. K. Dean, J. T. Sears, and W. S. Venable, "A Taxonomy of Problem-Solving Activities and Its Implications for Teaching", *The Teaching of Elementary Problem Solving in Engineering and Related Fields*, J. L. Lubkin (ed.), American Society for Engineering Education, Washington, 1980, pp. 21-34.

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