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How do engineering students misunderstand the concept of accuracy? - Work in progress

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ABSTRACT: It is known that students find it difficult to understand the accuracy concept. In the current study, 57 electrical and electronics engineering students who took the Digital Electronics course in their third academic year participated. Two problems concerning the concept of accuracy were developed and appeared on the final examination. The problems concentrated on error and quantisation of electrical signals with noise in digital systems. Both problems required calculations; the second problem also required students to provide explanations. Open interviews with students and analysis of their written solutions and explanations were conducted. Analysis of the solutions revealed that the students used incorrect accuracy formulas and demonstrated misunderstanding of the relationship between accuracy and error. Examination of students' explanations exposed new aspects of misunderstandings linked to digitalisation of electrical signals. The results of the current study demonstrate that some engineering students misperceive the concept of accuracy even at advanced stages of their study programme.

INTRODUCTION

Accuracy is an important basic engineering concept. The Collins English Dictionary defines accuracy in physics and chemistry as *...the degree of agreement between a measured or computed value of a physical quantity and the standard or accepted value for that quantity* [1]. For engineering, the above definition is insufficient; the aspect of practicality must also be taken into consideration. For example, there is no merit in seeking accuracy in milligrams when the measuring instrument is calibrated in grams.

An additional aspect of the importance of the accuracy concept in engineering has been illustrated by McCready: *A scientist will test nature and produce a number and its expected accuracy. An engineer needs to get the number (by any available means), its reliability or accuracy and then is expected to provide an opinion or judgment that will enable a device or process to be constructed* [2]. In other words, an engineering decision about the suitability of a device designed to meet design requirements, in most cases, is based on this parameter. An ethical guide for engineers illustrates this assertion in the following words: *Accuracy and attention to detail ensure[s] 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]. As pointed out by Streveler et al, engineering students must learn the conceptual knowledge that is critical for the development of their professional competencies [4]. Grasping the concept of accuracy is extremely important for engineers and, therefore, engineering education must pay appropriate attention to this concept.

The learning of science and engineering go hand in hand with the creation of misconceptions - incorrect understanding of basic science concepts. According to Cromley and Mislevy, misconceptions *...are ideas derived from daily experience that students bring to their learning experience and that contradict scientific understanding and [are] often resistant to change* [5]. Students' misconceptions in science are widely investigated in pedagogical literature. However, there is a lack of research on misconceptions related to accuracy and uncertainty, which are typical of engineering students. The researchers [6] claim that engineering students never think about measurement uncertainty. The article by Elshorbagy asserts that the misconception that accuracy and uncertainty are dichotomous in engineering practice exists among engineering students [7].

A series of studies investigating additional aspects of students' understandings of the accuracy concept were carried out during the last two years. Thus, Trotskovsky et al reveal misconceptions about the accuracy concept expressed by engineering students taking basic electricity and electronics courses while using engineering models [8]. Some students misperceive accuracy as the number of digits right of the point in the result they reach. According to Trotskovsky and Sabag, it was shown that engineering students from different engineering programmes - mechanical engineering, electrical and electronic engineering, and industrial engineering and management - demonstrated insufficient understanding of the concept of accuracy and the relationship between accuracy and error in measurement [9]. Only about half of more than 300 study participants 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. It was with great interest that the authors continued their research into students' misconceptions about accuracy in different engineering courses, which effort resulted in the present article.

THE RESEARCH AIM

The purpose of the current study is to investigate students' perceptions relating to the accuracy concept and additionally, students' understandings of the concept as it applies to the terms quantisation, resolution and noise in the framework of the basic Digital Electronics course.

METHOD

Streveler et al point out that the conceptual understanding of students can be investigated by presenting students with examination problems and subsequently questioning on their solution process [10]. This qualitative method was chosen for the current research. The first tool was a questionnaire that included two problems involving the concept of accuracy, which was developed and incorporated into the final examination of the Digital Electronics course. An analysis of students' written solutions and explanations was carried out. The second research tool applied in this research was open interviews with students who expressed erroneous understanding of accuracy.

POPULATION

The research population was 57 electrical and electronics engineering students who took the Digital Electronics course in their third academic year.

THE QUESTIONNAIRE

The problems concentrated on error and quantisation of electrical signals accompanied with noise, in digital systems. The first question was a multiple-choice one, aimed at examining students' understanding of the relation between reference voltage of an analogue to digital converter (ADC), the resolution and the accuracy of a measuring system. Students were meant to explain that the resolution of ADC is the smallest measuring unit, which is determined by the reference voltage and the number of bits. The second question at the examination was an open problem, in which the students were expected to understand that in the case when a signal is accompanied with noise greater than resolution, the size of the resolution is not important; when the noise is greater than the resolution, the noise dictates the error and the accuracy as well. Both problems required calculations; the second problem also required students to provide an explanations. The detailed questionnaire appears below.

Question 1: A block diagram of the system for voltage measuring is described in Figure 1.

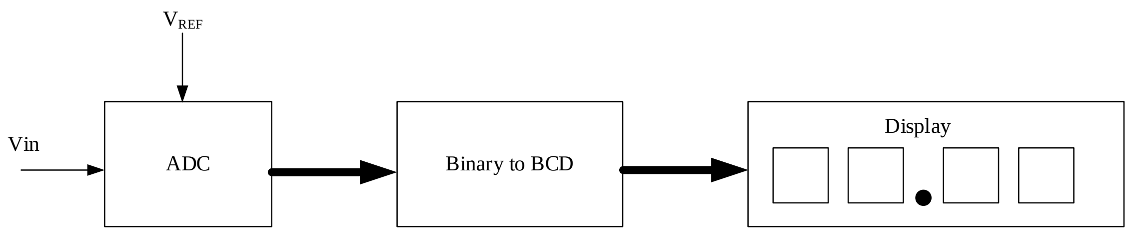

Figure 1: A block diagram of the system for voltage measuring.

The measured analogue voltage (Vin) is translated into binary number by 8 Bit-ADC and, then, converted into decimal form that is displayed on a four-digit panel. There are two digits for the integer and two for the fraction part of the number. The smallest value that can be displayed on the panel is 10mV.

Given that the resolution is 10 mV/bit, what is the reference voltage (V_{REF}) value of the ADC? Please, choose the most correct answer.

1. V_{REF} = 2.56V
2. V_{REF} = 2.562V
3. V_{REF} = 2.5625V
4. All the answers are correct.

Question 2: An input voltage of 0.3V DC entered into 16 Bit-ADC with a reference voltage of 1.25V. It is known that the measurement is carried out in a noisy environment, which radiates noise with amplitude $50\mu V$ on the input signal.

1. Calculate the measurement relative accuracy in percentage of the input voltage.
2. How will your answer change if the reference voltage changes to 2.5V? Will the relative accuracy go up or go down? Please explain your answer.
3. How will your answer change if the reference voltage is 3.28V? How will the accuracy change - will it go up or go down? Please explain your answer.

RESULTS

On the first question, most students used the given resolution to calculate the reference voltage of the ADC and got the result of 2.56V, which is a correct answer. Nevertheless, smart students who went beyond this and calculated the resolution for the two other cases, i.e., V_{REF} = 2.562V and V_{REF} = 2.5625V, got the values 10.0078mV/bit and 10.00976mV/bit, respectively. An engineering student should understand that more than two numbers to the right of the decimal point are redundant; they cannot affect the display in the given case. Therefore, the correct answer is 4 - all the answers are correct.

The written explanation of this fact, which was provided by student A in the examination, is described as follows:

A: *Since we can't see values smaller than 10mV on the display, all reference voltages given in the question will reach the same result.*

Only 22 participants marked the correct answer. Among the other 35 students, 8 did not indicate any answer, and the remaining 27 students selected the first answer, which is 2.56V.

Although the first problem was a multiple-choice question, some students provided an explanation for their selection. Thus, student N calculated the resolution and got the result of 10 mV/bit. He illustrated his incorrect choosing of the first answer by the following reasoning:

N: *Any reference value different from 2.56V will cause a resolution different from 10 mV/bit.*

The student did not see that the measured value can be displayed only in quants of 10mV, and he did not understand that resolutions 10.0078mV/bit and 10.00976mV/bit will not cause the display to change.

This explanation can be classified as misunderstanding of digitalisation concept, which is discussed below.

Other students marked the same answer, but for different reasons; they did not reflect on their thinking way, which led them to the answer they chose. Five students who made this error were interviewed and explained in the same manner as student O, their considerations when choosing the incorrect first answer:

O: *I solved the problem and got a reference voltage of 2.56V. I saw the first answer, marked it and did not even try to think about other answers.*

The diversity of the answers to the second problem was larger compared to the first problem. Only 27 students tried to solve the second question; the remaining 30 students did not mark any answer. Among the 27, only six students demonstrated full understanding and provided the correct solution, another six students only partly solved the problem correctly and the remaining 15 participants solved it incorrectly. Ten of the students' errors can be classified as misconceptions and misunderstandings of the accuracy concept; the other five students made different mistakes, which are not relevant to the current study. In their written explanations, the students demonstrated various misunderstandings concerning accuracy.

The most popular error in calculating of an accuracy value (Question 2.1) was the usage of an incorrect formula. It is known that the relative measurement error and accuracy are defined in percentage as follows:

$$\begin{aligned} &Absolute\ Error = \left|A_{MEASURED} - A_{TRUE}\right| \\ &Relative\ Error = \frac{\left|A_{MEASURED} - A_{TRUE}\right|}{A_{TRUE}} \times 100\% \\ &Accuracy = 100\% - Relative\ Error \end{aligned} \tag{1}$$

A_{TRUE} is a true value of a measured parameter,
$A_{MEASURED}$ is a measured value.

There are other definitions of accuracy in engineering literature. For example, Smith defined accuracy as *...the difference between the true value and the mean of underlying process* [11], which is the absolute error according to the definition used in the current article.

Among the six students, some calculated the relative error value and called it accuracy. Therefore, they got a very low accuracy value of about 0.038%. Because this relation to accuracy took place, it convinced these students that they understand the idea of accuracy. The least significant error was the usage of a measured value in the denominator of Formula (1) instead of its true value, as shown in student G's work:

$$Accuracy = \frac{|A_{MEASURED} - A_{TRUE}|}{A_{MEASURED}} \times 100\% \cdot$$

This answer was classified as a partially correct solution because the students got 99.9% accuracy, which is very close to the true result.

Another 10 students made more serious mistakes, which were classified as erroneous solutions. Four students demonstrated misunderstanding of the accuracy concept; they calculated accuracy as the ratio between resolution and amplitude of noise signal. They got an insufficient accuracy value of about 38%. A few students calculated the accuracy as a ratio between noise signal to resolution, as shown in student R's work:

$$\text{Percentage error = Vnoise/resolution} = (50\mu\text{V}/19.1\mu\text{V}) \times 100\% \approx 262\%$$

All of these students demonstrated complete misunderstanding of the accuracy concept.

Examination of students' explanations for the second question exposed new aspects of misunderstandings linked to digitalisation of electrical signals. For example, student E added the noise to the resolution to calculate the error, as written in the following citation:

$$Error = \frac{Resolution + Noise}{Vin} \times 100\% \cdot$$

This student did not understand that the composed signal and noise entering the system is quantised and displayed.

Student S calculated the resolutions in Questions 2.2, 2.3 and erroneously concluded:

S: *The resolution in 2.2, 2.3 goes up; therefore, the accuracy goes down.*

Five students gave the last standard explanation. They misperceived that in the case of measurement of a noisy signal, if the noise is smaller than the resolution, then the resolution defines the error of the measurement system; but if the noise is larger than the resolution, the error of the system is defined by the quantised noise value. Nevertheless, if the resolution goes up and becomes equal or less than the noise, the noise cannot change the value in the ADC output and displayed value. Therefore, measurement accuracy goes up.

CONCLUSIONS

The questionnaire included two questions involving the concept of accuracy. The low ratio of correct answers (22 in the first question and 12 in the second question out of 57 participants) may indicate that a lot of students do not grasp the accuracy concept.

As noted above, the first question referred to the relationship between the ADC reference voltage and measurement accuracy of the system and sought to find a reference voltage of the converter. About a half of students (27 out of 57) chose the answer 2.56V, which was only one option among the correct answers in the multiple-choice question.

Analysis of students' interviews shows that some students have a bad habit of only seeking one answer, which seems correct to them and, then, moving to the next question without checking the other answer options, when solving multiple-choice problems. Therefore, the students' results when answering the first question do not allow the authors to claim that all 27 students do not understand the relationship between ADC reference voltage and measurement accuracy.

The results of the second question, where students were asked to calculate accuracy values and explain their thinking; allowed the authors to determine some facts about students' misconceptions and misunderstandings. Only 12 of the 57 third-year students know, either fully or partly, the very simple Formula (1) and can calculate an accuracy value. These results are in line with previous studies that showed that engineering students misperceive the accuracy concept and have difficulties with definition and calculation of accuracy values [8][9].

The current research also exposes new aspects in students' misunderstanding of accuracy linked to digitalisation of electrical signals. Students misperceived the essence of quantisation of signal and noise, tended to confuse quantisation and noise errors and confused the relationships between noise and resolution. In students' answers, all these concepts intertwine in different erroneous forms, and it is difficult to separate one from the other.

It can be concluded that the issue of accuracy causes a lot of errors in problem solutions. Therefore, engineering educators must pay attention to teaching the concept of accuracy, explain its theoretical foundations and require students calculate the accuracy of measured parameters and explain their results. The authors of the current article intend to continue their research to acquire a complete understanding of this issue.

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