Trustworthiness as Central Design Principle for Introducing Uncertainties of Measurements to Students

Mag. Dr. Clemens NAGEL (1)

(1) Universität Wien, Fakultät für Physik, Experimentelle Grundausbildung und Hochschuldidaktik Porzellangasse 4, Austria.

Abstract. Two curricula of introducing measurement uncertainties for high school students have been developed. The central design principle was "trustworthiness of experiments and data" following the GUM recommendations of Type-A and Type-B methods. A time-delayed post-test showed the long term acceptance of the key ideas.

In lower secondary level starts with an experiment that leads them to measurement uncertainties. Sources for uncertainties and the trustworthiness are discussed and data is analysed by simple statistical means. In upper secondary level, students first build a measuring instrument by themselves for introducing Type-B uncertainties. Both curricula together provide a complete introduction in ISO standardized methods how to deal with uncertainties of measurement.

Introduction

Acquiring experimental skills is part of every physics curriculum. While the hands-on part of experiments raises the interest in physics, the part of calculating and discussing measurement uncertainties sometimes has an unsatisfactory character for students, also at university level [1]. However, interpreting measurement uncertainties opens interesting discussions about conducting experiments. It may also deepen the understanding of the examined phenomena and allows a different view on how scientists derive and discuss results. Unfortunately, (Austrian) teachers do not broach the issue of uncertainties in their lessons, although, they are convinced about their importance and significance in science literacy [2]. Therefore, two curricula of introducing measurement uncertainties have been developed and evaluated [3, 4].

Methods

The development was done in two separate design-based-research studies and have been evaluated in several classes all over Austria. The R&D-Cycles contained: building a prototype based on the Model of Educational Reconstruction (MER) [5], pretesting of draft version, expert-interviews [6], probing acceptance [7], expert-discussions, validation in classrooms and a time-delayed post-test [6]. Within these cycles, mostly qualitative empirical research methods were used to evaluate the curricula: interviews using the method of probing acceptance, video-analysis of laboratory- and classroom-settings, participating observation, communicative validation (triangulation) [6,7].

Common Design Principles and Key Ideas

<u>Design principals</u> were: Trustworthiness of measurement, continuous strategy in conceptual change (teaching method), content structure is determined by learners needs and context-independent, practicability for teaching in common classroom settings, simple statistics and mathematics, expandable concepts.

<u>Key Ideas</u> were: individual results of a measurement series are usually not identical, uncertainties can be determined by 2 different means (Type-A and Type-B), results of

measurements can be distinguished by their trustworthiness, results must always contain an adequate information of uncertainty and measured variables must have a numeric value and a unit.

Curricula Design (Findings)

Lower secondary level: In the first lesson, students conduct an easy looking experiment in small groups of 2-4 that leads them to the existence of uncertainties. With a scale to tick the level of trustworthiness the students shall estimate the uncertainty of their experiment. In the second lesson the experiment is to be analysed using simple methods of statistics such as the arithmetic mean and range of the data. Worksheets lead the students through both lessons. Hint-cards and additional tasks provide differentiated instruction. To conclude the second lesson, a concept cartoon is used to discuss the different types of measurement uncertainties and errors in small groups [3].

Upper secondary level: Students first build a measuring instrument for length (scaled in inch) by themselves for introducing Type-B uncertainties. In the second lesson, the instrument is used for measuring a given length. With the scattering results of the class, Type-A uncertainty is statistically calculated. Applying the new concepts in different cases is trained. In the optional third lesson, the (recent and historical) context of unit-systems and dimensions is also captured. The material is provided by presentation slides, worksheets and online-questionnaires [4].

Conclusion

The analysed data of the interventions showed positive results in the learning of measurement uncertainties for both levels. The experiments and tasks turned out to be an easy tool to familiarize students with the existence of uncertainties and errors (as a different concept) in measurement. In the written assessments the students were able to name different kinds of sources for uncertainties and showed good results in comparing the trustworthiness of different outcomes by regarding measurement uncertainties. All key ideas could be satisfactorily covered by the curricula [3,4].

The delayed additional test showed the long term acceptance of the key ideas by the students. Trustworthiness as central design principle for introducing uncertainties of measurements to students in secondary level turned out as a successful approach.

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Theory of Measurement Uncertainties in GUM

The concept of measurement uncertainties in GUM (Guide of the expression of uncertainties in measurement) is based on the unknown true value of a measurand [5]. In GUM, there is a strict distinction between errors and uncertainties [6]. While errors like miscalculation must be prevented, systematic errors need to be corrected. However, uncertainties must be calculated. There are two ways of calculating uncertainties: *Type A* is evaluated by means of statistical methods, *Type B* is evaluated by other means.

The research question was to develop

Type A uncertainties include measurements that are repeated and result in a series of values. If a measurand is derived by a single observation the uncertainty will be described by type B evaluation. This, for example, includes the uncertainty of a gauge, which is often specified in its handbook. Otherwise, a reasonable estimation of the instrument's uncertainty is required. Hence, the three main types of type B uncertainties contributing to the uncertainty of a gauge, namely scale, nonlinearity and digitizing uncertainty, must be geometrically summed up [4, 5].