COMBINED MEASURES OF STUDENTS' SUCCESS: RECENT TRENDS AND DEVELOPMENTS IN SCIENCE EDUCATION RESEARCH

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Abstract

Besides measures of students' performances, a valid assessment of students' efficiency in a teaching process should also include measures of invested mental effort. The research presented herein covers several approaches in measuring students' mental effort including 5, 7 and 9-point Likert type scales, time on task, as well as eye tracking technique which in combination with performance measures provide valid information on students' success. Results of the research showed good correlation between mental effort assessed by 7 and 5-point Likert type scales and students' performance, while the use of the 9-point scale showed a low degree of correlation, thus recommending the use of a scales with 5 and 7 points for educational purposes over 9-point scales. The research presented herein illustrates how eye tracking can be used to support the evaluation of invested mental effort. Additionally, this method enabled the identification of some student difficulties in the analyzed area – Stereochemistry.
Keywords: *efficiency measure, mental effort, students' performance, science education*.

Introduction

Over the years a vast majority of researchers performed their research on students' efficiency in teaching process relying only on measures of students' performances. However, although such measures provide valuable information about the effectiveness of the teaching process, they cannot be its only indicator. It is found that one also has to take into account the basic idea of Cognitive Load Theory (Paas & van Merrienboer, 1993) about the limited capacity of the working memory. Accordingly, research showed an increasing interest in cognitive load measures in recent years, and in particular, measures of its important construct – mental effort.

There have been developed various approaches to measuring mental effort. The main classification of mental effort measures implies subjective and objective approach. The objective approach is mainly based on physiological and behavioural measures. Some of the most common techniques used within this framework are eye tracking technique (Baluyut & Holme, 2019; Tang & Pienta, 2012), brain activity measurement (Whelan, 2007) and measurements of cardiovascular indicators (Paas & Merrienboer, 1994).

Subjective measures are the most frequently applied empirical methods for measuring mental effort in science education research. They are based on the assumption

that people are able to revise their cognitive processes and assign a numerical value to the invested mental effort (Paas et al., 2003). Subjective measures are usually based on the use of scales such as the Likert type scale. Their usage as a reliable measurement instrument for assessing the invested mental effort is very-well documented in the literature (Ayres, 2006; Kalyuga, Chandler, & Sweller, 2000; Kalyuga, Chandler, & Sweller, 2001; Tindall-Ford, Chandler, & Sweller, 1997). The above-mentioned authors suggest that such measures are the most reliable and most sensitive to detect relatively small differences in mental effort. In addition, such measures highly correlate with objective measures.

Modern trends in the assessment of efficiency include both performance and mental effort measures. One of the affirmed approaches in modelling the relation between performance and mental effort was proposed by Paas and van Merrienboer (1993). This model made it possible to determine, in a relatively simple way, the relation between performance and mental effort, that is, the combined effect of these two indicators on students' efficiency.

The aim of this research was to compare various approaches in measuring students' mental effort (subjective – Likert type scales and objective: time on task and eye-tracking) as well as to combine them with measures of performance to provide valid information on students' efficiency.

Research Methodology

The research was carried out in several stages:

(i) Application of 5, 7- and 9-point Likert type scales and determining which of the scales is the most sensitive in evaluating the mental effort.
(ii) Measuring the time necessary for the task to be solved.
(iii) Employing the eye tracking methodology to provide information on the invested mental effort.
(iv) Combining measures of performance and mental effort, thus providing information about instructional efficiency (main study).

Different stages of the research included different research samples. Thus, the first stage of the research included 62 secondary school students aged 15 to 16. The second and third included 17 students majoring in chemistry teaching from the Faculty of Sciences, University of Novi Sad, who were in their final year of the Bachelor studies. The last (main) stage included 189 secondary school students from Novi Sad (Serbia).

Research instruments were designed according to the objectives of individual studies. The first stage of research included 3 tests with 6 items, belonging to the teaching topic Dispersions. All three tests had analogous tasks, the design of which was identical, and the only difference could be found in numerical values and types of substances used. It is important to note that the first test included a 5-point Likert type scale, the second included 7-point scale, while the third included 9-point Likert type scale. This kind of design enabled a direct comparison of the sensitivity of the applied scales. The second and third stage of the research included an online test with 6 items, which belonged to the teaching topic Stereochemistry. The instrument used in the main stage included 15 two-tier items, covering the topics: Group 14, 15, 16 and 17 Elements.

All the participants, included in the research, accepted to willingly participate without any constraint or expectation of reward. All necessary permissions were obtained prior to research.

Research Results

Results of the first stage of research showed that 7-point Likert type scale correlated best with students' performance, while the 9-point scale showed poor correlation. Such results indicated justification of the use of 7-point scales in research designs. Poor correlation in the case of a 9-point scale could be explained by the fact that students were not able to evaluate fine differences in the mental effort (for instance nuances between very difficult and extremely difficult). A 5-point scale gave satisfactory correlation values which can be explained by the fact that students are familiar with such a way of evaluation due to the same way of grading (1 to 5) in the school system. These results are significant because they show that by selecting a scale of the appropriate range we allow students to reflect on their mental processes and to determine the amount of invested mental effort by assigning it a numerical value. In addition, these results support the application of subjective methods of evaluation of mental effort as convenient non-intrusive tools in educational research designs.

The following stage of the research was focused on measuring the time needed to solve the task as well as on the results of eye tracking analysis. This powerful method enabled us to monitor the individual steps of the problem-solving procedure, to examine how much time is spent on various aspects of the task, as well as to keep track of revisited student's fixations. This approach allowed us to determine what are the difficulties that students encounter within Stereochemistry, which impose the investment of a large amount of mental effort. Some of the identified difficulties involved the determination of the chirality of the molecules, as well as the absolute configuration of atoms in both acyclic and cyclic structures.

Last but not least, combined measures of performance and mental effort provided valid information on instructional efficiency of several instructional designs which enabled inferring that the efficiency of instruction or individual in the teaching process cannot be considered separately from the Cognitive Load Theory. One of the instructions that proved to be very effective in mastering chemical concepts is the instruction based on the Triplet model. Namely, using combined measures of students' success, it was found that this instruction increased student performance and reduced amount of invested mental effort.

Conclusions and Implications

The results of the research confirmed the expectations of the theoretical background that is, the need to include parameters related to the Cognitive Load Theory in efficiency evaluation. Instructional efficiency represents an important area of science education research and therefore, research based on the improvement of the methods and techniques of its evaluation is highly requisite.

In addition to the described results, further research should be focused on the application of the eye tracking technique as a very powerful tool which, in addition to the described benefits, also provides very important information on students' misconceptions. Besides, tested parameters should also include information on students' motivation as an important indicator of students' success.

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