Studying the relationship between performance and confidence in physics and mathematics

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Abstract. This study focused on the relationship between mathematics and physics education and students' confidence when using mathematical tools such as derivatives, integrals, and vectors to solve problems. We conducted a longitudinal study with 260 secondary school students, who were given a modified version of the Test of Calculus and Vectors in Mathematics and Physics. The results showed an overall improvement in test and confidence scores but did not lead to a balance between over-confidence and under-confidence. Males showed consistently more confidence than females. This research highlights the importance of working on confidence assessment practices alongside performance in academic achievements.

Background

Physics and mathematics are inherently intertwined, with mathematics playing a structural role beyond the merely technical aspects [1]. The "FisicaMente al Liceo" project was designed to assist secondary school students and teachers in this endeavour by identifying difficulties in using mathematical concepts and devising strategies to reinforce integrated physics and mathematics competencies. The main research instrument was an adapted version of the Test of Calculus and Vectors in Mathematics and Physics (TCV-MP) questionnaire, containing 17 pairs of coupled mathematics and physics items covering the use of vectors, derivatives, and integrals in introductory mechanics [2,3]. In the latest implementation of the project, presented in this contribution, an additional level of analysis was added regarding students' confidence in answering each of the questions in the TCV-MP. A synergic relationship exists between performance and confidence, the latter being, however, often overlooked [4]. Recent research [4,5] suggests that regular confidence assessment (CA) practices can enhance self-evaluation and metacognitive abilities, thereby providing more effective guidance for learning. Examining students' confidence in their answers after responding helps address misalignments between confidence and competence (known as over- and under-confidence) and helps students achieve better "calibration". While the importance of self-assessment has been studied with university students, its applicability to secondary school students remains an open research question [5].

Here we explore the connection between secondary school students' confidence levels and their performance in the high-school version of the TCV-MP. More precisely, this study tackles the following research questions: (1) What is the correlation between students' confidence levels and test scores, and how does it evolve after an intervention aimed at improving their mathematical/physical competence? (2) Are there any differences based on students' gender?

Methods and findings

For this research, we modified the high-school version of the TCV-MP by including a question on student's confidence level in answering each item. The confidence question was formulated as a 4-point Likert scale from "I guessed" to "Very sure". After a pilot test in a single school, in 2022/23 the modified test was administered to 260 students from 4 secondary schools in northern Italy. The test was used as a pre/post tool; in between, the teachers used materials inspired by Uhden's modelling cycle [1] to integrate the link between mathematics and physics and distinguish technical and structural skills. The activities were designed to enhance performance and to determine whether bolstering comprehension and application of concepts alone would improve confidence calibration. An overview of preliminary findings is presented in Table 1 (test scores

are normalized to 10). Both in the pre and post-test, a moderate correlation between test scores and confidence scores was observed (pre: Pearson's $r = 0.549$, $p < 0.001$; post: $r = 0.500$, $p < 0.001$).

Table 1. Descriptive statistics and significance (Student's t-test) of the broader study (N = 260).

	Mean / Median (pre)	**SD**	**Mean / Median (post)**	**SD**	***W***	***p***	**Effect size**
Test score	5.56 / 5.29	1.89	7.10 / 7.06	1.78	1481.5	< 0.001	rb = 0.90
Confidence	2.75 / 2.71	0.47	2.84 / 2.85	0.51	10935.5	< 0.001	rb = 0.27

Table 2 reports the analysis by gender (N=110 females and 150 males). Other analyses show the comparison between females and males for the correlation between test score and confidence (female: pre r=0.390, p<0.001; post r=0.344, p<0.001; males: pre r=0.582, p<0.001; post r=0.550, p<0.001). Although there is a significant improvement for girls between pre- and post-test (test score W=239; p<0.001, rb=0.905; confidence score t=2.423; p=0.017; d=0.231), it does not eliminate the disparity with boys (test score W=528; p<0.001, rb=0.895; confidence score W=3481; p=0.005; d=0.274).

Table 2. Descriptive statistics by gender (110 females, 150 males).

		Females		**Males**				
		Mean(Median)	**SD**	**Mean(Median)**	**SD**	***t or U***	***p***	**Effect size**
pre	Test score	5.07 (4.86)	1.68	5.92 (5.59)	1.96	U = 6155	< 0.001	rb = 0.25
	Confidence	2.59	0.37	2.86	0.51	t = 4.936*	< 0.001	d = 0.61
post	Test score	6.72	1.70	7.38 (7.35)	1.79	U = 6456.5	0.003	rb = 0.22
	Confidence	2.68	0.42	2.96 (2.97)	0.53	t = 4.598	< 0.001	d = 0.58

(*) Welch's t-test

Preliminary findings

The findings reveal a significant difference in test scores between pre and post-test, with a large effect size. Confidence levels also exhibited a general uptick in total scores, albeit with a moderate effect size. Despite this, the correlation between confidence levels and actual performance is only moderate. Regarding gender-based differences, consistent with previous literature [6] males showed higher performance and higher confidence than females (Table 2) requiring a serious reflection on the equity of teaching strategies. Analyses showing the breakdown for each school and classroom are in progress, and correlations with the type of intervention and working methods that were employed in each school will be explored.

These results have implications for instruction. For example, they suggest that focusing only on the development of disciplinary skills does not lead to greater calibration and does not tackle gender inequalities. Regular use of confidence assessment can be a tool to gradually enhance students' abilities of self-assessment and their calibration. Currently, we are studying how to integrate CA in the original university project and how to use this assessment to enhance students' learning and facilitate the transition between school and university.

References

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