

Physics Education

The effect of virtual reality-based experiments on spectrum in high school

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Abstract

Understanding the concept of hydrogen emission spectrum in intermediate physics is challenging because students must connect observed spectral lines to abstract atomic models. This study investigates whether virtual reality (VR) laboratories improve conceptual understanding more than conventional teaching does and which cognitive processes, as revised by Bloom's taxonomy, are most improved. The quasi-experimental, quantitative, pretest–posttest, control-group design involved 216 twelfth-grade students from three schools (108 in the virtual-reality group and 108 in the control group). A 30-item, validated test measured interpretation, example giving, classification, summarization, explanation, inference, and comparison. Learning improvement was quantified using normalized improvement (N -gain). The VR group had high normalized gains across all indicators, with the largest gains in summarizing ($g = 0.882$) and interpreting ($g = 0.875$), followed by strong gains in inferring ($g = 0.829$) and classifying ($g = 0.806$). The control group had high increases in interpreting ($g = 0.906$) and summarizing ($g = 0.882$), and moderate increases in giving examples ($g = 0.602$), inferring ($g = 0.620$), and comparing ($g = 0.569$). Since the score distribution was not normal (Kolmogorov-Smirnov $p < 0.001$), within-group improvement was tested using the Wilcoxon signed-rank test, while between-group differences were tested using the Mann–Whitney U test. Both groups improved significantly (Wilcoxon $Z = -9.026$, $p < 0.001$ for each group) and baseline equivalence was confirmed ($U = 58\,161.5$, $Z = -0.034$, $p = 0.973$). Posttest performance was better in the VR group (mean rank: 133.57 vs 83.43; U : 3,124.00; Z : -5.970 ; p : < 0.001). These results suggest that VR laboratories can improve conceptual understanding and strengthen cognitive processes oriented toward reasoning when learning about the hydrogen emission spectrum.