METHODOLOGY FOR DIAGNOSING STUDENT MASTERY AND DETERMINING INDIVIDUAL LEARNING TRAJECTORIES IN A DIGITAL ENVIRONMENT (EXEMPLIFIED BY THE MECHANICS SECTION)

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When inquiring about learning outcomes from a student who has studied mechanics, one typically receives general responses such as "I understood" or "not really." The students themselves rarely recognize the exact subtopics or problem types that cause difficulty. A single test score fails to reveal this nuance: a student answering 12 out of 20 questions correctly may lack formula knowledge, confuse measurement units, or misinterpret graphs; in all three scenarios, the numerical score remains identical. In pedagogical practice, this ambiguity hinders the determination of the student's subsequent instructional step.

This issue is extensively addressed in international scholarship. Black and Wiliam demonstrated that formative assessment and feeding evidence back into instruction significantly enhance learning outcomes. According to Hattie and Timperley, feedback efficacy relies heavily on its substance: it becomes constructive when addressing where the student is going, where they currently stand, and what the next step entails. For mechanics instruction, an additional consideration emerges: Hestenes and colleagues established that students' conceptual misconceptions regarding Newtonian mechanics often persist even after formal instruction. Consequently, diagnostic assessment in mechanics must extend beyond merely tallying correct and incorrect answers to classifying the specific types of errors.

The primary objective of this study is to develop and evaluate the efficacy of a methodology within a digital environment designed to diagnose student mastery across classified error categories in mechanics, thereby formulating personalized learning trajectories. The operational hypothesis posits that tailoring recommendations to diagnostic mastery profiles enables students to achieve higher academic growth in their vulnerable subtopics compared to traditional assessment based solely on aggregate scores. This hypothesis is subject to empirical validation or refutation.

The methodology begins by subdividing the mechanics curriculum into distinct subtopics (e.g., kinematics, dynamics, and conservation laws). Learning objectives are specified for each subtopic, and assessment items are indexed with three parameters: subtopic, difficulty tier, and error type. Error categories are structured into four domains: incorrect selection of the physical model, unit conversion errors, graphical misinterpretation, and computational inaccuracies. Test distractors are systematically designed rather than randomized, with each representing a distinct error category. Consequently, the chosen distractor directly identifies the underlying misconception. The item bank draws from problems and model solutions compiled in the author's textbook *Fizika ZERO*.

To ensure diagnostic reliability, isolated errors are not overinterpreted. An inadvertent error does not necessarily signify a conceptual deficit; hence, multiple items are assigned per subtopic and error type, deriving conclusions only from recurring patterns. To ensure tagging validity, items are independently reviewed and indexed by two experienced physics educators, with discrepancies resolved through deliberative review.

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Prior to entering a unit, students undergo a brief baseline diagnostic test. Based on the outcome, the digital platform places the student into an initial or advanced instructional level. Exact threshold criteria will be calibrated during the pilot phase. These levels remain dynamic, adjusting according to ongoing performance throughout the unit.

Upon completing a unit, the student receives a mastery profile outlining performance ratios per subtopic alongside observed error types. For instance, a student demonstrating proficiency in kinematics equations but consistently stumbling on graphical interpretation receives direct visual feedback. This profile addresses the three central inquiries framed by Hattie and Timperley: what goals have been achieved, how close the student is to the benchmark, and what step should follow next.

Guided by this profile, the system outlines an individual learning trajectory. If performance in a given subtopic falls below a defined benchmark, the system recommends theoretical reviews, instructional video lessons, targeted remedial exercises corresponding to the specific error category, and prompt re-assessment notifications. High performers are directed to advanced problem-solving tracks. Threshold parameters will be empirically determined in pilot trials to avoid arbitrary baselines. Furthermore, the trajectory integrates with a formula revision algorithm, prioritizing equations associated with identified deficit areas.

For the instructor, the system aggregates class-level diagnostic reports detailing the subtopics and error categories presenting the greatest difficulty across the cohort. This data informs targeted instructional adjustments during classroom sessions. Thus, digital diagnostics do not displace the educator; rather, they provide data-driven insights to guide pedagogical decisions.

The methodology's efficacy will be evaluated through a pedagogical experiment focused on mechanics, comparing experimental and control cohorts. The control group will receive aggregate scores and answer keys upon unit completion, while the experimental group will receive granular mastery profiles and personalized learning trajectories. Baseline competence, curriculum scope, and instructional duration will be aligned across groups. Mastery will be assessed at baseline, upon unit completion, and via a 30-day retention post-test, with particular focus on performance gains in initially weak subtopics. Conceptual understanding will be evaluated independently from quantitative problem-solving. Data will be analyzed using statistical criteria and reported alongside calculated effect sizes. Given that most participants are minors, participant and parental consent procedures and data privacy protocols will be strictly maintained.

Methodological limitations are also acknowledged. Closed-format testing cannot fully capture cognitive reasoning processes. Therefore, qualitative interviews will be conducted with select students during the experiment to verify whether identified system errors align with genuine underlying reasoning. Because proficiency profiles should guide remediation rather than create stigmas, diagnostic feedback will be structured constructively to sustain learner motivation.

The scientific novelty of this research lies in tagging digital mechanics assessments by explicit error taxonomies, generating multidimensional student mastery profiles, and algorithmically deriving individualized learning trajectories and targeted review sequences. Its practical significance allows educators to identify specific student difficulties across the class, while enabling autonomous learners to navigate clear learning steps independently. It should be noted that the software platform and empirical trial data are currently in development; this paper articulates the theoretical foundation and research design. Subsequent phases will focus on item indexing and pilot calibration.

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