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METHODOLOGY FOR ORGANIZING INDEPENDENT LEARNING IN MASTERING THE ELECTROMAGNETISM UNIT BASED ON AN INDIVIDUAL LEARNING TRAJECTORY FOR PROSPECTIVE PHYSICS TEACHERS

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Abstract
This article presents a methodology for organizing independent learning in the teaching of the electromagnetism unit of physics based on an individual learning trajectory (ILT). The theoretical foundations of the approach and methods for its practical implementation are described. Designed for pre-service physics teachers, this approach uses individualized assignments and a portfolio-based assessment to create a learning process tailored to each student. The significance of the proposed methodology lies in its ability to help students gain a deep understanding of electromagnetism while developing their professional competencies and self-directed learning skills.

Keywords: Individual learning trajectory; independent learning; electromagnetism education; portfolio assessment; personalized learning; physics teacher training.

Introduction

МЕТОДИКА ОРГАНИЗАЦИИ САМОСТОЯТЕЛЬНОГО ОБУЧЕНИЯ ПРИ ОСВОЕНИИ РАЗДЕЛА «ЭЛЕКТРОМАГНЕТИЗМ» НА ОСНОВЕ ИНДИВИДУАЛЬНОЙ ОБРАЗОВАТЕЛЬНОЙ ТРАЕКТОРИИ У БУДУЩИХ УЧИТЕЛЕЙ ФИЗИКИ

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Аннотация:
В данной статье представлена методика организации самостоятельного обучения при изучении раздела «Электромагнетизм» курса физики на основе индивидуальной образовательной траектории (ИОТ). Описаны теоретические основы данного подхода и методы его практической реализации. Предложенная методика ориентирована на подготовку будущих учителей физики и предполагает использование индивидуализированных заданий и портфолио-оценивания, что позволяет создать учебный процесс, адаптированный к особенностям каждого студента. Значимость предложенной методики заключается в том, что она способствует более глубокому усвоению курса электромагнетизма, а также развитию профессиональных компетенций и навыков самостоятельного обучения у студентов.

Ключевые слова: индивидуальная образовательная траектория; самостоятельное обучение; обучение электромагнетизму; портфолио-оценивание; персонализированное обучение; подготовка учителей физики.

INTRODUCTION

In modern higher education, there is a strong shift toward student-centered and personalized learning approaches[1]. Students are expected not only to acquire subject knowledge and skills, but also to learn how to learn independently so they can continue developing expertise throughout their careers. Developing the capacity for independent, self-directed learning is especially crucial for future educators, who must be able to guide themselves and their students in lifelong learning. One way to foster these capacities is by designing an individual learning trajectory (ILT) for each student - a personalized educational path that takes into account the learner's abilities, needs, and interests. Implementing ILTs allows instructors to move away from the traditional "one-size-fits-all" model and instead differentiate instruction, which has been shown to improve student engagement and achievement[4].

Physics education, particularly in complex domains like electromagnetism, stands to benefit significantly from an ILT-based approach. The electromagnetism unit covers numerous fundamental but abstract concepts - electric and magnetic fields, Maxwell's equations, electromagnetic waves, and so

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on - often involving advanced mathematics. It is challenging to fully cover these extensive topics within the limited lecture and lab hours of a standard course. As a result, some important subtopics may be rushed or omitted in class. Relying on independent learning for portions of the material is a practical necessity to ensure complete coverage. Moreover, engaging students in independent learning not only deepens their content knowledge but also cultivates critical thinking, problem-solving, and self-regulation skills[1,5]. Research in educational psychology indicates that when learners take greater ownership of the learning process, their motivation and higher-order thinking abilities improve. For these reasons, recent curriculum reforms (including the adoption of credit-modular systems in universities) allocate a significant portion of students' study time - often 50% or more - to guided independent work outside the classroom. In a general physics course, this means students are expected to learn large parts of units like electromagnetism through self-study under an instructor's guidance.

The concept of an individual learning trajectory has gained traction in pedagogy as a way to implement student-centered learning in a structured manner. An ILT is essentially a customized learning plan for each student, outlining the path and pace at which they will achieve the learning objectives[3,6]. In constructing ILTs, the instructor considers each student's prior knowledge, learning style, strengths and weaknesses, and even professional goals. This approach aligns with differentiated instruction principles that emphasize responding to the needs of each learner rather than teaching to the "average" student. By following an ILT, students can maximize their progress – advanced students can be challenged with deeper or broader tasks, while those who struggle can receive the specific support they need. Importantly for independent learning, an ILT provides a clear structure for what the student should accomplish on their own, reducing the aimlessness that students might otherwise feel when tasked with self-study.

This paper outlines a methodology for integrating independent learning into the teaching of the electromagnetism unit using individual learning trajectories. We describe how to design and implement ILTs for a cohort of physics students, the types of independent assignments and projects that can be used, and the role of formative assessment and portfolio-based evaluation in this approach. We also discuss the outcomes observed with this methodology and its pedagogical implications for preparing future physics teachers.

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METHODS

Our ILT-based approach to teaching electromagnetism involves several stages, from initial diagnostics to final assessment. Below, we detail each step in the methodology and provide examples of its implementation.

Diagnostic Assessment of Students: To effectively personalize learning, the instructor first evaluates each student's background and preparedness in physics. A diagnostic test or pre-test on core electromagnetism concepts (or a brief oral interview) is conducted to gauge the student's baseline knowledge. In addition, the instructor may survey students about their interests in physics, prior experiences (e.g. lab work, projects), and their self-reported study habits. This diagnostic phase identifies each student's strengths, weaknesses, and learning needs, forming the basis for their individual trajectory. For example, one student might already grasp basic electromagnetic field concepts but struggle with mathematical problem-solving, while another has the opposite profile. Such information is crucial for tailoring subsequent independent tasks.

Design of Individual Learning Trajectories: Using the diagnostic information, the instructor develops a written individual learning plan for each student. This plan outlines which topics in the electromagnetism unit the student will need to learn independently, what assignments or projects they will complete for those topics, and the timeline or checkpoints for completion. All students will cover the core curriculum, but an ILT specifies different pathways to get there. For instance, a student with weaker background might be assigned additional readings or foundational problems on electromagnetic theory, whereas a more advanced student could be given an extended project (such as a simulation of electromagnetic wave propagation). The ILT also sets personal goals for the student (e.g. improving experimental skills, gaining deeper conceptual insight into Maxwell's equations) to enhance motivation and purpose. The instructor reviews each ILT with the respective student, ensuring they understand the expectations and have input into their own learning trajectory.

Division of Course Content: The electromagnetism syllabus is systematically divided into two categories: (a) fundamental topics to be taught in class under the instructor's guidance, and (b) supplementary or advanced topics assigned for independent study. This division takes into account the limited class time and the complexity of topics. Essential principles and any particularly challenging core concepts (for example, Maxwell's equations derivations, or the formulation of

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electromagnetic wave equations) are covered through lectures, demonstrations, and guided problem-solving sessions in class. Meanwhile, related subtopics that enrich understanding or applications that extend beyond the basics are designated for independent learning. For instance, phenomena such as ferromagnetism and paramagnetism, magnetic hysteresis and the significance of the Curie temperature, or additional applications of electromagnetic induction could be explored by students independently. If the curriculum is crowded, even some important concepts might be learned independently with proper support. The guiding principle is to ensure that every critical learning outcome is achieved either in class or through structured independent work. Each student's ILT will specify exactly which topics they personally need to study on their own. By individualizing this content distribution, the approach accommodates different learning speeds and interests - a student particularly interested in radio technology, for example, might investigate electromagnetic wave applications more deeply as part of their independent work.

Development of Independent Assignments: For each topic assigned to independent study, the instructor prepares a set of assignments and learning resources that will enable the student to master the material on their own[7,8]. These assignments are the heart of the independent learning process, guiding students through exploration and application of concepts. The tasks are designed to provoke critical and analytical thinking, not just rote reading. They may take various forms, including:

Theoretical questions: Students answer open-ended questions that test their conceptual understanding. For example, for a topic on magnetism, questions might include "What distinguishes the magnetic properties of ferromagnetic materials from paramagnetic materials? Explain in terms of atomic structure," or "What is the Curie temperature and how does exceeding this temperature affect a ferromagnet's magnetic behavior?" Answering such questions in writing requires students to research and explain key principles, ensuring they grasp the theory behind the phenomena.

Comparative analysis tasks: Students perform comparisons or classify concepts to deepen their understanding. For instance, a task might ask the student to construct a comparison table of ferromagnets vs. paramagnets, highlighting their similarities and differences across various criteria (internal structure of domains, behavior in the absence of an external field, magnetization characteristics, existence of a Curie point, etc.). By compiling this information, the student actively analyzes and contrasts the two categories of materials, reinforcing their comprehension of underlying concepts.

Concept mapping and systematization: Students may be given a concept map or diagram (e.g. a block diagram of topics in "magnetic phenomena") and asked to explain the relationships between the concepts on it. This exercise forces the student to synthesize information and see the "big picture." Describing how concepts like magnetic field, induction, permeability, hysteresis, etc. interconnect builds the student's ability to organize knowledge into a coherent structure.

Problem-solving and applied questions: Students tackle quantitative or explanatory problems that apply the theory to new situations. For example, an assignment could pose a scenario: "A ferromagnetic material is heated beyond its Curie temperature. Explain what happens to its magnetization and discuss the practical implications of this change (for instance, in the design of magnetic storage or transformers)." Such an open-ended problem requires the student to integrate their theoretical knowledge (Curie law, phase transitions in magnetic materials) and demonstrate understanding of real-world consequences. Solving problems like this nurtures both deductive reasoning (applying general laws to specific cases) and inductive reasoning (drawing conclusions from observations), which are key components of scientific critical thinking.

Along with these tasks, the instructor provides or recommends learning resources for each topic: textbook sections, lecture notes, videos, or research articles. The independent assignments are carefully calibrated in difficulty and scope to match the individual student's capabilities (as determined in the diagnostic phase). A student with limited background might get more guided questions and structured problems, whereas an advanced student might receive a more open-ended research project. Crucially, every assignment is designed to ensure that by completing it, the student will have achieved a deep understanding of the independently learned topic.

Guidance and Ongoing Support: Although the bulk of learning happens independently, the instructor's role during this period is active mentorship rather than passive oversight. The instructor maintains regular communication and monitoring to keep students on track and to help with difficulties. This can be done through scheduled check-ins, Q&A sessions, or online forums where students can post questions. Periodic formative assessments (such as short

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quizzes or progress discussions) are used to gauge each student's understanding of the material they are studying on their own. Based on these interactions, the instructor provides timely feedback and scaffolding – for example, clarifying confusing points, suggesting additional resources for a student who is struggling, or offering an extra challenge to a student who has mastered the material early. This personalized feedback is critical for self-directed learning, as it helps students regulate their own study strategies and stay motivated. In practice, an instructor might review students' partial work or outlines in the middle of the independent study period and give constructive comments. Maintaining an open line of communication ensures that no student falls behind in silence; each student feels supported despite working at their own pace. Importantly, the instructor acts as a consultant and coach rather than a traditional lecturer during this stage, guiding each student along their trajectory and fostering self-confidence in their independent learning abilities.

Portfolio-Based Assessment: To organize and evaluate the outcomes of independent work, each student is required to maintain a learning portfolio throughout the electromagnetism unit. The portfolio is a collection of the student's work and reflections, serving both as a formative tool and summative assessment instrument. Students include in their portfolio all materials from their independent learning: summaries of readings, answers to theoretical questions, solved problem sets, lab or simulation reports, charts and diagrams they created, and any other evidence of learning (such as a brief reflective journal about what they found challenging or interesting). The process of building the portfolio encourages students to reflect on their own learning, which further develops their metacognitive skills and ability to self-assess. Periodically, the instructor reviews the portfolios (for example, every two weeks) and provides brief feedback or asks questions, which helps students correct course if needed and reinforces that their independent efforts are being monitored and valued. At the end of the unit or semester, the portfolio is submitted for final evaluation. The assessment criteria are made clear in advance, typically including: completeness (did the student do all assigned tasks?), understanding and accuracy (are the explanations and solutions correct and thorough?), and insight/creativity (did the student go beyond the minimum, explore additional resources, or connect concepts in a novel way?). Because the portfolio encapsulates the student's entire learning journey, it gives a more holistic picture of their competence than a single exam would. It also showcases each student's individual strengths – no two portfolios will be exactly alike, reflecting the personalized nature of the trajectories. Grading such individualized work requires effort and clear rubrics to ensure fairness, but it rewards students for their sustained engagement and progress. Research has shown that portfolio assessment can significantly enhance students' self-directed learning skills and provide better insight into their learning progress compared to traditional exams. In our approach, the portfolio not only grades the student but teaches the student, by embedding self-reflection and responsibility into the learning process [2,3]. By following these steps, we establish a structured yet flexible framework for independent learning in the electromagnetism unit. Each student receives a customized path and tasks, works independently with guidance, and is assessed in a comprehensive manner. The next sections describe the outcomes observed from implementing this methodology and discuss its implications.

RESULTS

Implementing an ILT-based independent learning methodology in the electromagnetism unit has yielded positive outcomes in both student learning and skill development. Key results observed include:

Deeper Conceptual Understanding: Students attained a strong grasp of complex electromagnetic concepts and retained knowledge more effectively. By actively researching and solving problems themselves, they moved beyond rote memorization. For example, many students could clearly explain phenomena like magnetic hysteresis or Maxwell's displacement current in their own words after independent study, indicating genuine understanding.

Improved Critical Thinking Skills: There was noticeable growth in students' ability to analyze and reason scientifically. The open-ended questions and problem-solving tasks helped students practice critical thinking. This outcome is consistent with external findings: a controlled study of physics teaching in Indonesia found that students who learned via a portfolio-based independent model showed significantly greater gains in critical thinking compared to those taught by traditional methods (measured by pre- and post-test assessments, $p < 0.05$). The independent learners not only absorbed facts but learned to question assumptions and apply concepts to new scenarios.

Enhanced Self-Directed Learning Skills: Students demonstrated improved self-regulation and study skills. Throughout the process, they learned how to plan their work, manage their time, and seek out information – essential components of lifelong learning. In fact, an educational study showed that the use of portfolios and personalized feedback can significantly boost students' self-directed learning abilities in secondary education. In our implementation, students became more adept at identifying their own knowledge gaps and proactively addressing them, which is a key indicator of independent learning competence.

Higher Engagement and Motivation: Giving students agency through individual trajectories and choice in projects led to higher motivation. Students reported feeling more invested in learning when they could explore topics of personal interest (within the electromagnetism domain) and when tasks were appropriately challenging for their level. Many students took pride in their portfolios and treated them as a personal achievement. Overall class engagement increased, as even quieter students were more active in consultations and discussions, armed with the questions and insights they gained during independent study.

Performance Outcomes: Although the primary goal was deeper learning rather than teaching to the test, students' performance in formal assessments improved. On subsequent exams and quizzes covering electromagnetism, the ILT-group students on average outperformed those from previous cohorts taught with traditional methods, particularly on conceptual questions. This aligns with research from Turkey where high school students assessed via portfolios constructed more thorough knowledge than those assessed conventionally. While our implementation was in a university context, the trend of improved conceptual performance held true.

Positive Feedback from Students and Faculty: Qualitatively, the response to this approach was very positive. Students appreciated the individualized attention and the opportunity to learn at their own pace. They reported that although the independent work was challenging, it was also rewarding and increased their confidence in tackling difficult topics. In the Indonesian study mentioned earlier, participating teachers and students expressed high satisfaction with the portfolio-based model of learning, and we noted similar sentiments in our classes. Faculty observers noted that students in the ILT-based course appeared more self-reliant and displayed better problem-solving strategies than typically seen[1,3].

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These results suggest that the ILT-based independent learning methodology not only helps students master the content of electromagnetism but also builds broader competencies that are essential for their future roles as physics educators. The next section further examines these outcomes and situates them in the context of educational best practices and future implementation.

DISCUSSION

The positive outcomes from this approach underscore the value of combining independent learning with individualized planning in science education. There are several important implications and points of discussion:

Personalized Learning in Practice: Our experience demonstrates that creating individual learning trajectories is a feasible and effective way to implement personalized learning in a university course. Although personalization often sounds idealistic, the structured ILT method provided a clear roadmap for both instructor and student. Each student benefiting from a custom plan meant that stronger students were not held back and weaker students were not left behind. This approach resonates with the concept of differentiated instruction, which has been advocated in education research as a means to address diverse learner needs within the same classroom[3]. In our case, differentiation was achieved not by fragmenting the class into separate groups, but by assigning different independent tasks and supports within a common framework. This is an important model for higher education, where students enter with varying preparation levels. Rather than teaching to the middle, an ILT allows every student to be appropriately challenged and supported.

Deeper Learning and Knowledge Retention: Engaging in independent inquiry and problem-solving led students to develop a deeper understanding of electromagnetism than a lecture-only approach might have achieved. When students actively construct knowledge (for instance, by deriving a formula through a guided problem or by researching the history of Maxwell's equations), they tend to remember it longer and understand its applications better. We observed that even weeks after the unit ended, students could recall and apply concepts that they had learned independently, often with better retention than concepts that were only covered in lectures. This aligns with constructivist learning theory, which posits that knowledge is internalized best when learners actively participate in the learning process. From a practical standpoint, future

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physics teachers who have learned in this manner are likely to retain a strong command of fundamental concepts and be able to explain them more effectively to their own students.

Development of 21st Century Skills: A major aim of using independent learning in teacher education is to foster skills like critical thinking, self-learning, and problem-solving – essentially, to develop teachers who are themselves adept learners. The ILT-based methodology proved fruitful in this regard. Students had to analyze new topics, evaluate information sources, synthesize answers, and reflect on their learning. These activities inherently build critical thinking and metacognition. The improvement in critical thinking is evidenced not only by formal assessments (as noted in Results and studies like Tawil & Amin 2013) but also by the kinds of questions students began to ask. Over time, their questions became more probing and analytical, indicating a shift from passive reception to active inquiry. Such skills are invaluable for future teachers: a teacher who can think critically and learn independently is better equipped to continuously improve their knowledge and to cultivate those same skills in school students. Moreover, the practice of reflection through the portfolio helps future teachers become reflective practitioners - a quality much emphasized in teacher education.

Changes in the Teacher's Role: Implementing this methodology requires the instructor to adopt new roles of facilitator, mentor, and evaluator. Instead of being the sole source of knowledge, the instructor guides students in discovering knowledge themselves. This can initially be a challenging transition for those accustomed to traditional lecturing. In our implementation, we found that the instructor's workload shifted rather than reduced: time saved on delivering repetitive lectures was reinvested into one-on-one consultations, designing customized materials, and providing feedback on portfolios. This mentorship role is demanding, as it calls for high pedagogical skill, flexibility, and attentiveness to each student's progress. However, it is also highly rewarding. The instructor gains deeper insight into each student's learning process and can witness more directly how students overcome difficulties. Our observations concur with the idea that teaching with ILTs is a dynamic collaboration between teacher and student. The teacher continuously adjusts strategies based on student feedback, essentially personalizing teaching in real-time. This approach can contribute to the instructor's own professional growth; dealing with varied student trajectories hones the teacher's ability to address diverse learning needs and solve

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pedagogical challenges on the fly. In short, the methodology elevates the teaching process to a more interactive, mentorship-based practice.

Challenges and Considerations: Despite its benefits, the ILT-based independent learning approach does come with challenges. One major consideration is feasibility with large class sizes. Personalizing learning for many students and reviewing numerous portfolios can be labor-intensive. Technology (like learning management systems, automated quizzes, etc.) can assist in scaling up some aspects, but the instructor's qualitative input remains essential. There is also a learning curve for students, especially those not used to independent work. Early in the course, some students felt overwhelmed by the freedom and responsibility; a few struggled with time management when facing open-ended tasks. These issues were mitigated through gradual scaffolding - for example, initially providing more structured guidance and then fostering greater independence as students became comfortable. Another potential challenge is ensuring academic integrity during independent work; because students largely work on their own, one must cultivate a culture of honesty and make expectations clear (for instance, requiring that reflections be personal and that sources are cited properly in portfolios). In our experience, when assignments are personalized and creative, students are less inclined to resort to dishonest practices, as the work genuinely reflects their own curiosity. Lastly, institutional support is important: faculty and administrators should value the development of independent learning skills and be willing to allocate time and resources (like smaller student-to-teacher ratios or tutoring support) to such initiatives.

Applicability to Other Subjects**:** While our focus was on electromagnetism in a physics teacher education program, the general methodology could be applied to other subjects and disciplines. Any field with substantial conceptual breadth or depth might benefit from an ILT approach to ensure students truly engage with all important topics. For example, a biology course could use ILTs for units like genetics or ecology, or a history course for independent projects on specific historical events. The principles of diagnosing student needs, personalizing content, guiding independent inquiry, and using portfolio assessment are broadly applicable. Adapting the strategy to another domain would involve identifying which parts of the curriculum are suitable for independent study and what unique forms independent assignments might take in that field (lab experiments, case studies, creative projects, etc.).

In summary, the discussion highlights that an individual learning trajectory-based model of independent learning can significantly enhance both the learning experience and outcomes for students, especially in challenging subject areas. It aligns well with modern educational priorities of personalization, competency development, and lifelong learning skills. By embracing this approach in teacher education, we not only improve our students' mastery of physics but also model for them an effective pedagogical strategy which they can carry into their future classrooms.

CONCLUSION

Adopting an individual learning trajectory-based methodology to organize independent learning in the electromagnetism unit has proven to be a pedagogically sound and effective innovation. This approach transforms the learning process into one that is learner-centered, adaptive, and skill-oriented. Each student, working along a custom-designed path, can learn complex scientific content at a comfortable pace and depth, with appropriate challenges and support. As a result, students develop not only a robust understanding of electromagnetism but also invaluable skills such as self-motivation, critical thinking, and the ability to learn independently.

For pre-service physics teachers, these benefits are twofold. First, by engaging in independent learning themselves, they solidify their own physics knowledge and become confident in tackling new problems – an essential trait for any teacher expected to continually update and expand their expertise. Second, having experienced the advantages of a personalized, inquiry-driven learning process, they are more likely to implement similar student-centered strategies in their future teaching. We observed that students who went through this ILT-based approach expressed a desire to "teach the way we were taught," by paying attention to each school pupil's individual needs and encouraging independent inquiry rather than rote learning. In the long term, this mindset can contribute to higher quality teaching in schools, fostering a generation of learners who are curious, self-reliant, and capable of critical thought.

Overall, the methodology described is supported by both our classroom experience and existing educational research demonstrating its efficacy. Like any innovation, it requires careful planning, effort, and a willingness to shift traditional roles. Yet, the outcomes justify the investment: more engaged

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students, improved learning outcomes, and the cultivation of skills that extend far beyond a single physics course. We conclude that integrating individual learning trajectories with independent learning assignments and portfolio assessment is a powerful approach to higher education instruction. It holds particular promise for science and engineering education, where developing problem-solving abilities and conceptual understanding is paramount. Future work could involve formal studies to quantitatively measure learning gains with ILT-based independent learning versus traditional methods, as well as exploring how technology (such as adaptive learning systems or online collaboration tools) might further enhance the effectiveness of this approach.

By continuing to refine and champion such methodologies, educators can contribute to a more personalized and effective education system - one that not only imparts knowledge but truly prepares learners for the demands of the modern world.

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