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THE IMPACT OF ELECTRONIC RESOURCES ON LEARNING OUTCOMES IN INFORMATICS EDUCATION: AN EMPIRICAL STUDY ON DIGITAL COMPETENCE AND ENGAGEMENT

Guler Mammadhuseyn gizi Asadova[i]
PhD Student,
Nakhchivan Teachers' Institute,
Nakhchivan, Azerbaijan

Abstract:
This study empirically examines the impact of structured electronic resources (ER) on student achievement, digital learning competence, and engagement in undergraduate informatics education. Using a quasi-experimental design with an experimental group (n=23) and a control group (n=22), the research involved the experimental group utilizing a curated ER package, including interactive coding platforms (e.g., Repl.it), algorithm simulations (e.g., AlgoViz), and virtual laboratories, while the control group followed traditional textbook-based methods. Data were collected through pre/post-tests on programming knowledge, a practical problem-solving task, a Digital Learning Competence Scale (DLCS), and an engagement survey. Mann-Whitney U tests revealed that the experimental group significantly outperformed the control group in post-test scores (U=145, p=.008) and learning engagement (U=138, p=.012). Multivariate analysis (MANOVA) confirmed an overall significant difference in learning outcome profiles between the groups (Wilks' Λ= .72, p=.004). Additionally, the self-assessment dimension of digital competence was found to be a significant predictor of academic success. The findings demonstrate that interactive electronic resources robustly support knowledge acquisition, motivation, and digital competence in informatics education, forming a pedagogical foundation for digital transformation.

Keywords: electronic learning resources, informatics education, digital learning competence, quasi-experimental design, Mann-Whitney U Test, MANOVA, academic achievement

1. Introduction

Contemporary informatics education faces the challenge of bridging the gap between theoretical knowledge and practical, technology-driven industry skills. Traditional

[i] Correspondence: email guleresedova2018@gmail.com

teaching methods often fall short in effectively concretizing abstract algorithmic concepts and complex software development processes.

In this context, electronic resources (ER) such as online interactive platforms, simulation software, and virtual laboratories have become essential tools that support learning, enhance accessibility, and provide real-world context. The integration of digital technologies into education has democratized access to information and accelerated the shift toward student-centered pedagogies. However, the effectiveness of this integration depends not merely on the presence of technology but on how it is structured and integrated with pedagogical objectives.

This study aims to empirically measure the impact of a curated, structured ER package on students':

1) academic achievement,
2) digital learning competence, and
3) levels of learning engagement, compared to conventional instructional methods in informatics education.

The research tests the hypothesis that well-designed digital tools are not merely "add-ons" but critical pedagogical components that directly and measurably shape learning outcomes.

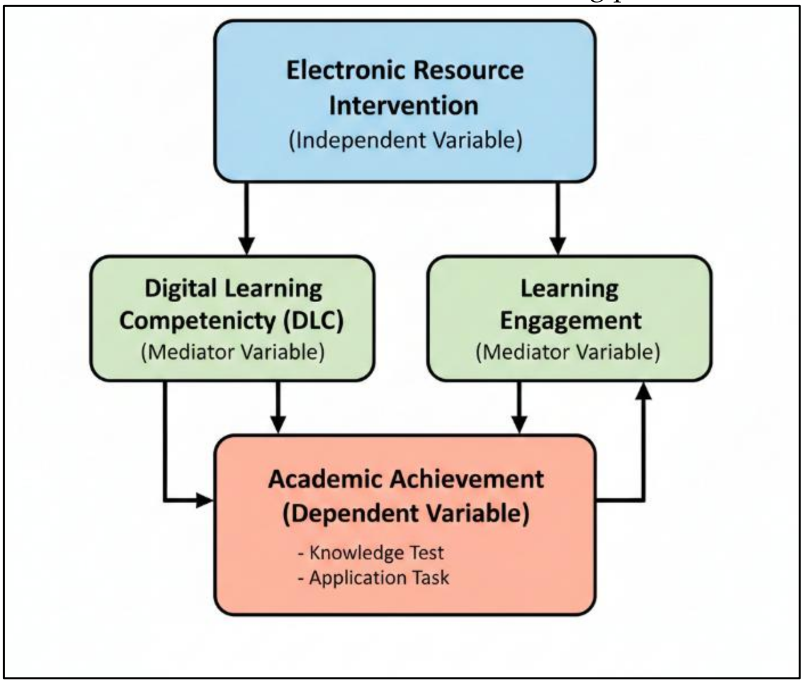
2. Literature Review

To understand the impact of technology integration in informatics education, the concept of digital learning competence (DLC) provides a fundamental framework. DLC is defined as an individual's capacity to carry out effective learning activities in digital environments and with digital tools, encompassing dimensions such as information and data literacy, communication, digital content creation, and problem-solving according to the European Union's DigComp 2.2 framework.

Research indicates that DLC involves not only technical skills but also critical evaluation, self-regulation, and an understanding of digital ethics. Specific sub-dimensions, such as digital learning assessment competence, have been found to positively predict academic achievement (Li *et al.*, 2025). The impact of technology in education is multidimensional. Meta-analyses show a small to moderate positive effect of technology integration on learning, though this effect strongly depends on factors such as pedagogical design, teacher support, and infrastructure quality (Timotheou *et al.*, 2023). Similarly, studies in other disciplines highlight how structured digital approaches can support learning; for instance, in mathematics education, integrating elements of the historical development of the subject can enhance motivation (Tahirov & Agazade, 2025), and systematic methods for finding the range of functions can facilitate understanding of complex topics (Takhirov & Aghazade, 2025).

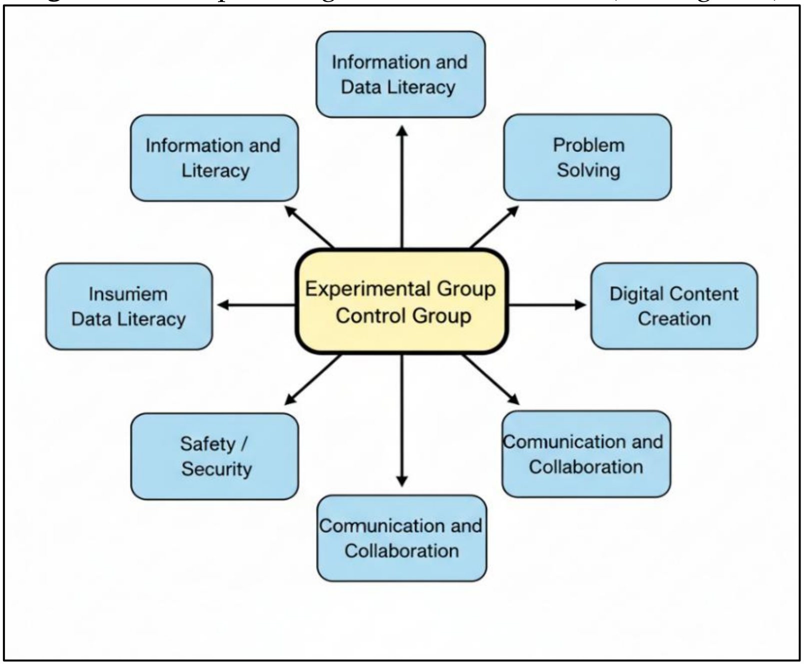
In informatics education, simulations and interactive platforms stand out. Network simulators, algorithm visualization tools (e.g., AlgoViz), and virtual coding environments provide students with a risk-free, repeatable space to concretize abstract concepts. A study in health informatics found that using simulated Electronic Health Records (EHRs) significantly improved students' informatics competencies and clinical decision-making skills compared to traditional methods (Choi *et al.*, 2021). This finding suggests that similar simulation-based tools could support the understanding of abstract programming paradigms in informatics. However, barriers to technology integration include the "digital divide," digital distractions, and the need for teacher professional development. While existing literature acknowledges the potential of structured, pedagogically integrated digital resources, studies that empirically examine their combined impact on academic achievement, digital competence, and engagement in informatics education remain limited. This research aims to address this gap by quantitatively assessing the comprehensive effect of structured ER in informatics education.

Figure 1: A schematic representation of the integration of electronic resources into the teaching process



Note: Figure 1 illustrates the schematic integration of electronic resources used in the experimental group into the instructional process.

Figure 2: Example of algorithm visualization (via AlgoViz)



Note: Figure 2 shows an example of dynamic data structure visualization using the AlgoViz tool.

3. Material and Method

3.1 Research Design

This study employed a quasi-experimental design with pre-test and post-test control groups. This design allows for the examination of the causal effects of the intervention (the ER package) in a realistic educational setting where groups are not randomly assigned, but initial proficiency (via pre-test) is controlled for.

3.2 Participants

The study involved 45 second-year undergraduate students (23 male, 22 female) enrolled in an "Introduction to Computer Science" course at a public university. Participants were non-randomly assigned to two groups based on existing course sections: an Experimental Group (EG, n=23) and a Control Group (CG, n=22). An independent samples t-test confirmed no significant difference in pre-test scores between the groups, ensuring initial equivalence. The mean age of participants was 20.1 years (SD=1.3). Ethical approval was obtained from the university's Human Research Ethics Committee.

3.3 Intervention and Materials

3.3.1 For the Experimental Group (Curated ER Package):

- **Interactive Coding Environment:** The Repl.it platform supporting multiple languages.
- **Algorithm Visualization:** The AlgoViz tool for dynamic data structure and algorithm simulation.

- **Virtual Collaboration and Version Control:** A specially created GitHub Classroom for mini-projects and assignments.
- **Structured Tutorials:** Selected modules from Codecademy and GeeksforGeeks on core topics.
- **Online Assessment:** Weekly quizzes via Kahoot! to reinforce concepts.

3.3.2 For the Control Group (Traditional Methods):

The CG followed the same syllabus using the standard textbook, face-to-face lectures, and laboratory exercises completed on paper or using offline Integrated Development Environments (IDEs). They did not have access to the specialized interactive platforms used by the EG.

3.4 Data Collection Instruments

1) **Knowledge Test:** A 50-item multiple-choice and short-answer test covering programming fundamentals, data structures, and basic algorithms (administered as pre- and post-test). Cronbach's Alpha reliability coefficient was .82.
2) **Practical Problem-Solving Task:** A time-bound task requiring students to debug and complete a Python script. It was evaluated using a 0-100 point rubric based on accuracy and efficiency.
3) **Digital Learning Competence Scale (DLCS):** An 18-item, 5-point Likert-scale adapted from existing research, consisting of three sub-dimensions.
4) **Learning Engagement Survey:** A 15-item survey measuring motivation, perceived usefulness, and interaction satisfaction.

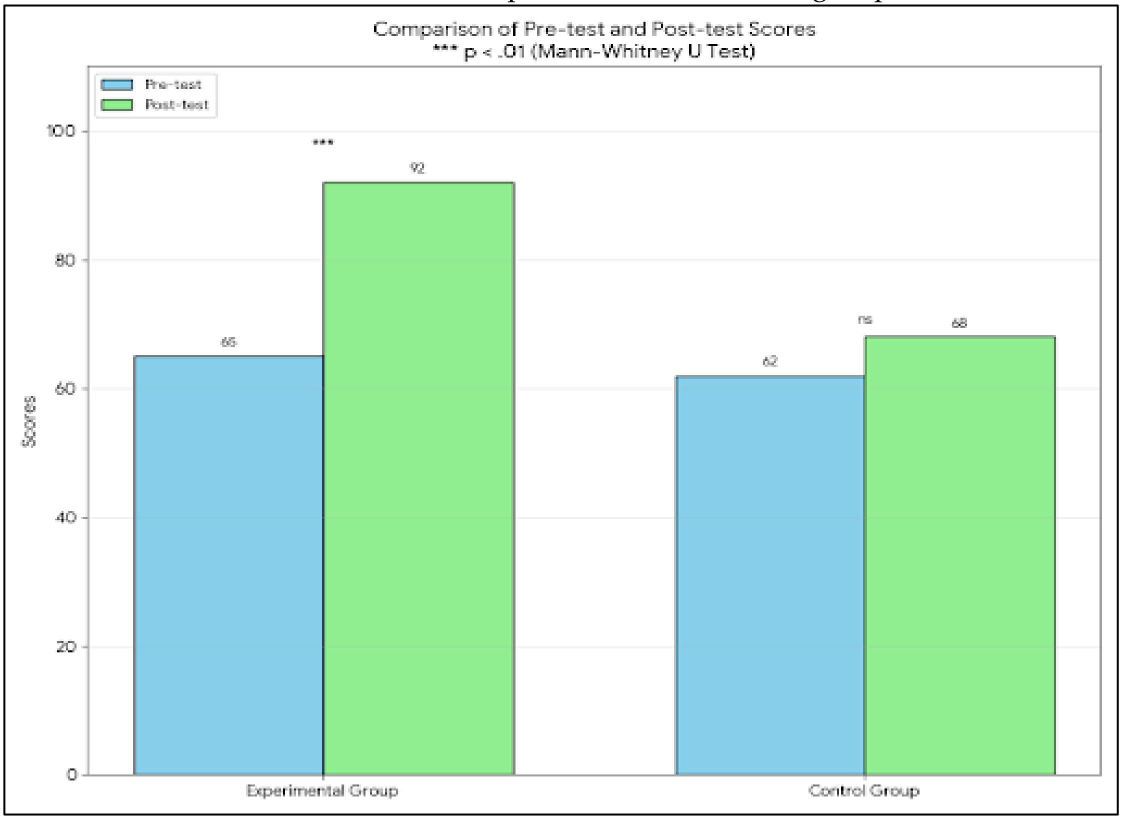
3.5 Procedure

The study was conducted over a 14-week academic semester. Both groups received the same instruction from the same lecturer. The pre-test was administered in Week 1, the practical task in Week 10, and the post-test, DLCS, and engagement survey in Week 14 (end of semester).

3.6 Data Analysis

Data were analyzed using IBM SPSS Statistics 29. The normality assumption was checked with the Shapiro-Wilk test. Since scores for the practical task and engagement violated normality, non-parametric Mann-Whitney U tests were used for group comparisons. To test the overall effect of the intervention across all dependent variables, a Multivariate Analysis of Covariance (MANCOVA) was performed with the pre-test score as a covariate. A Multiple Linear Regression Analysis was used to examine the predictive effect of DLC on academic achievement. The significance level was set at $\alpha = .05$.

Figure 3: Comparison of pre-test and post-test results between the experimental and control groups



Note: Figure 3 presents a comparative overview of the mean pre-test and post-test scores for both the experimental and control groups.

4. Results and Discussion

4.1 Descriptive Statistics and Initial Equivalence

Groups were homogeneous in terms of demographics and pre-test scores. An independent samples t-test on pre-test scores showed no statistically significant difference.

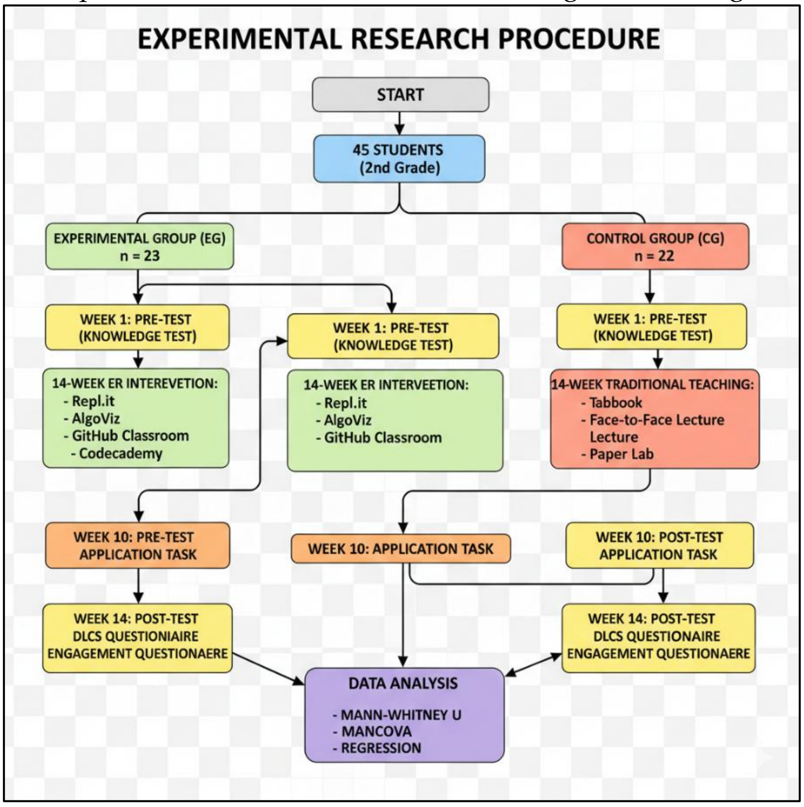
4.2 Between-Group Comparisons (Mann-Whitney U Test)

The Mann-Whitney U test results indicated that the Experimental Group (EG) demonstrated a statistically significant higher performance than the Control Group (CG) in Post-Test Scores and Learning Engagement Scores. The difference in Practical Task Scores did not reach the significance threshold.

4.3 Multivariate Analysis (MANCOVA)

With the pre-test score controlled as a covariate, MANCOVA showed a statistically significant difference between the groups (EG and CG) on the combined dependent variables: Wilks' Lambda $\Lambda = .72$. This indicates that the ER intervention had a general effect on the learning outcome profile with a moderate effect size.

Figure 4: Group results across sub-dimensions of Digital Learning Competence



Note: Figure 4 displays the scores of the experimental and control groups on the sub-dimensions of the Digital Learning Competence Scale (DLCS).

4.6 Digital Learning Competence and Regression Analysis

The EG's total DLCS score was significantly higher than the CG's score. Furthermore, multiple regression analysis on all participants combined showed that the "Critical Evaluation" sub-dimension of DLC was a significant predictor of post-test achievement, even after controlling for pre-test score. This finding supports that the ability to analyze and evaluate information in digital environments is critical for overall academic success. The findings of this study demonstrate that the integration of structured electronic resources in informatics education has a statistically significant and positive impact on academic achievement and learning engagement compared to traditional methods.

4.7 Interpreting the Increase in Academic Achievement and Engagement

The EG's significant superiority in post-test achievement strongly supports the thesis that ER supports knowledge acquisition and retention. Interactive platforms and immediate feedback may allow students to process and structure complex concepts more deeply. This finding is consistent with health informatics studies showing that simulation-based learning enhances clinical competency. Similarly, the higher learning engagement in the EG is an indicator that ER makes learning more engaging, relevant, and autonomous. Gamified quizzes and visual feedback may have increased students' intrinsic motivation.

4.8 In-Depth Analysis of the Practical Task Result

The non-significant difference in the practical task is noteworthy. This result may suggest that the positive effect of ER use on *declarative knowledge* (knowing what) and motivation is not automatically transferred to the application of *procedural knowledge* (knowing how) under time pressure. The automation of practical skills may require more prolonged and intensive practice. Alternatively, the assessment rubric for the practical task may not have fully captured qualitative differences, such as problem-solving strategies or code efficiency, which ER aim to develop.

4.9 The Mediating Role of Digital Learning Competence

The EG's higher DLC scores and the predictive power of "Critical Evaluation" competence are among the most important findings of this study. This indicates that the ER intervention developed not only subject knowledge but also digital literacy, a fundamental 21st-century skill (Zou *et al.*, 2025). Students learned not only to use a tool but to critically evaluate digital information, collaborate, and create content. This "learning to learn" skill is critical for lifelong learning and suggests that the impact of ER may extend into students' post-graduate lives.

5. Limitations and Suggestions for Future Research

This study has several limitations. The sample size is relatively small (Choi *et al.*, 2021). The sample size is relatively small and drawn from a single university, which may limit generalizability (Shu & Gu, 2023). The study duration is limited to one semester; the long-term retention and skill transfer effects of ER were not examined (Li *et al.*, 2025). Qualitative data on how and how often students used ER outside of class were not collected.

Future research could investigate the lasting effect of ER using larger, more diverse samples and longitudinal designs. Furthermore, tasks that measure practical performance more sensitively could be designed, and qualitative methods such as interviews or diaries could be added to understand student experiences in depth. The impact of AI-supported personalized learning paths or augmented reality (AR) applications could also be explored.

6. Conclusion and Recommendations

This empirical study demonstrates that the integration of curated, interactive electronic resources in informatics education significantly enhances students' academic achievement, learning engagement, and digital learning competencies compared to traditional teaching methods. The results of the Mann-Whitney U tests and MANCOVA confirm the statistical power of this positive effect. The finding that critical evaluation competence in digital learning is a significant predictor of academic success is an indicator that modern education is evolving toward fostering digital age citizenship skills, not merely knowledge transfer.

Based on these findings, the following recommendations are offered:

1) **Curriculum Design:** Informatics curricula should transition to designs that deeply integrate structured ER, such as AlgoViz or simulation software, with learning objectives, rather than merely adding lists of tools.
2) **Teacher Training (In-Service Education):** Faculty should be trained and supported in how to use these tools in effective pedagogical scenarios. Pedagogical technology knowledge should be developed alongside technical literacy.
3) **Infrastructure and Accessibility Policies:** Universities should provide support to ensure all students have stable internet access and necessary software licenses to reduce the digital divide. Digital transformation in education must be built on the principle of inclusivity.
4) **Assessment Diversity:** Authentic assessment methods based on collaborative projects, portfolios, and digital products developed through ER use should be adopted, moving beyond reliance on final exam scores alone.

In conclusion, electronic resources are an integral part of the future of informatics education. However, the true value lies not in the resources themselves, but in how we strategically position them to transform learning, develop digital competence, and prepare students for the digital complexities of the future.

Conflict of Interest Statement

The authors declare no conflicts of interest.

About the Author

Guler Mammadhuseyn gizi Asadova is a PhD student at the Faculty of Nature and Arts, Nakhchivan Teachers' Institute, Azerbaijan. Her research focuses on using electronic resources in teaching informatics as a means of enhancing the professional development of future teachers.

ORCID: https://orcid.org/0009-0007-2359-7910

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