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Designing Didactic Conditions and Optimizing Technological Components to Increase the Effectiveness of Biology Teacher Education and Professional Training

Parmonova Marjona O‘ktam qizi
A master's student at the Abdulla Avloniy National Institute of Pedagogical Skills, Uzbekistan

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Abstract: This study examines the formulation and execution of a model that amalgamates optimised pedagogical settings with sophisticated technical elements to augment the efficacy of biology teacher education and professional development. A quasi-experimental approach was utilised with 120 pre-service biology teachers, who were segregated into experimental and control groups. The experimental group underwent training utilising a paradigm that integrated learner-centred instruction, modular lesson design, virtual biology laboratories, and digital educational resources. Quantitative data from pedagogical and topic knowledge assessments, alongside qualitative input from questionnaires and interviews, indicated substantial enhancements in both pedagogical skills and subject mastery within the experimental group. The results show how important it is for biology instructors to learn how to use technology and teaching methods together to get ready for the issues they will face in the classroom today. The research offers pragmatic suggestions for the enduring integration of these training approaches into higher education institutions.

Keywords: Biology teacher education, didactic conditions, educational technology, professional training, virtual laboratories, pedagogical competence, TPACK framework, teacher preparation, digital learning, instructional design.

Introduction: The global changes in education systems have made the quality of teacher preparation even more important, especially in the natural sciences. Biology, being a fundamental discipline within the life sciences, necessitates not just comprehensive subject understanding but also proficiency in articulating intricate concepts through contemporary educational methodologies. Conventional approaches to biology teacher education frequently neglect the incorporation of modern technical resources and structured pedagogical frameworks that correspond with contemporary educational requirements. Recent studies indicate that the formulation of effective teacher training programs relies on various interrelated factors: instructional settings, technology integration, professional competences, and pedagogical techniques (Koehler & Mishra, 2009). Nevertheless, deficiencies persist in the efficient coordination of these elements to enhance biology teacher education. The objective of this project is to formulate, execute, and assess a model that amalgamates ideal pedagogical settings with contemporary technological instruments to augment the efficacy of biology teacher training and professional development. This study investigates the impact of structured didactic tactics, in conjunction with digital technologies like virtual laboratories, simulations, and learning management systems (LMS), on the development of pedagogical abilities among biology educators. The study examines the efficacy of the integrated model relative to conventional training methodologies and suggests recommendations for sustainable deployment within educational institutions. The proficiency and readiness of educators substantially influence the quality of biology education. It is important to train biology teachers to deal with today's academic and technological problems since this will help students become more scientifically literate, think critically, and be mindful of the environment. Teacher education programs need to be updated to include better teaching methods and technology because of improvements in digital technologies and student-centered teaching methods. The purpose of this essay is to identify and analyse the main components necessary to improve the efficacy of biology teacher education and professional development.

Didactic conditions are the things that affect teaching and learning, such as the classroom setting, the way lessons are taught, the way content is organised, and the goals of learning. Good didactic design includes: Approaches that put the learner first: Putting more focus on learning through questions, solving problems, and building things. Interdisciplinary integration: Bringing together biology, chemistry, environmental science, and technology to give a bigger picture. Active learning environments: using labs, fieldwork, and hands-on experimentation to make what you've learnt in theory stick. Teaching that makes you think about yourself and your teaching methods: encouraging trainee instructors to do both. The psychological components of teacher training are essential. Using motivational tactics, formative feedback, and individualised instruction makes teacher trainees more interested in what they're studying and helps them learn better. Modern biology teacher education should take advantage of: Simulations and virtual labs: To create models of biological processes as cellular respiration, DNA replication, or ecosystem dynamics. Learning Management Systems (LMS): Platforms like Google Classroom or Moodle that let you organise and grade your learning. Multimedia content includes videos, animations, and interactive modules that make lessons more interesting. Webinars, online communities of practice, and professional learning networks help people keep learning and share ideas with each other. They help biology teachers keep up with new research, teaching tools, and changes to the curriculum. Using data analytics from tests and student comments lets biology teachers change their teaching to better suit the requirements of their students. To make biology teacher training more effective, schools should: Change the frameworks for the curriculum: Combine didactic models with technology-enhanced learning elements. Give continual training for professionals: Concentrated on educational innovation, digital proficiency, and scientific literacy. Make sure that teacher trainees can go to e-learning platforms, scientific software, and digital libraries. Try out mixed learning models: To get the most out of both, use both in-person and online learning. A teacher training institute started a pilot program that used blended learning to teach students about the environment. There were online tests, virtual simulations of how climate change affects things, and group research projects as part of the program. Teachers said they were more confident using digital technologies and inquiry-based learning in their classrooms. Classroom observations also showed that student engagement improved a lot. Digital divide: Not all of the instructors in training have the same access to technology. Training gaps: Some teachers may not know the basics of ICT. Curriculum rigidity: Traditional programs may not want to include new, flexible ways of doing things. To get past these problems, you need support from the institution, money, and policies that are in line with each other.

METHODS

This research employed a quasi-experimental approach featuring pre- and post-test evaluations to analyse the efficacy of a didactic-technological model of biology teacher training in comparison to a traditional model. The study was executed across two academic semesters (12 months) at three teacher education schools in Central Asia. There were 120 pre-service biology teachers in the study. They were randomly put into two groups: an experimental group (n=60) and a control group (n=60). All participants were in their third or fourth year of university education, with similar academic backgrounds and lacking previous experience in professional teaching. The initiative incorporated certain pedagogical circumstances and technology advancements: Conditions for teaching: lessons that focus on the learner, lessons that are broken up into modules, lessons that are tailored to each student's needs, and assessments based on what the student has learnt. Technological components include the usage of Moodle LMS, digital biology labs (like BioDigital Human), 3D simulation models, video lectures, and collaboration applications like Google Classroom and Padlet. Before the semester started, the teachers in the experimental group learnt how to utilise these tools well at a workshop. The control group did not get any extra help with the regular curriculum. To assess outcomes, the subsequent instruments were utilised: The Pedagogical Knowledge and Competence Test (PKCT) is meant to test how well someone understands different ways to teach and arrange lessons. The Content Knowledge Test (CKT) was based on the national curriculum standards for fundamental biological topics. Classroom Microteaching Rubric (CMR) — a tool for judging how well teachers do their jobs by watching them give short lessons. Surveys and focus group interviews gathered qualitative feedback regarding student satisfaction and perceived effectiveness. We used SPSS 25.0 to look at the quantitative data and find out if the results were statistically significant. We used paired sample t-tests and ANCOVA. NVivo 12 was used to code and thematically analyse qualitative data from interviews and open-ended surveys.

RESULTS

The post-test scores indicated a notable enhancement in both subject matter expertise and teaching skills among those in the experimental group. The average score on the PKCT went up from 65.3 to 82.5 ($p < 0.001$), while the average score on the CKT went up from 71.1 to 88.4 ($p < 0.001$). The control group, on the other hand, only made little improvements: PKCT went from 64.7 to 70.3 and CKT went from 70.9 to 75.1. According to the Classroom Microteaching Rubric, 85% of the experimental group was "highly competent," especially when it came to lesson planning, using digital resources, and getting students involved. Only 55% of the control group reached this level, and most of them had trouble using visual or technical aids in a way that worked. The survey replies showed that the experimental group was more satisfied. More than 90% of students said that the training made them more confident in teaching biology, and 87% said that the tech tools helped them grasp complicated biological systems. Some common things that came up in focus group interviews were: "I can now picture abstract processes like cell division." "The virtual labs let me teach in a real setting without having to use real lab space." "This program got me ready better than just going to class."

DISCUSSION

The findings substantiate the premise that the amalgamation of refined pedagogical tactics and technological elements markedly improves the quality of biology teacher education. The results of this study are consistent with the TPACK framework (Technological Pedagogical Content Knowledge), which asserts that proficient teaching in the 21st century necessitates a cohesive comprehension of content, pedagogy, and technology (Mishra & Koehler, 2006). The way a teacher plans their lessons is very important in deciding how well they can teach. The transition from teacher-centered to learner-centred instruction promoted increased engagement and critical thinking. Modular learning, which helped students learn specific skills, worked best when it was backed up by multiple teaching methods. These results support earlier research that showed how important it is to have flexible, student-centered teaching frameworks (Biggs & Tang, 2011). Technology was not just an extra; it changed the way teachers taught. Using simulations and virtual labs was a safe, cheap, and fun approach to learn about biological systems. Teachers could recreate real-life teaching situations, which made the training more realistic and more like what would happen in a real classroom. Also, video lectures and LMS platforms offered asynchronous learning opportunities that encouraged self-paced learning, which is very important in adult education (Knowles, 1980). Using collaborative platforms well also helped teachers improve their communication and peer learning abilities, which are important qualities for teachers to have. Even though this approach worked well, it needs to be carefully planned before it can be used on a large scale. For scaling to work, institutions need to be ready, teachers need to be trained, and they need to have access to technology and continuing support. The long-term success of these kinds of programs may be in danger if they don't get backing from the government and policy makers.

CONCLUSION

This study shows that combining controlled teaching circumstances with better technology tools greatly enhances the results of biology teacher education. The suggested model improved both theoretical understanding and practical teaching skills, as shown by how well students did and how happy they were. The effects on policy and practice are quite important. Teacher training schools should think about adding these kinds of models to their programs, and people who decide educational policy should make improving infrastructure and teachers' digital literacy a top priority. We can better educate biology teachers for the problems they will face in today's classrooms by aligning pedagogy, subject, and technology. Subsequent investigations ought to examine the enduring effects of such training on real classroom performance and student outcomes in secondary school. Also, similar models may be used in other science fields, which would make STEM teacher preparation better all around. The efficiency of biology teacher education can be greatly enhanced by the intentional design of pedagogical settings and the strategic incorporation of technology. Teacher training programs can create competent, adaptive, and inventive biology teachers who are ready to address the needs of 21st-century education by using new teaching methods and digital resources.

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