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Effectiveness of Transformative Learning Theory in Physics Laboratories of Physics Students of Mongolian National University of Education(MNUE)

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A B S T R A C T

As part of the conceptual reform of the curriculum, the orientation of changes in content, teaching methods, and evaluation are defined by the principles of "Simplifying Content, Amplifying Methodology, and Amplifying Process Evaluation". In this study, we examined how Transformative Learning Theory can be applied to enhance students' scientific inquiry abilities in the "Practicum of Physics Experiment" course within the MNUE's Physics Teacher Training Program. The discussion focuses on developing a teaching and learning method for the physics laboratory, rooted in Transformative Learning Theory, to improve the experimental proficiency of Physics students at MNUE. The findings of the experimental study demonstrate a notable enhancement in students' initial average score across various domains. Specifically, there was an increase of 2.57 points in conceptual knowledge, 2.61 points in planning skills, 2.75 points in the skills related to conducting experiments and collecting data, and 2.31 points in data analysis skills. When the students' laboratory performance evaluation results were analyzed using a t-test, the results showed t = -43.096 and p = 0.001, indicating a statistically significant differences between pre and post-test.

1. INTRODUCTION

Recent social development and technical progress are requiring shift from closed 'cookbook'-style physics laboratories (labs) to incorporating open-ended elements (Smith & Holmes, 2021, p. 662). Laboratories with clear instructions and guidelines facilitate practical work; however, relying solely on step-by-step directions can decrease creativity and hinder the development of essential skills. Research on Interactive Pedagogy in higher education (HE) remains underexplored (Sami et al., 2023, p. 2), and research reveals persistent challenges in teachers' methodologies for guiding physics experiments and laboratory work.

In the teacher training program concept of MNUE (Mongolian National University of Education, 2023, p. 4), XXI century's teacher is defined as "a lifelong learner and a

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learning guide who critically absorbs and transforms new knowledge, information, and cultural insights from diverse sources into personal understanding, creates new values, adapts problem-solving approaches with flexibility, and effectively applies their acquired expertise to tackle complex challenges". For example, S. Amartuvshin (Amartuvshin, 2023, p. 3) argues that fostering a professional attitude aligned with student values will be an innovative concept for program reform (Battulga & Sandui, 2022, p.35).

In teacher education, transformative learning plays a crucial role in shaping students' action theories, self-efficacy and professional attributes (Jones, 2009, p. 16). This study explores the development of physics laboratory teaching methodology based on Transformative Learning Theory. First, we organised eight weeks of physics laboratory sessions using a teacher-centered approach that is driven by instruction and guided by pre-prepared directives and equipment, involving 15 third-year Physics students. In the following eight weeks, we conducted research using our self-developed methodology, incorporating modern experimental measurement tools, particularly sensors: with the same 15 students from the previous phase. The assessment of the students' laboratory skills demonstrated significant improvement in key areas such as problem identification, planning, execution, and conclusion-making. Through comprehensive qualitative and quantitative analyses, it was determined that transformative learning theory effectively fosters deeper understanding and skill development in laboratory settings. The detailed evaluation highlighted that students not only improved in technical execution but also in their ability to critically analyze and draw conclusions from their laboratory work, thereby reinforcing the theory's effectiveness in educational contexts.

Literature review

Transformative learning: Transformative learning, considered unique to adult education, is a process that explained as getting beyond factual knowledge alone to become changed in some meaningful way by what one learns (Taylor, 1998, p. 26). Transformative learning is the process of effecting change in the frame of reference that define their life world: coherent body of experience-associations, concepts, values, feelings and conditioned responses (Mezirow, 1991, p. 14; 1995, p. 6; 1996, p. 160). Transformative learning is also important for developing autonomous thinking and provides a framework for ongoing personal and professional development (Cranton, P, 1994, p. 25; 1996, p. 12). The learner, as a whole individual, continuously changes and regulates himself through learning, which is interdependent (inseparable) with the environment and context (Anne et al, 2012, p. 6). During the learning process, the student regulates his learning while interacting with other people and objects (Jadamba et al, 2023, p. 56). Researchers have suggested that the transformative learning is a cyclic, evolving, or developmental process (Freire, 1970, p. 17; Tennant, 1993, p. 39; Taylor, 1998, p. 175).

Mezirow (1997, p. 8) proposed four processes of transformative learning. The first is elaborating on an existing point of view. The second is establishing new points of view. The third involves transforming our point of view. Finally, we may transform our ethnocentric habits of mind by becoming aware of and critically reflective on our generalized biases toward groups other than our own.

There are various models of learning based on transformative learning. We focused on Charity Johansson's "Integrative Model for Transformative Learning" (Charity Johansson, 2008, p. 2). Transformation begins with the mindset, beliefs, or actions that a learner brings to the process. Initially, the learner experiences disorientation, which leads to a phase of analysis where they critically examine their current ways of being. From this analysis, the learner enters a verification process to determine what aligns best with their core beliefs and values, and then takes appropriate action. Ultimately, this verification leads to the integration of new ways of being. This integration requires ongoing practice to establish a new status that can serve as a foundation for further learning.

While scientists propose and study learning models based on transformative theory, physics teaching methods rooted in this theory are scarce in our context. Sami Lehesvuori, Antti Lehtinen (2023, p. 2) noted that the research on interaction and interactive pedagogy in higher education (HE) is still an under-researched area. Transformative learning is a systematic process focused on changing stages of development (reaching the appropriate stage, stabilization and renewal), with methodology based on the theory of improvement being crucial for higher education.

Physics Teaching Laboratory: The effective performance of a teacher is defined by integrating essential knowledge, skills, attitudes, and values (Erdenetsetseg et al, 2022, p. 36). From this perspective, the Physics Laboratory Course is crucial in preparing physics teachers.

While there are still a number of problems in traditional physics experiment teaching (Xiulin Ma et al., 2021, p. 320), several reasons contribute to the ineffectiveness of experiment teaching. These include the lack of time and planning (Backus, 2005, p. 56), large-scale courses (Prades & Espinar, 2010, p. 450), teachers' low-level attitudes toward experiments, negative perception and beliefs (Windschitl, 2003, p. 114), lack of effective and sufficient course materials (Kiviahdem, 2005, p. 98; Lawson, 2000, p. 645), and challenges related to classroom management, including the lack of explanation of laboratory safety precautions (Deters, 2005, p. 7). Students prepare to carry out experiments based on the teacher's pre-prepared instructions, without being taught how to apply their memorized knowledge (Yunden, 2016, p. 95). Previous studies have reported high attrition rates in large-enrollment science courses where teacher-centered instruction is prevalent.

The scientific literature provides strong evidence that student-centered teaching, which involves extensive active learning, leads to deeper learning as a result of effective student engagement (Nancy & DeJarnette, 2020, p. 58). Lab work should involve students in designing investigations, formulating explanations, developing models, and expressing and justifying their ideas (Sami et al., 2023, p. 3). Their findings revealed different ways in which student-centredness can be facilitated in physics laboratory settings through communication, including dialogic elements. Mara Bangun Harahap (2016, p. 396) developed a theoretical model of learning based on the Theory of Transformative Learning to improve the conceptual knowledge of

physics students. Stripling Barbara (2011, p. 33) developed the Inquiry Model, which graphically represents the inquiry process to help students make sense of it. The iterative process of inquiry is most accurately represented by a spiral or cycle. Inquiry is not a linear progression; rather, it is messy and recursive. Inquiry does, however, generally progress through phases. Each phase involves critical thinking skills that empower young people to learn on their own. Bell (2005, p. 9) employs a functional framework to actively engage students in cognitive processes through laboratory lessons. Conducting these laboratory lessons is crucial for fostering motivation, enhancing cognition, and developing emotional understanding. Additionally, they help in creating experimental and evidence-based models, which support productive activities. Merrill (1991, p. 46) suggested that students' learning opportunities emerge from cognitive conflicts, doubts, or dilemmas, as well as from structured problem-solving activities. University physics laboratories are increasingly adopting various teaching technologies, such as project-based learning, problem-solving approaches, and inquiry-based learning. However, there is a growing demand to move away from traditional 'cookbook'-style physics labs, which often provide step-by-step instructions, and to incorporate more open-ended elements into the experiments (Smith & Holmes, 2021, p. 664). Although they may have their place, for example, in more technical and hands-on training, following detailed steps in a lab task aligns with passively listening to a lecture. It is essential to employ the methodology based on the transformative theory mentioned earlier when utilizing various tools to enhance student learning.
Research question: Can the methodology of a physics laboratory be enhanced by using Transformative Learning Theory? and Is it possible to improve the student's performance in the laboratory by applying this methodology?

2. MATERIALS AND METHOD

We used following types of analysis such as, descriptive, analytical, and experimental method with a pre-experimental study design for this study. Our study design consisted of a total of 16 weeks as one semester in HE (e.g., in MNUE). Our survey divided into following two periods, first 8 weeks, a traditional teaching methodology was used (as control group), and following 8 weeks, we used transformative theory (as experiment group). The same group of students (n = 15) were participated in both periods. In the traditional methodology, tasks typically follow a specific sequence guided by pre-prepared instructions. These steps generally include: 1. Familiarizing oneself with the objective of the task, 2. Reading and taking notes on the relevant theory, 3. Setting up the equipment according to the provided instructions, 4. Taking measurements, 5. Calculating measurement errors. However, important activities such as observing, reflecting, gaining a deep understanding of the task, defining the objective, planning the process, experimenting with various approaches, and reporting or expressing the results are often overlooked. We developed and tested a methodology based on Charity Johansson's "an integrative Model for transformative learning" (Figure 1).

This methodology guides students through the stages of transformative learning: Task assignment, Disorientation, Task interpretation, Task analysis, Observations or measurements, Results, and Conclusion of the labs. During the disorientation stage, students explore their experiences and uncover unexamined assumptions related to the task. In the task analysis stage, they challenge these assumptions, engage in introspection, and define key parameters. Throughout the observations or measurements stage, students formulate hypotheses, design and conduct experiments, and derive results by reflecting on their actions to address the task. This approach is distinctive as it encourages students to understand and enhance their learning processes.

Prior to embarking on the experimental study, we rigorously applied our meticulously developed methodology to several physics courses, aiming to rigorously test and enhance its adaptability and effectiveness. This methodology underwent a comprehensive analysis alongside a renowned model in physics education, Barbara Stripling's (2011, p. 33) inquiry model and Kendi Muchungi (2021, p. 10) the transformative learning cycle for students. The results were compelling, demonstrating that our innovative methodology not only aligns seamlessly with established educational models but also outperforms expectations in practical applications. We used paired t-test to measure mean differences between pre and post-tests in this study.

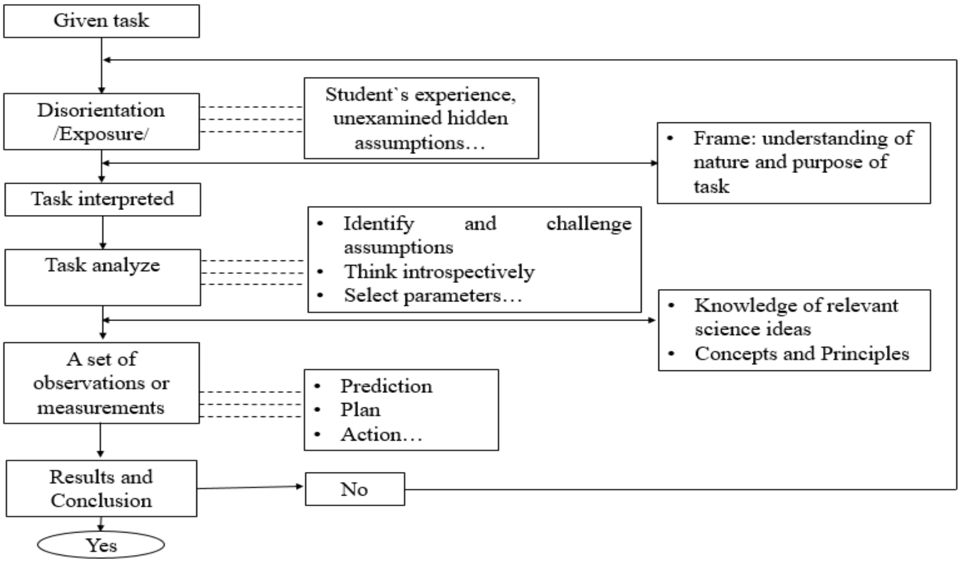

Figure 1. Laboratory teaching methodology based on transformative theory

3. RESULT

The interviews with 15 students about the stages of disorientation, task interpretation, and task analysis: The findings from the interview study reveal a critical insight: during the exposure, task interpreted, and task analysis stages, students often struggle to maintain their action orientation. This disorientation can significantly hinder their ability to engage with the task effectively. The influence of their past experiences and unexamined hidden assumptions can lead to a fragmented approach to the task, preventing them from considering it from various perspectives. This stage emerges as the most challenging one, underscoring the need for targeted strategies to support students in overcoming these obstacles, as highlighted by the comprehensive data gathered from interviews and observational research (Table 1).

Table 1. Case of interview

Student	Traditional Laboratory Methodology	Transformative Learning theory-based methodology
S002	Executes experiments according to guidelines, records measurement values, calculates errors, and computes results.	This laboratory lesson was different from other laboratory lessons. Initially, we faced questions like what to do, how to do it, and where to start. We thought it would be helpful if the teacher provided instructions quickly because we were unsure of what to do.
S004	Finds it difficult to assemble tools when conducting laboratory work. Also, performs laboratory tasks according to the teacher's instructions, asks the teacher about anything he/she cannot do, and answers control questions.	We encountered unfamiliar situations, such as understanding the assignment's purpose, identifying problems, formulating hypotheses, and determining measurement parameters. Although this was challenging for us, it ultimately gave us a sense of accomplishment for having created something new.
S006	Repeats the experiment multiple times if the measurements are not taken correctly.	The sequence of this laboratory work was quite different from what we had done before, especially the introductory section. We spent a lot of time on the introduction and conclusion.
S008	Has a table prepared for recording measurement values according to the teacher's instructions? Must follow the guidelines well.	I had to get involved in planning my experiment from the beginning. It raised doubts and challenges about what should be done.
S011	I perform my laboratory work directly according to the sequence of tasks, process the measurement values, calculate errors, and have the results checked by my teacher.	It was intriguing to uncover the mysteries of how to conduct the experiment and what results would emerge.
S013	The most challenging part is reporting laboratory performance and results to the teacher. It is easier to explain measurement errors.	Conducting laboratory work was very difficult. Although the initial tasks were quite challenging, it gradually became easier, and I began to learn how to do things.

The analyze of laboratory performance or process: Additionally, the action research examined students' performance in laboratory work, defining it through four indicators: conceptual knowledge, experiment planning, conducting experiments, and analyzing experimental data. Each criterion is rigorously scored on a scale from 0 to 5, culminating in a maximum total of 20 points. The Cronbach's alpha coefficient for assessing the reliability and appropriateness of the evaluation criteria is 0.817, indicating that the criteria and indicators are suitable. The initial performance level and final assessment of the laboratory work of the 15 students involved in the study were determined using the above criteria (Table 2).

Table 2. Assessment of the laboratory performance. Pre-test = first 8 weeks; Post-test = second 8 weeks

Item		N	Mean	Std. Deviation	Correlation	t (paired)	*p* (sig)
Pre-test	Conceptual knowledge	15	1.11	.562	. 802	-29.545	.000
Post-test		15	3.68	.482			
Pre-test	Experiment planning	15	.91	.341	.798	-32.450	.000
Post-test		15	3.52	.508			
Pre-test	Carrying out experiment and collect data	15	1.75	.569	.790	-21.521	.000
Post-test		15	4.50	.802			
Pre-test	Analyzing process and data	15	1.56	.292	.837	-37.879	.000
Post-test		15	3.87	.418			

Our findings indicate that for conceptual knowledge $p = 0.000$ and t = - 29.545; skill of planning $p = 0.000$, t = -32.450; skill of carrying out experiment and collect data $p = 0.000$, t = -21.521; skill of analyze data $p = 0.000$, t = -37.879; reflecting a statistically significant difference. The correlation between the initial and final evaluations shows that r = 0.772 indicates a significant relationship. The initial average score of students' planning skills was rated at 0.91, while after the experimental research, it improved to 3.52.

The disparity between students' final and initial assessments stands at a striking -10.253, confidently situated within the statistically significant confidence interval of (-10.764; -9.743) at a 95% probability level (Table 3). The t- test reveals an impressive value of -43.096, with a significance level of $p = 0.000$, underscoring a substantial and meaningful difference. This compelling evidence unequivocally demonstrates that students' final assessments markedly surpass their initial assessments, reflecting a significant enhancement in their performance.This confirms that the laboratory teaching methodology based on the transformative learning theory we developed is effective. This substantial evidence highlights the importance of these skills in enhancing laboratory performance and suggests a solid foundation for educational improvements in scientific training.

Table 3. Paired sample t test results for laboratory performance

		Differences					t	df	Sig. (2-tailed)
		Mean	SDEV	SE	95% CI of the Difference				
					Lower	Upper			
1	/Pre vs Post/	-10.253	0.922	0.238	-10.7	-9.7	-43.096	14	0.000

4. DISCUSSION

A key learning process based on transformative learning theory was students' critical reflection and perspective-shifting. Applying this theory to the physics laboratory setting was important to help students move beyond memorization of procedures and formulas to develop a deeper understanding of concepts and the ability to apply knowledge in a variety of situations. A key element of the teaching method in the physics laboratory was to involve students in active experimentation and solving important problems. Instead of passively following step-by-step instructions, students are encouraged to design experiments, make predictions, and improve their predictions.

The approach was to change their understanding by connecting theoretical knowledge with practical applications. Transformative learning focuses on reflective practice. Throughout the physics lab, it is important to keep detailed lab notes as students reflect on thought processes, experimental observations, and unexpected results. By developing and implementing this methodology not only for laboratory courses, but also for lectures and seminars, students can participate in critical reflection, become aware of their preconceived notions, and develop the ability to correct their understanding based on new evidence. Transformative learning emphasizes the real-life application of learning experiences. Designing experiments related to real problems in the physics laboratory increases the relevance of scientific principles.

Conclusion: This study developed and tested a transformative learning-based methodology for physics laboratory work, highlighting the critical importance of active student engagement. It reveals a significant demand among physics students for learning through their own participation and for enhancing their experiences, rather than passively relying on pre-prepared guidance from instructors. The discussions in this paper provide valuable insights into key areas such as conceptual knowledge, experimental planning, execution, data collection, and analysis. By focusing on a transformative learning framework, this research aims to significantly improve the laboratory skills of physics students at MNUE, preparing them for real-world scientific challenges and fostering a deeper understanding and retention of knowledge.

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