The Effect of Flipped Learning Based on Mathematical Software on the Behavioral and Cognitive Competencies of Pre-Service Teachers

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Abstract

The present study aimed to examine the effect of flipped learning based on mathematical software on the behavioral and cognitive competencies of pre-service teachers. This research employed a quasi-experimental design with a pretest-posttest-follow-up format, including a control group. The study sought to answer the question: Does flipped learning based on mathematical software influence the professional competencies of mathematics education pre-service teachers at Farhangian University in Tehran Province? The statistical population consisted of all male mathematics education pre-service teachers at Farhangian University in Tehran Province during the 2023–2024 academic year. A total of 40 participants were selected through multistage cluster sampling and randomly assigned to experimental and control groups. The research instrument was Karimi's (2009) Professional Competency Questionnaire for Teachers. Data were analyzed using repeated measures ANOVA and Bonferroni post-hoc test via SPSS version 26. The results indicated that flipped learning based on mathematical software had a positive effect on the behavioral and cognitive competencies of pre-service teachers. Analytical results revealed that the use of mathematical software in flipped learning led to a 20% improvement in social interactions and a 15% increase in students' conceptual understanding. This learning approach helps students enhance their problem-solving abilities and engage more actively in the learning process.

Keywords: *flipped learning, mathematical software, behavioral competency, cognitive competency, pre-service teachers.*

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1. Introduction

Since ancient times, the foundation and continuity of human societies have rested on education, and as history progresses, the significance and fundamental role of education continue to increase. This is because education carries the vital responsibility of teaching and nurturing human beings, and the advancement and prosperity of societies depend on the healthy, dynamic functioning of this institution. Among the numerous factors involved in education [1], the role of the teacher stands out as central and foundational. Teachers are indeed the leaders of future generations in any society, and thus, a teacher must possess a personality that students can regard as a knowledgeable, kind, and trustworthy guide—an exemplary role model [2]. Naturally, a teacher can fulfill this educational mission and meet societal expectations only when they possess sufficient and essential characteristics. One such characteristic, directly linked to teacher success or failure, is professional competency.

Teacher competency refers to the teacher's ability to meet the demands and expectations of the teaching profession adequately, using an integrated set of knowledge, skills, and attitudes that manifest in teaching performance and behavior [3]. Maleki (2023) defines teacher competency as the set of knowledge and skills that enables teachers to support students' physical, intellectual, emotional, social, and spiritual development, categorizing these competencies into cognitive, affective, and skill-based domains [4].

Overall, existing studies emphasize that teacher characteristics—such as professional attitude, self-efficacy, and professional competency—play a critical role in increasing teacher effectiveness and enabling them to fulfill their educational mission and meet societal demands. Therefore, any factors affecting teachers' professional competency are of great importance [1, 5-8], and flipped learning can be considered one such factor.

Flipped learning is a form of blended learning that is fundamentally grounded in individualized instruction [9, 10]. In this method, learners independently study course materials through educational videos, books, websites, and blogs at home. Classroom time is then devoted to practical exercises, collaborative assignments, and reinforcing key concepts that learners have encountered independently [11, 12]. Based on this model, lower-level cognitive processes—such as "remembering and understanding"—occur outside the classroom, while higher-level processes—such as "application, analysis, synthesis, and evaluation"—take place in the classroom with teacher guidance [13]. In this approach, the classroom is no longer a place for information transfer but a center for learning and inquiry [12]. Class time is primarily used for collaborative learning, problem-solving, and developing a deep understanding of the content [14].

The term "flipped classroom" was first introduced in the year 2000 by Maureen Lage and colleagues in educational literature. They asserted that with the advent of new and multimedia technologies, instructional activities traditionally conducted in classrooms should now occur outside of them [15]. However, the earliest research references point to Salman Khan's TED talk on using videos to improve listening skills in foreign language learning. The first book on the topic, titled *Flip Your Classroom*, was authored by Bergmann and Sams in 2012 [12]. Flipped learning consists of two main components: interactive in-class learning and computer-assisted instruction outside the classroom. Thus, flipped classrooms represent a hybrid model of traditional and modern instruction, both of which are vital to achieving learning goals [16]. In this model, the teacher's role is not diminished. According to Bergmann and Sams (2021), the most valuable moments in education are those spent between teacher and learner. They argue that the belief that technology can replace teachers in this model is misguided. If education were solely about knowledge transmission, students could simply watch instructional videos online. However, education involves complex cognitive interactions between teacher and learner, and no computer can substitute for a teacher. In a flipped classroom, the teacher becomes even more valuable. Although content can be distributed in various ways, the goal of flipped learning is to cultivate learners who are engaged, thoughtful, ethical, and spiritually aware—individuals who can positively influence the world. Hence, the teacher's presence in the flipped classroom is not eliminated but transformed into an active and essential role, distinct from that in traditional instruction [12].

A review of the literature reveals a growing body of research supporting the effectiveness of flipped learning across various educational contexts. Islami et al. (2023) found that gamified flipped learning significantly enhanced the critical thinking skills of early childhood education students [6], while Omrani, Afkari, and Ghaderi (2023) confirmed its positive impact on academic engagement in environmental studies [5]. Alipour and Alipour (2022) reported that student-teachers viewed flipped learning as a constructive method with broad educational benefits [17]. Similarly, Khoshnood et al. (2021) showed that flipped classrooms were more effective than social media-based instruction in enhancing creativity and self-directed learning [18]. Najafabadi (2021) and Mirzaei Matin et al. (2020) also found improvements in students' attitudes, motivation, and self-regulation through gamified flipped instruction [15, 19]. Several studies, including those by Sahebyar et al. (2021), Dadgar et al. (2020), and Dinarvand and Golzari (2019), have highlighted the method's role in promoting student engagement, professional attitudes, and self-efficacy [1, 20, 21]. Piri et al. (2018) and Bagheri & Joshaghan Nejad (2016) confirmed its positive influence on self-directed learning readiness [22, 23]. Internationally, Gonzalez et al. (2022) and Jaday Tawi (2019) observed enhanced self-efficacy and social interaction among students in flipped classrooms. Studies reported increased learning retention, motivation, and academic involvement [7, 24, 25]. Myung & Bu (2018) demonstrated improved clinical performance among nursing students taught via flipped learning [26]. Other empirical evidence emphasized the model's effectiveness in boosting academic achievement and problem-solving abilities [16, 27]. Rutkowski & Moscinska (2015) and Farah (2014) also showed that flipped instruction significantly supported self-directed learning and academic performance, particularly in engineering and mathematics courses [28, 29]. Collectively, these findings underscore flipped learning's capacity to enhance cognitive, emotional, and behavioral dimensions of learning across diverse disciplines.

However, it must be acknowledged that the flipped classroom changes both the structure of traditional instruction and the teacher's role. In this model, students are exposed to instructional content before class and enter the classroom with inquisitive minds. During class, the teacher facilitates learning activities such as group discussions, questioning, short quizzes, student presentations, experiments, and more. Here, the teacher functions as the designer and manager of classroom activities [8]. Accordingly, the teacher's role and relationship with learners are transformed through flipped learning. In traditional classrooms, teachers serve primarily as transmitters of information. According to Bagheri (2013), the teacher plays the central role as the direct instructor, with the primary goal of informing students through lecture-based instruction supported by textbooks [30]. In contrast, the new classroom model redefines the teacher's role as a supportive guide and co-learner, helping students construct knowledge collaboratively. Likewise, the technological tools used in flipped learning, like other educational technologies, bring about significant changes in teaching and learning. Given the importance of professional competency, this study seeks to examine flipped instruction as a factor influencing teachers' professional attitudes and self-efficacy.

Considering the need to meet the evolving demands of teachers and learners, their engagement in the teaching-learning process, the importance of integrating digital tools creatively, the vast amount of subject matter, and the limited instructional time in classrooms, it is essential to go beyond traditional methods. There is a growing need to enhance the skills and professional competencies of teachers in using innovative instructional approaches, particularly in core subjects like mathematics. Improving these skills can lead to better academic achievement and deeper learner engagement in classrooms. Furthermore, given the significance of active learning and engagement, especially in mathematics, and the inefficiency of traditional methods in effectively facilitating teaching and learning in this subject—and considering the limited number of studies available in local databases regarding the impact of flipped learning on pre-service teachers' professional competencies—this study is both necessary and important. The objective of this research is to evaluate the effect of flipped learning based on mathematical software on the professional competencies of mathematics education pre-service teachers in Tehran Province.

2. Methodology

2.1. Study Design and Participants

The research method varied according to the type and nature of the study. The present research is applied in terms of its objective, aiming primarily to achieve practical goals and to expand applied knowledge related to the research topic. Since it was not possible to control all intervening variables, despite random selection and assignment, a quasi-experimental method with a pretest-posttest control group design and a follow-up phase was used. It is noteworthy that prior to implementing the intervention, efforts were made to ensure that the groups under study were demographically similar (e.g., gender, age, socio-economic status, academic major, etc.) to enhance control.

The research population consisted of all male pre-service mathematics teachers at Farhangian University in Tehran Province during the 2023–2024 academic year.

The sampling method used in this study was multistage cluster random sampling. The sampling procedure involved randomly selecting one campus or center from among the male campuses in Tehran Province (including Shahid Chamran, Nasībeh, Shahid Rajaee Teacher Training, Zeinabiyeh-Pishva, Shahid Moftah, and Zeinabiyeh). The selected center was Nasībeh Campus in Tehran. From this center, two cohorts in mathematics education (admission years 2020 and 2022) were randomly selected. Based on the type of study and sources such as Delavar (2011) and Borg & Gall (2003), a sample size of at least 10 participants per group is sufficient for quasi-experimental research. Thus, 40 pre-service teachers with low professional competency scores—based on responses to the Professional Competency Questionnaire—were randomly selected. They were then randomly assigned to experimental and control groups, with 20 participants in each. Inclusion and exclusion criteria involved gender, academic major, and access to computers, smartphones, and multimedia tools.

The experimental group participated in 17 one-hour flipped learning sessions (two sessions per week), while the control group did not receive any intervention. After the intervention, a posttest was administered to both groups. It should be noted that ethical principles were upheld by obtaining informed consent from participants, and all aspects of the intervention were disclosed to them. Control group members were assured they would receive the intervention after the research process was complete. To assess the sustainability of the program's effectiveness, a follow-up measurement was conducted two months after the final session. The study adhered strictly to ethical standards, including confidentiality, clarity of research goals, prioritization of participants' psychological well-being, and respect for withdrawal requests.

Inclusion criteria included: male gender, at least undergraduate-level enrollment, majoring in mathematics education, age range between 20–35 years (allowing the researcher flexibility in participant selection), willingness to attend all sessions, absence of psychotic or severe mental disorders, and the ability to attend sessions regularly and consistently.

Exclusion criteria included: enrollment in a major other than mathematics education, history of medication use for or diagnosis of psychotic or severe mental disorders, concurrent participation in similar intervention programs, and lack of willingness to participate or continue in the study.

2.2. Data Collection Tool

Karimi developed the questionnaire by reviewing literature and previous studies, extracting 8 core components and 99 subcomponents, and drafting the instrument accordingly. After conducting factor analysis, the final questionnaire included 9 core components and 90 items. Responses are measured on a Likert scale (very low to very high), and both the total score and subcomponent scores were used for data analysis. In Karimi’s (2009) study, content validity was confirmed by experts, and the questionnaire's reliability was assessed through a pilot study, resulting in a Cronbach’s alpha of 0.96 [31]. In another study by Salehi Sadeghiani and Qaraeepour (2011), the questionnaire’s content validity was confirmed by specialists in human resources and theoretical alignment, and its reliability was confirmed with a Cronbach’s alpha of 0.81, indicating satisfactory internal consistency [32]s.

2.3. Intervention

Phase 1: Defining the Objective Scope

In this phase, the main and specific goals of the lesson were defined by the researcher (acting as the instructor) and used to guide the subsequent stages.

Phase 2: Pre-Class Content Preparation

The researcher, based on the instructional objectives, developed professional competency training materials in the form of software, instructional videos, handouts, audio files, worksheets, and sample problems to be used in class. This phase involved determining the content and its modes of presentation.

Phase 3: Pre-Class Activities

In this phase, mathematical software, videos, and learning materials were shared with students via downloadable online files one session before class. Students accessed the materials in sequence and engaged with them based on the topic. Flipped classes were managed either individually or in groups, depending on students’ conditions and the researcher’s judgment. Students were required to study the materials thoroughly outside class. If issues arose, students engaged in online group discussions or posed questions to peers or the researcher to receive feedback. Responses were provided directly or through references to websites or specific sources. Alternatively, students wrote down their questions for in-class discussions. Throughout this process, the teacher monitored pre-class engagement, reviewed students' notes, worksheets, and guided questions, and provided relevant feedback.

Phase 4: In-Class Activities (13 Sessions)

Outside the classroom, students used the provided software, clips, resources, and materials to learn concepts. In class, they focused on solving textbook exercises, self-developed and researcher-provided problems, addressing individual difficulties, and completing higher-order cognitive tasks under the researcher's supervision. Before each session, the researcher evaluated students' preparedness and conceptual understanding, offering necessary feedback. Active learning was promoted through researcher and peer feedback. Students actively interacted with peers, content, and the researcher to resolve challenging problems and clarify doubts. A continuous feedback loop was maintained, and more complex questions were posed. When many students struggled with a concept, group discussions facilitated mutual understanding. The researcher enriched the sessions with thoughtfully designed activities and challenging questions. Students also occasionally brought in self-designed questions for class problem-solving. After brief presentations and summaries, students worked individually or in triads on exercises. The researcher circulated during class to assist with professional competency exercises.

Phase 5: Post-Class Activities

In this phase, students had two responsibilities: first, to prepare for the next session by reviewing the designated materials, including components related to professional competency prepared in advance by the researcher; second, to complete supplemental assignments from the previous session. If additional materials such as videos, handouts, or worksheets were uploaded after class, students were expected to review and practice them.

2.4. Implementation Procedure

After coordinating with the Office of Campus Affairs at Farhangian University in Tehran Province and obtaining the necessary permissions, the researcher visited Nasībeh Campus in Tehran. Following discussions with campus administration and security, and clarification of the research objectives, the Professional Competency Questionnaire was distributed among students admitted in 2020 and 2022. Based on responses, 40 pre-service teachers with low competency scores were randomly selected and assigned to experimental and control groups (20 each). Criteria for inclusion and exclusion were based on gender, academic major, and access to computers, smartphones, and multimedia tools. The experimental group attended 17 one-hour flipped learning sessions (two sessions per week), while the control group received no intervention. A posttest was conducted for both groups after the sessions. Ethical protocols were strictly followed: informed consent was obtained, participants were briefed on the intervention stages, and control group members were assured access to the intervention afterward. A follow-up measurement was administered two months after the final session to assess the program's long-term effectiveness. Confidentiality, voluntary participation, clarity of purpose, prioritization of psychological safety, and the right to withdraw were fully observed. Participants were informed about the free benefits of the intervention (e.g., reduced professional competency challenges) and the consequences of withdrawing (e.g., loss of improvement opportunity and skewed research results). The only burden for the experimental group was participation in 17 one-hour sessions. After the follow-up, the control group received the same intervention, thereby ensuring ethical compliance regarding delayed treatment.

2.5. Data Analysis

Initially, the data were analyzed using descriptive statistics, including mean, standard deviation, frequency, tables, and charts. Subsequently, in line with the quasi-experimental design of the study, the data were analyzed using multivariate analysis of covariance (MANCOVA) to test the research hypotheses, employing SPSS version 26 software.

3. Findings and Results

In this study, the mean and standard deviation of the participants' age in the experimental group was 22.75 ± 1.58 years, while the control group's mean age was 23.25 ± 1.29 years. Additionally, in the experimental group, the fathers of most participants (40%) held a bachelor's degree, whereas in the control group, the majority of fathers (35%) had completed high school. In terms of maternal education, 40% of the mothers in both groups held a high school diploma.

Table 1. Means and Standard Deviations of the Dependent Variables in Pretest, Posttest, and Follow-Up Phases by Group

Variables	Control Group	Experimental Group
	Follow-up	Posttest
Behavioral-Cognitive	54.90 ± 6.16	55.65 ± 6.20
Educational Competency	46.45 ± 6.57	46.80 ± 6.60
Professional Ethics	22.15 ± 1.81	22.25 ± 1.74
Personality Competency	9.35 ± 1.84	9.65 ± 1.75
Cognitive Competency	5.60 ± 1.23	6.15 ± 0.98

Since univariate analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA) were used in this study, the assumptions of these tests were first assessed.

The purpose of checking the normality assumption is to ensure that the distribution of scores in the sample does not significantly differ from a normal distribution. The Kolmogorov-Smirnov test was used.

Table 2. Kolmogorov-Smirnov Test Results for Normality of Dependent Variables by Group

Variable	Phase	Experimental Group (Z / p)	Control Group (Z / p)
Behavioral-Cognitive	Pretest	0.12 / 0.20	0.10 / 0.20
	Posttest	0.17 / 0.10	0.13 / 0.20
	Follow-up	0.13 / 0.20	0.10 / 0.20

Professional Ethics	Pretest	0.15 / 0.20	0.15 / 0.20
	Posttest	0.08 / 0.20	0.15 / 0.20
	Follow-up	0.19 / 0.20	0.13 / 0.09
Personality Competency	Pretest	0.17 / 0.13	0.17 / 0.13
	Posttest	0.16 / 0.14	0.16 / 0.16
	Follow-up	0.18 / 0.07	0.15 / 0.20
Cognitive Competency	Pretest	0.19 / 0.20	0.16 / 0.15
	Posttest	0.14 / 0.20	0.16 / 0.15
	Follow-up	0.16 / 0.15	0.17 / 0.09

Since none of the Kolmogorov–Smirnov test results were statistically significant ($p > 0.05$), the normality assumption was confirmed for all variables.

To verify equal variances across groups, Levene's Test was conducted.

Table 3. Levene's Test for Homogeneity of Variances

Variable	F	df1	df2	p-value
Behavioral-Cognitive	0.02	1	38	0.88
Professional Ethics	1.16	1	38	0.28
Personality Competency	0.007	1	38	0.93
Cognitive Competency	0.89	1	38	0.35

As shown, all p-values are greater than 0.05, confirming the assumption of variance homogeneity.

Scatter plots were used to test the linearity between covariates and dependent variables. The regression lines did not intersect, indicating linear relationships.

Table 4. Box's Test Results

Box's M	F	df1	df2	p-value
8.43	1.24	55	4663.12	0.28

Since the p-value is greater than 0.05, the assumption of equal covariance matrices holds.

With all assumptions met, results from the repeated measures ANOVA are presented below.

Table 5. Repeated Measures ANOVA Results for Dependent Variables

Variable	Effect	Test	F	df (hyp)	df (err)	p-value	Partial η²
Behavioral-Cognitive	Time	Pillai's Trace	10.26	2	37	0.01	0.35
	Time*Group	Pillai's Trace	31.02	2	37	0.01	0.62
Professional Ethics	Time	Pillai's Trace	24.96	2	37	0.01	0.57
	Time*Group	Pillai's Trace	3.05	2	37	0.05	0.14
Personality	Time	Pillai's Trace	68.59	2	37	0.01	0.78
	Time*Group	Pillai's Trace	59.47	2	37	0.01	0.76
Cognitive	Time	Pillai's Trace	35.63	2	37	0.01	0.65
	Time*Group	Pillai's Trace	31.77	2	37	0.01	0.78

As shown, all time-related effects are statistically significant at the 0.05 level, indicating differences across time points for the dependent variables. Partial eta squared indicates the magnitude of these effects. Additionally, significant time*group interaction effects suggest that the changes over time differed between the experimental and control groups.

Table 6. Mauchly's Test of Sphericity

Variable	Mauchly's W	Chi-Square	df	p-value	Greenhouse-Geisser	Huynh-Feldt	Lower Bound
Behavioral-Cognitive	0.58	20.05	2	0.01	0.70	0.74	0.50
Professional Ethics	0.27	47.96	2	0.01	0.57	0.60	0.50
Personality	0.23	54.05	2	0.01	0.56	0.58	0.50
Cognitive	0.54	22.62	2	0.01	0.68	0.72	0.50

Since the p-values for Mauchly's Test are less than 0.05, the sphericity assumption is violated for all variables. Therefore, conservative corrections such as Greenhouse-Geisser were applied to adjust the degrees of freedom and ensure valid results.

Hypothesis One: The use of flipped learning based on mathematical software affects the behavioral-cognitive competency of pre-service mathematics teachers.

Table 7. Repeated Measures ANOVA Results for the Effectiveness and Durability of the Flipped Learning Program Based on Mathematical Software on Behavioral-Cognitive Competency

Variable	Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Group	512.533	1	512.533	6.11	0.01	0.13	1
Time	108.600	1.41	77.021	11.67	0.01	0.23	1
Time * Group	476.467	1.41	337.920	51.20	0.01	0.57	1

The results indicate that the main effects of group, time, and the interaction between time and group are all statistically significant ($p < 0.01$). The flipped learning program based on mathematical software led to an improvement in the behavioral-cognitive competency of the experimental group compared to the control group. Moreover, significant differences were observed across the pretest, posttest, and follow-up phases.

Table 8. Bonferroni Post Hoc Test for Behavioral-Cognitive Competency at Different Assessment Phases

Phase 1	Phase 2	Mean Difference	Std. Error	Sig.
Pretest	Posttest	-6.40	0.74	0.01
Pretest	Follow-up	-5.95	0.76	0.01
Posttest	Follow-up	0.45	0.21	0.13

The results show that the mean differences between pretest and both posttest and follow-up for behavioral-cognitive competency were statistically significant ($p < 0.01$), while the difference between posttest and follow-up was not. This suggests that the flipped learning program had a significant effect, and its impact remained stable over time.

Hypothesis Two: The use of flipped learning based on mathematical software affects the professional development competency of pre-service mathematics teachers.

Table 9. Repeated Measures ANOVA Results for the Effectiveness and Durability of the Flipped Learning Program on Professional Development Competency

Variable	Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Group	232.408	1	232.408	20.05	0.01	0.34	1
Time	161.817	1.22	131.636	40.89	0.01	0.51	1
Time * Group	229.817	1.22	186.953	58.08	0.01	0.60	1

The results show statistically significant effects for group, time, and the time*group interaction ($p < 0.01$). This confirms the effectiveness of the flipped learning intervention in improving professional development competency, with differences sustained through follow-up.

Table 10. Bonferroni Post Hoc Test for Professional Development Competency at Different Assessment Phases

Phase 1	Phase 2	Mean Difference	Std. Error	Sig.
Pretest	Posttest	-5.55	0.66	0.01
Pretest	Follow-up	-5.20	0.64	0.01
Posttest	Follow-up	0.35	0.20	0.33

The difference between pretest and both posttest and follow-up for professional development competency was significant ($p < 0.01$), but the difference between posttest and follow-up was not. This suggests that the improvement persisted over time.

Hypothesis Three: The use of flipped learning based on mathematical software affects the personality competency of pre-service mathematics teachers.

Table 11. Repeated Measures ANOVA Results for the Effectiveness and Durability of the Flipped Learning Program on Personality Competency

Variable	Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Group	69.008	1	69.008	9.93	0.01	0.20	1
Time	191.617	1.13	169.388	114.91	0.01	0.75	1
Time * Group	191.017	1.13	168.857	114.55	0.01	0.75	1

Statistically significant differences were observed for the main effects and the interaction ($p < 0.01$), confirming the effectiveness and retention of impact on personality competency through the flipped learning intervention.

Table 12. Bonferroni Post Hoc Test for Personality Competency at Different Assessment Phases

Phase 1	Phase 2	Mean Difference	Std. Error	Sig.
Pretest	Posttest	-2.77	0.24	0.01
Pretest	Follow-up	-2.57	0.25	0.01
Posttest	Follow-up	0.20	0.07	0.06

The mean differences between pretest and posttest/follow-up were significant ($p < 0.01$), while the difference between posttest and follow-up was not. This indicates a sustained improvement in personality competency due to the intervention.

Hypothesis Four: The use of flipped learning based on mathematical software affects the cognitive competency of pre-service mathematics teachers.

Table 13. Repeated Measures ANOVA Results for the Effectiveness and Durability of the Flipped Learning Program on Cognitive Competency

Variable	Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Group	130.208	1	130.208	53.36	0.01	0.58	1
Time	132.267	1.37	96.384	159.39	0.01	0.80	1
Time * Group	50.867	1.37	37.067	61.29	0.01	0.61	1

All main and interaction effects were statistically significant ($p < 0.01$), suggesting that the flipped learning program significantly improved cognitive competency and that the effects persisted through the follow-up.

Table 14. Bonferroni Post Hoc Test for Cognitive Competency at Different Assessment Phases

Phase 1	Phase 2	Mean Difference	Std. Error	Sig.
Pretest	Posttest	-3.70	0.26	0.01
Pretest	Follow-up	-3.45	0.25	0.01
Posttest	Follow-up	0.25	0.09	0.06

Statistically significant differences were found between pretest and both posttest and follow-up phases ($p < 0.01$), confirming the effectiveness and sustainability of the flipped learning intervention on cognitive competency. The non-significant difference between posttest and follow-up indicates long-term retention of the gains.

4. Discussion and Conclusion

This study aimed to investigate the impact of flipped learning based on mathematical software on the professional competencies of pre-service mathematics teachers in Tehran Province. The statistical population included all male pre-service mathematics teachers at Farhangian University in Tehran during the 2023–2024 academic year. A multi-stage cluster random sampling method was used, and 40 pre-service teachers with low professional competency scores were randomly selected and assigned to experimental (n = 20) and control (n = 20) groups. The Karimi Teacher Professional Competency Questionnaire (2009) was used for data collection. The Kolmogorov–Smirnov (K-S) test was used to examine the normality of the variables. Data were analyzed using repeated measures ANOVA and Bonferroni post hoc tests.

The results of the first hypothesis indicated that in the behavioral-cognitive competency variable, the control group showed little variation across pretest (M = 57.55), posttest (M = 55.65), and follow-up (M = 54.90). However, the experimental group showed improvement from pretest (M = 56.05) to posttest (M = 62.45), and this improvement was maintained at follow-up (M = 62.00). This suggests that the flipped learning program based on mathematical software positively influenced the behavioral-cognitive competency of pre-service teachers. The repeated measures ANOVA ($F = 6.11$, $p < .01$) confirmed the significant differences between the groups, and Bonferroni post hoc tests revealed significant differences between the pretest and both posttest and follow-up ($p < .01$), while the difference between posttest and follow-up was not significant. These findings support the effectiveness and sustainability of the flipped learning program, confirming Hypothesis 1.

Although no identical study was found, the results align with Zamzami (2018), who found that gamified flipped classrooms enhance learner motivation and engagement [24].

These findings can be explained by the fact that flipped classrooms promote the use of four major metacognitive strategies: planning, self-monitoring, self-assessment, and focused attention. Planning occurs before interacting with the software and involves organizing time and tasks. Self-monitoring is employed while engaging with the software and instructional content to reflect on understanding. Self-assessment involves evaluating comprehension, and focused attention includes note-taking and managing distractions. In this study, participants were able to evaluate their learning process and enhance their self-awareness, thereby improving their behavioral-cognitive competencies.

The results of the second hypothesis showed no significant changes in the control group's mean scores in professional ethics competency from pretest (M = 21.45) to posttest (M = 22.25) and follow-up (M = 22.15). However, the experimental group demonstrated an increase from pretest (M = 19.40) to posttest (M = 21.00), which was maintained at follow-up (M = 20.75). This indicates a positive effect of the flipped learning program on professional ethics. Repeated measures ANOVA ($F = 20.05$, $p < .01$) confirmed this effect, and Bonferroni tests showed significant differences between pretest and both posttest and follow-up ($p < .01$), with no significant difference between posttest and follow-up. Thus, Hypothesis 2 is supported.

While no identical study was found, the findings are consistent with Jaday Tawi (2019), who reported higher self-regulation and social interaction in flipped classrooms. Sun, Wu, and Lee (2017) also confirmed improved self-directed learning among students in flipped settings [27]. Bagheri and Josheghan Nejad (2016) found that flipped instruction improved self-directed learning readiness. No contradictory studies were identified [23].

These results suggest that the traditional classroom model, which limits teacher-student interaction and increases teacher workload, particularly in secondary education, can reduce job satisfaction. Flipped learning reduces these challenges by allowing instruction to occur outside the classroom, thereby freeing class time for engagement and feedback. This dynamic enhances teaching quality, learner participation, and teacher satisfaction, which in turn boosts professional ethics.

The third hypothesis results indicated little variation in the control group's personality competency scores between pretest (M = 9.50), posttest (M = 9.65), and follow-up (M = 9.35). The experimental group showed significant improvement from pretest (M = 7.45) to posttest (M = 12.85), sustained at follow-up (M = 12.75). Repeated measures ANOVA ($F = 9.93$, $p < .01$) and Bonferroni tests confirmed the significance of these changes ($p < .01$), while the posttest–follow-up difference was non-significant. These findings validate Hypothesis 3.

Although no identical studies were found, the results are consistent with Najafabadi (2021), who observed that gamified flipped instruction improved students' attitudes and learning [19]. Mirzaei Matin et al. (2020) found that flipped learning increased motivational beliefs and self-regulation strategies [15]. Nik Khou Koraim (2018) found that flipped classrooms significantly influenced higher-order learning but not lower-order skills in Bloom’s taxonomy [33]. Myung and Bu (2018) found enhanced self-efficacy, self-leadership, and problem-solving skills in clinical nursing students trained through flipped learning [26]. No contradictory findings were reported.

This may be attributed to the engaging nature of flipped learning using mathematical software, which stimulates cognitive, emotional, and behavioral mechanisms. The exposure to technology-enhanced instruction likely facilitated greater self-reflection, social adaptability, and psychological resilience, all of which contribute to enhanced personality competency.

For the fourth hypothesis, cognitive competency scores in the control group remained relatively stable across pretest (M = 5.05), posttest (M = 6.15), and follow-up (M = 5.60). However, the experimental group improved from pretest (M = 5.30) to posttest (M = 9.00), and the gains remained stable at follow-up (M = 8.75). Repeated measures ANOVA ($F = 53.36$, $p < .01$) confirmed these differences, and Bonferroni tests showed significant differences between pretest and both posttest and follow-up ($p < .01$), but not between posttest and follow-up. Therefore, Hypothesis 4 is also confirmed.

Although no directly comparable studies were found, these results align with Islami et al. (2023), who found that gamified flipped instruction improved students' critical thinking [6]. Omrani et al. (2023) reported positive effects of flipped learning on academic engagement [5]. Pourpasha and Kord (2022) confirmed that flipped learning was effective in promoting both surface and deep learning in mathematics [34]. Piri et al. (2018) showed that flipped classrooms enhance self-direction [22]. Gonzalez-Fernandez et al. (2022) found that the flipped classroom model positively affected self-efficacy and attitudes toward science [35]. Similarly, Myung and Bu (2018) found that flipped instruction significantly improved clinical performance and cognitive skills [26]. No contradictory studies were identified.

Regarding cognitive development, pre-service teachers with higher cognitive maturity tend to consider diverse perspectives, remain unbiased, and adapt their decisions based on new information. Flipped learning, by promoting exposure to complex problems and dynamic discussions, fosters critical thinking and cognitive growth. In this study, class observations revealed greater peer interaction and cognitive engagement, contributing to improved problem-solving and decision-making skills.

Moreover, the results demonstrated that flipped instruction enriched with mathematical software enhanced students’ cognitive engagement. Cognitive engagement refers to learners' active pursuit of problem-solving, interest in exploring diverse topics, and enjoyment in overcoming intellectual challenges. The learners in this study were consistently exposed to challenging tasks that required internal motivation, resulting in higher cognitive involvement and, subsequently, improved cognitive competency. Therefore, in flipped classrooms enriched with mathematical software, learners actively engage in problem-solving, explore multiple strategies, and enhance their cognitive skills.

Authors’ Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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