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간호대학생을 위한 실습실 안전교육 프로그램의 효과: 유사실험연구

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Effects of Laboratory Safety Education Programs for Nursing Students: A Quasi-experimental Study

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Abstract

Purpose : This study aimed to develop and apply a laboratory safety education program based on the Theory of Planned Behavior (TPB) for nursing students and evaluate its effects. **Methods :** This quasi-experimental study with a pretest-posttest design included a nonequivalent control group. Using convenience sampling, a total of 63 participants were selected (intervention group, 30 participants; control group, 33 participants). The intervention group participated in eight sessions (two 60-minute sessions per week for 4 weeks) of in-person group education. The control group was provided with general safety education via booklets. **Results :** After completion of the education program, the pre-post difference scores of knowledge, attitude, perceived behavioral control, and behavioral intention scores in the intervention group were significantly higher than those of the control group. However, no significant differences in the subjective norms of the intervention and control groups were observed. **Conclusion :** Because of the characteristics of nursing studies, in-person laboratory safety education is feasible for nursing students. Furthermore, in-person laboratory safety education effectively improved the understanding of TPB concepts and behavioral intention. This education program could be used as an effective method of improving laboratory safety awareness among nursing students and creating a safe educational environment.

Key words : Laboratories, Students, Nursing, Planned behavior, Safety management

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Ⅰ. Introduction

Laboratory practical classes provided at universities are generally characterized by a variety of equipment and experimental materials as well as a large number of students, resulting in considerable difficulty managing safety [1]. Approximately 18% of industrial accidents that occurred at higher education institutions in the United States were related to work in the laboratory, and the main victims of 30% of these accidents were students [2]. In South Korea, of 1,277 accidents that occurred during laboratory practical classes between 2017 and 2022, 845 (66.2%) occurred at universities [3]. The Korean Accreditation Board of Nursing Education [4] created new safety management requirements for on-campus practical classes necessary for nursing accreditation and indicated that nursing students must receive at least 6 hours of mandatory safety education each semester. However, current safety education is considered perfunctory because it is provided as individual online theory-based learning; therefore, the ability to acquire the knowledge and skills necessary for safety competency is limited [5,6,7].

On-campus practical education includes various devices and models that are used to expand the theoretical understanding and competency of nursing students through practice. Various learning methods, including the use of simulators, mannequins, and other equipment, can effectively improve the self-efficacy, self-confidence, skills, and competency of nursing students [8]. However, on-campus practical classes are conducted in small spaces with unfamiliar environments and objects and include activities that can compromise safety, such as moving and handling heavy models and simulators [9], using needles [10], and handling hazardous materials such as gas, electricity, disinfectant, mercury, glass, and sharps [1,11]. The safety of nurses in clinical practice [12] is an important measure of skills, competency, and performance [8,13]. Previous studies on safety education for nursing students have mainly focused on online or theory-based training programs, which are limited in reflecting the complex and context-specific risks of practical laboratory environments [5,6,7]. In addition, although some studies have applied theory-based interventions such as the theory of planned behavior [14,15,16,17], these have often been conducted in abstract or controlled settings rather than real laboratory contexts. Therefore, research on context-specific safety education reflecting actual laboratory environments remains limited. In particular, self-guided training and unsupervised practical learning methods have been recommended to improve self-confidence and preparedness in clinical settings [9]; however, because inadequate safety awareness during practical classes can directly increase the risk of accidents and injuries, safety education should be prioritized in practical class environments.

The Theory of Planned Behavior (TPB) explains the process of behavioral changes and personal predictive factors for certain behaviors [14]. Several prior studies [15,16,17] have reported that the TPB informs predictions of behavioral intention as well as healthcare interventions. Knowledge, which is insufficient by itself and not explicitly included in the TPB, is considered a predisposing factor for behavioral intention [18]. Therefore, increasing one’s knowledge of safety may improve the intention to perform safety behaviors, thereby preventing safety accidents. Behavioral intention is predicted by attitudes, subjective norms, and perceived behavioral control, and it is the strongest predisposing factor for behavior [19]. Therefore, we developed a laboratory safety education program based on the TPB for nursing students and tested its effectiveness.

Ⅱ. Methods

1. Study design and Participants

This quasi-experimental study had a pretest-posttest design and included a nonequivalent control group. Participants were recruited from two universities in South Korea with similar numbers of students enrolled in nursing programs, similar academic levels, and similar curricula. To prevent diffusion effects, the intervention group was recruited from one university and the control group was recruited from another university. The inclusion criteria were as follows: second-year students enrolled in the standard nursing studies program in South Korea; individuals with no experience participating in a laboratory safety education program; and individuals with no clinical practice experience. The sample size needed for this study was calculated using G*Power 3.1. Based on an effect size (d) of .80 [20], significance level of .05, and power of .80, the minimum sample size was 52 participants (26 in the intervention group and 26 in the control group). Problem-based learning (PBL) was included as a core component of the educational intervention in this study. Previous studies have reported relatively large effect sizes of PBL-based education on learning outcomes [20]. However, as the study populations and educational settings differed from those of the present study, this evidence was used only as a limited reference. In addition, the present intervention was designed as a multifaceted educational approach incorporating lectures, peer coaching, discussions, and quizzes, aiming to enhance learner engagement and interaction. In this respect, the effectiveness of the intervention may be maintained or potentially enhanced. However, as it differs from single PBL-based interventions, there may be limitations in directly applying this effect size. Nevertheless, based on prior findings and the inclusion of PBL as a key strategy, an effect size of d = .80 was used. When the study was first started, the intervention group comprised 30 participants and the control group comprised 35 participants (total of 65 participants). However, two participants in the control group were excluded during the study because they did not participate in the posttest. At the time of the final analysis, 30 participants comprised the intervention group and 33 participants comprised the control group.

2. Instruments

Data regarding sex, age, satisfaction with the nursing major, and experience with safety accidents were collected to investigate sociodemographic characteristics of the participants. Knowledge of laboratory safety was measured using an instrument developed by the researchers based on regulations and guidelines created by Korea Institute of Human Resources Development in Science [21] and Technology and Ministry of Education [22]. The preliminary measurement instrument was validated by an expert panel (three nursing professors). The content validity index of the items was ≥.78, and the content validity index of the scale was .90. The final instrument consisted of 36 items, and each item could be answered with responses of yes, no, or not sure. Correct responses were scored as 1 point, and incorrect or unsure responses were scored as 0 points. The potential scores ranged from 0 to 36 points, and higher scores indicated better knowledge of laboratory safety. The Kuder–Richardson Formula 20 (KR-20) coefficients were .62 for the pretest and .60 for the posttest.

Attitudes regarding safety, subjective norms, and perceived behavioral control were measured using a modified instrument based on the work of Ajzen [23], with wording adapted for laboratory safety. Although the original instrument used a 7-point scale, a 5-point Likert scale was adopted in the present study to facilitate respondents’ understanding and reduce response burden.

The instrument comprised eight items regarding safety attitudes, four items regarding subjective norms, and five items regarding perceived behavioral control. Each item was scored on a 5-point Likert scale ranging from completely disagree (1 point) to strongly agree (5 points). Higher total scores indicated more positive attitudes regarding safety, stronger subjective norms, and better perceived behavioral control. Cronbach's α values for the pretest/posttest were .92/.90 for attitudes regarding safety, .74/.78 for subjective norms, and .79/.77 for perceived behavioral control. The intention to perform safety behaviors in the laboratory was measured using an instrument developed by the researchers based on the work by Ajzen [23]. The preliminary instrument was validated by an expert panel. The content validity index of the items was $\geq$.78, and the content validity index of the scale was .90. The instrument comprised three items, and each was scored using a 5-point Likert scale, with responses ranging from completely disagree (1 point) to strongly agree (5 points). The potential scores ranged from 3 to 15 points, and higher scores indicated stronger intention to perform laboratory safety behaviors. Cronbach's α was .85 for both the pretest and posttest.

3. Study procedures

1) Development of the laboratory safety education program

In this study, an education program was developed according to the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model [24] to prevent laboratory safety accidents among nursing students.

2) Analysis stage

To identify the educational needs of the participants, focus group interviews were conducted among a panel of six third-year nursing students. During these interviews, the following six questions were asked: "have you experienced a safety accident during practical classes?"; "what types of safety accidents can occur during practical classes?"; "do you know about methods of coping with safety accidents that might occur during practical classes?"; "what factors do you think would help with performing safety behaviors during practical classes?"; "what factors do you think would interfere with performing safety behaviors during practical classes"; and "what do you think are the benefits of receiving laboratory safety education?". The interview time was 90 minutes.

3) Design stage

The goals of the education program were to improve safety knowledge and attitudes, subjective norms, perceived behavioral control, intention to perform safety behaviors, and safety behaviors, as well as to improve adherence to behaviors that prevent safety accidents and competency in performing behaviors that prevent safety accidents. These goals were created with the aim of preventing laboratory accidents among nursing students. Several education methods, such as lectures, problem-based learning (PBL), peer situation coaching, discussions, and quizzes, were planned to provide participants with an effective education program. Educational audiovisual materials, such as images and case study videos, were also used appropriately.

4) Development stage

In this study, educational materials were developed based on the content and goals set during the design stage. To test the content validity of the program, an expert panel of three nursing professors (who were responsible for the on-campus practical module) verified the suitability of the content, composition and running time of the educational materials, and education methods. The validity of the overall content of the education program was rated as very suitable or suitable by all three nursing professors, and the total content validity index was 1.00.

Table 1. Laboratory Safety Education Program

Session	Topic	Educational content	Teaching method	Duration	Related theory of planned behavior constructs
1	Necessity of laboratory safety education	• Necessity of laboratory safety education • Types of laboratory safety accidents	• Lecture Presentation	60 min	Knowledge, Attitude
2	Electrical safety education	• Types and causes of electrical accidents in the laboratory • Methods to prevent electrical accidents in the laboratory	• Lecture • Video viewing • Peer situation coaching • Presentation	60 min	Knowledge, Perceived behavioral control
3	Fire and firefighting safety education	• Causes of laboratory fires • Types and usage of firefighting equipment • Guidelines for responding to fire safety accidents	• Lecture • Video viewing • Problem-based learning • Presentation	60 min	Knowledge, Perceived behavioral control
4	Management of hazardous chemicals and waste in the laboratory	• Types and management of laboratory waste • Disposal and storage of medical waste • Separation and disposal of medical waste	• Lecture • Video viewing • Peer situation coaching • Presentation	60 min	Knowledge, Perceived behavioral control
5	Personal Protective Equipment (PPE) and laboratory safety facilities	• Types and usage of personal protective equipment • Types and usage of laboratory safety facilities • Practical training on the use of personal protective equipment and safety facilities in the laboratory	• Lecture • Peer situation coaching • Presentation	60 min	Perceived behavioral control
6	Risks of using smart devices (mobile phones, tablets, etc.) during practice	• Overview of smart devices • Advantages and risks of using smart devices during practice • Safe usage of smart devices during practice	• Lecture • Problem-based learning • Presentation	60 min	Attitude, Subjective norms
7	First aid for laboratory safety accidents	• Types of first aid for common laboratory accidents (cuts, dizziness, bruises, bleeding, pain, etc.) • First aid methods for laboratory-related injuries • Necessity and basic principles of cardiopulmonary resuscitation	• Lecture • Video viewing • Problem-based learning • Presentation	60 min	Knowledge, Perceived behavioral control
8	Writing a safety checklist to be practiced during training	• Writing a safety checklist to be practiced during training	• Lecture • Discussion • Presentation	60 min	Behavioral intention

5) Implementation and evaluation stage

The intervention was conducted over 4 weeks, consisting of two 60-minute sessions per week, for a total of eight sessions (Table 1). The main education method was lectures using booklets, but time was also allocated for PBL, peer situation coaching, quizzes, discussions, and question and answer sessions to improve the effectiveness of content delivery. To maintain consistency, the program was conducted by a single researcher. To verify whether the learning goals were achieved and evaluate the effects of the program, the results of a questionnaire completed by the participants and administered by a trained research assistant were evaluated.

4. Program management and data collection

The data collection period ranged from April to July 2022. The pretest assessment was performed 1 week before the start of the education program. The intervention group participated in the education program presented by the researchers, whereas the control group received a booklet summarizing the program contents. A posttest assessment was conducted for both groups after completion of the education program. A trained research assistant administered the pretest and posttest questionnaires.

5. Ethical Considerations

This study was approved by the Institutional Review Board of K University (KNU-IRB-2022-036). Prior to participation, all students received an explanation of the study purpose, procedures, voluntary nature of participation, and their right to withdraw at any time without academic disadvantage. Written informed consent was obtained from all participants. Confidentiality and anonymity were ensured by assigning identification numbers and securely storing the collected data. Because the participants were students, special attention was paid to preventing educational disadvantage. To ensure equitable access to educational content, the control group received a booklet containing the same core educational material as that provided in the intervention program. In addition, after completion of the study, the educational materials used in the intervention were made available to the control group. After completing the posttest questionnaire, participants received a small gift (approximately 10,000 KRW) as a token of appreciation.

6. Statistical analysis

The collected data were analyzed using SPSS Statistics for Windows version 25.0 (IBM Inc., Armonk, NY, USA). The general characteristics and variables of interest of the intervention and control groups were expressed as the mean values, standard deviations, and percentages. The Shapiro-Wilk test was used to verify normality. Homogeneity of the general characteristics and research variables of the intervention and control groups was tested using the χ^2 test, Fisher's exact test, independent t-test, and one-way analysis of variance, as appropriate. Differences between pretest and posttest results were analyzed using paired t-tests, and differences between the intervention and control groups were analyzed using independent t-tests.

Ⅲ. Results

1. General characteristics and homogeneity

The mean age of the participants was 19.63 years, and 76.2% were female. The mean nursing major satisfaction score was 3.71 points (out of 5), and 14.3% of participants reported that they experienced laboratory safety accidents. Homogeneity testing of the general characteristics and research variables of the intervention and control-

Table 2. General Characteristics and Homogeneity between Groups (N=63)

Variables	Category	Exp. (n=30) Mean±SD or n(%)	Con. (n=33) Mean±SD or n(%)	χ^2 / t	p
Age		19.47±0.73	19.79±0.82	-0.64	.107
Sex	Male	7 (23.3)	8 (24.2)	0.01	.933
	Female	23 (76.7)	25 (75.8)		
Major satisfaction		3.80±0.96	3.64±0.70	0.78	.440
Safety accident experience	Yes	5 (16.7)	4 (12.1)		.725†
	No	25 (83.3)	29 (87.9)		
Knowledge		30.33±2.56	30.33±2.88	0.00	>.999
Attitude toward the behavior		36.60±6.10	38.42±3.32	-1.60	.119
Subjective norm		19.20±1.24	19.00±1.87	0.50	.616
Perceived behavioral control		19.63±3.59	20.21±3.17	-0.68	.499
Behavioral intention		14.03±1.45	14.18±1.69	-0.37	.710

SD=Standard Deviation; Exp=Experimental group; Con=Control group
† Fisher's exact test

trol groups provided by the pretest questionnaire indicated no statistically significant differences (Table 2).

2. Effectiveness of the laboratory safety education program

The mean knowledge score of the intervention group increased by 3.7 points from 30.00 points pretest to 33.70 points posttest (t = 6.94; p < .001), that of the control group increased by 1.88 points from 30.33 points pretest to 32.21 points posttest (t = 4.83; p < .001). A comparison of the pretest and posttest knowledge scores of both groups indicated that the intervention group experienced significantly greater improvement (t = 2.41; p = .019). The attitude toward the behavior score of the intervention group increased significantly by 3.37 points, from 36.60 at pretest to 39.97 at posttest (t = 3.03, p = .005); however, the difference between the pretest and posttest attitude scores of the control group was not significant. The attitude of the intervention group improved more than that of the control group (t = 2.95; p = .006). The perceived behavioral control score of the intervention group increased significantly by 3.53 points, from 19.63 at pretest to 23.17 at posttest (t = 5.92, p < .001), but the difference between the pretest and posttest scores of the control group was not significant. Perceived behavioral control of the intervention group improved more than that of the control group (t = 3.66; p < .001). The behavioral intention score of the intervention group increased significantly by 0.93 points, from 14.03 at pretest to 14.97 at posttest (t = 3.62, p < .001), but the difference between the pretest and posttest scores of the control group was not significant. The behavioral intention score of the intervention group increased more than that of the control group (t = 2.12; p = .038) (Table 3). In addition to statistical significance, effect sizes were estimated for the between-group differences.

Table 3. Effects of the Laboratory Safety Education Program (N=63)

Variables	Group	Pretest Mean±SD	Posttest Mean±SD	Within-group t(*p*)	Between-group t(*p*)
Knowledge	Exp.(n=30)	30.33±2.56	33.70±1.02	6.94 (<.001)	2.41(.019)
	Con.(n=33)	30.33±2.88	32.21±2.34	4.83 (<.001)	
Attitude toward the behavior	Exp.(n=30)	36.60±6.10	39.97±0.18	3.03 (.005)	2.95(.006)
	Con.(n=33)	38.42±3.32	38.42±3.32	-0.24 (.809)	
Subjective norm	Exp.(n=30)	19.20±1.24	19.93±0.25	3.27 (.003)	1.01(.315)
	Con.(n=33)	19.00±1.87	19.39±1.27	1.60 (.119)	
Perceived behavioral control	Exp.(n=30)	19.63±3.59	23.17±1.86	5.92 (<.001)	3.66(<.001)
	Con.(n=33)	20.21±3.17	20.39±3.55	0.27 (.792)	
Behavioral intention	Exp.(n=30)	14.03±1.45	14.97±0.18	3.62 (<.001)	2.12(.038)
	Con.(n=33)	14.18±1.69	14.33±1.36	0.58 (.567)	

SD=Standard Deviation; Exp=Experimental group; Con=Control group.

Ⅳ. Discussion

This study was designed based on the components of the TPB (attitudes, subjective norms, perceived behavioral control) as well as knowledge and conducted to determine the ability of an educational intervention to improve the intention to perform laboratory safety behaviors among nursing students. After implementing the education program, improvements in the mean safety knowledge scores and attitude scores of the intervention group were greater than those of the control group. Similar to our findings, Zomordi et al. [25] reported that a TPB-based educational intervention (four 60-minute to 90-minute sessions) improved knowledge of and attitudes toward human papillomavirus inoculation among female students (age, 18～26 years). Additionally, Hsieh et al. [26] reported that a single session (1 hour) of game-based and real-world training-based fire education improved the knowledge and attitudes of nurses, thus supporting the hypothesis that educational interventions can effectively improve knowledge and attitudes. The intervention duration (4 weeks with repeated sessions) was considered appropriate, as previous studies have shown that even short-term educational interventions with repeated sessions can effectively improve knowledge, attitudes, and behavioral outcomes among nursing students [25,26].

Lack of knowledge about laboratory safety is a problem among nursing students that can lead to unsafe behaviors and practices [27]. Not only the supervisor but also the students must have sufficient knowledge to identify potential safety risks in the laboratory as well as the self-confidence to protect themselves and their peers from preventable harms and adverse effects. Safety attitudes of nursing students are very important for creating a safe environment for themselves and their patients [28]. Unsafe and safe attitudes can have negative and positive effects, respectively, on safety behaviors [29]. The reliability of the knowledge measurement tool (KR-20=.60～.62) in this study was lower than the commonly recommended threshold. The relatively low KR-20 values may be attributable to the heterogeneous and dichotomous nature of the items, which were designed to cover multiple domains of laboratory safety. This limitation may have reduced the sensitivity to detect changes in knowledge; therefore, the results should be interpreted with caution.

Because of the diversity of safety laboratory settings, the educational intervention in the present study comprised multiple education methods, including lectures, PBL, and peer situation coaching. In particular, PBL is a student-centric method that focuses on a single designated problem, and it is the preferred method of improving long-term memory of the class content and problem-solving ability. The PBL scenarios developed in this study included those related to several potential safety accidents. Implementing PBL activities after lectures is expected to improve knowledge acquisition and attitudes. Jamshidi et al. [20] reported that eight sessions (45-minute to 60-minute sessions) of PBL-based education improved patient safety knowledge, attitudes, and awareness compared with those of a control group. In the current study, audiovisual materials and case videos were used to allow students to intuitively and indirectly experience success and failure; this approach aimed to effectively increase awareness of safety accidents among students. To implement safety behaviors effectively in future situations, students require knowledge of necessary actions and strategies and a positive attitude; therefore, safety education before practice is essential. Another limitation is that the intervention group received interactive education, whereas the control group received booklet-based education. Differences in participant engagement resulting from these educational formats may have contributed to the observed outcomes.

Bosnjak et al. [30] stated that if individuals have sufficient control over their own actions, then they will act according to their own behavioral intention when given the opportunity. In the present study, the level of perceived behavioral control associated with laboratory safety increased more in the intervention group than in the control group after the education program was implemented. This finding suggested that this educational intervention may have contributed to reducing factors that hinder improvements in perceived behavioral control. This education program included peer situation coaching, which comprises pairs of students who coach each other using examples that can occur in a laboratory environment. The instructor provided an initial demonstration and guidelines for the relevant safety behaviors. Then, the students formed pairs and practiced safety behaviors by role-playing the given scenario. As the incident unfolded, students asked their partners questions, such as "what are the potential risks in this situation?", and the actions and responses required of the partners were explained in the script. Next, the student pairs engaged in discussions during a debriefing session. The instructor monitored the student pairs and provided additional insights and feedback. These mutual activities were considered to have positive effects on perceived behavioral control associated with laboratory safety because they provided students with confidence in their ability to correctly and easily perform safety behaviors in future situations. Safety should be emphasized as a fundamental concept in promoting students' awareness and practice of safe behaviors. Nevertheless, the study findings should be interpreted with caution, as differences in intervention intensity and interaction levels between the intervention and control groups may have contributed to the observed effects.

In the present study, the intention to perform safety behaviors in the intervention group significantly increased compared with that in the control group after completing the education program. This finding suggested that the TPB-based educational intervention may have improved the intention to perform laboratory safety behaviors in the intervention group. Additionally, studies by Fernandez et al. [16] and Lapkin et al. [31] that included nursing students and nursing students who had recently graduated indicated that attitude, subjective norms, and perceived behavior control predicted behavioral intention associated with drug safety, thereby indirectly supporting the effects of the educational intervention. However, Omura et al. [32] reported no changes in the

TPB concepts or intentions among Japanese nursing students after a single session (90 minutes) of an assertive communication training program; however, they suggested that this finding was attributable to the cultural context and differences in professional hierarchy between physicians and nurses. The education program in the present study was in-depth and comprised eight sessions, and the various scenarios presented were able to offer students more opportunities to improve their preparedness and response capabilities in the event of safety accidents. Because the goal of safety education is to reduce accidents by improving the ability of participants to perform appropriate behaviors in response to safety situations, building safety habits through repeated education is essential [29].

No differences in subjective norms were observed after completion of the education program in this study. This finding was considered attributable to the high pretest scores of this measure (mean score, 19 out of 20 points) among participants because of their ethical awareness. Compared with other constituent concepts of the TPB, subjective norms may have a weaker relationship with behavioral intention, and their contribution to the TPB may be small [33]. Because changing beliefs within a short period of time is difficult, education should be provided repeatedly and continually each semester, both before and during practical courses. In addition, the use of an effect size derived from a PBL-based study should be interpreted with caution given the multifaceted nature of the intervention. Furthermore, the possibility of selection bias due to differences in institutional environments should also be considered when interpreting the findings. The findings of this study have practical implications for nursing education. This program can be applied in undergraduate curricula, particularly in laboratory-based courses, and integrated into existing safety training. As it uses lectures, PBL, and peer coaching, it can be implemented within regular class schedules without substantial additional resources. However, its effectiveness may depend on institutional support, instructor readiness, and available time, and may require adaptation to specific educational settings.

This study had several limitations. First, because this study included an convenience sample of second-year nursing students from two universities in South Korea, the results may not be generalizable to other populations. Second, because participants were not randomly assigned to the intervention and control groups, the possibility of selection bias could not be completely excluded. However, the two groups were recruited from different schools to minimize the negative impact on internal validity attributable to diffusion effects. In addition, recruitment from different institutions may have introduced unmeasured differences in educational environments, and the lack of statistical adjustment (e.g., ANCOVA or propensity score matching) limits internal validity. Although several baseline characteristics were collected, the relatively small sample size limited the use of advanced statistical adjustment methods to adequately control for potential selection bias and unmeasured confounding variables. Applying such methods under these conditions could have resulted in unstable estimates. Instead, efforts were made to ensure baseline comparability through homogeneity testing and the use of consistent measurement tools and procedures across groups. Third, it was not possible to control for bias of the respondents, such as their perceptions of a 'good student,' intentionally maintaining consistency, and social desirability. To control these factors, students were encouraged to provide honest answers to the questionnaire, and they were assured that their data would remain private. Fourth, individuals may have different learning motivations, different academic abilities, and preferred learning methods that could not be controlled in this study. Therefore, forming an educational environment that allows students to engage in practical learning while feeling safe from psychological harm is crucial [27]. Fifth, because students were assessed only once immediately after the intervention, only the short-term effects on safety knowledge, attitudes, perceived behavioral control, and intention to perform safety behaviors could be evaluated. Additionally, differences in intervention intensity and level of interaction between the intervention and control groups may have affected internal validity. Further longitudinal studies are required to investigate the processes of changes in awareness and behavior, as well as the mid-term and long-term outcomes of the intervention. Sixth, because only behavioral intention regarding the laboratory safety of nursing students was measured, it was not possible to predict actual laboratory safety behaviors. Finally, the reliability of the knowledge measurement tool (KR-20 = .60 ~ .62) was lower than the commonly recommended threshold, which may have affected the consistency of measurement and interpretation of the findings related to knowledge. In addition, the use of an effect size derived from a PBL-only study may have led to an overestimation of the effect size, potentially resulting in an underestimation of the required sample size.

Nevertheless, the education program used during this study is a feasible tool that provides laboratory safety education and considers the characteristics of nursing studies. This educational intervention had positive effects on the intention to perform laboratory safety behaviors, and the intervention group exhibited improvements in knowledge, attitude, and perceived behavioral control. Therefore, participants' knowledge of, perceptions of, and responses to potential safety accident situations were expressed in terms of behavioral intention. The students in this study achieved satisfactory learning outcomes by becoming familiar with their own roles through meaningful educational experiences. Future studies should include objective measures such as direct observation, performance-based assessment, and longitudinal follow-up to evaluate actual safety behaviors.

Ⅴ. Conclusion

This TPB-based education program could be a potentially effective method of improving safety awareness among nursing students and creating a safe environment by providing education about laboratory safety accidents and coping methods. This educational intervention may have contributed to improvements in laboratory safety knowledge, attitude, perceived behavioral control, and behavioral intention of nursing students. Additionally, this program is student-centric, interactive, case study-focused, and it can be used repeatedly. Instructors should provide ongoing laboratory safety education to strengthen students' safety awareness and promote safe behaviors in laboratory settings. The findings of this study provide reference materials for researchers and educators that can be used to design laboratory safety education programs for nursing students.

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