Research Article

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Learning Effects of Mechanical Ventilator/Tracheal Suctioning XR Simulators and Extracting Decision Making Criteria to Introduce a Novel Simulator

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Abstract

Researchers have developed Simmar+ESTE-SIM, a XR simulator that can train the multitask of "endotracheal suctioning for a patient with a mechanical-ventilator" as part of support for Technology-dependent children in the community. In this study, we conducted a questionnaire after using the simulator with the aim of extracting the learning effects of the simulator and judgment indicators when introducing a new simulator, based on feedback from 4th grade university students and the faculty members. As a result, both groups tended to score low on the question of whether the content was appropriate for learning in the third year, but the scores were generally high, at 3.0 or higher. The training task "endotracheal suctioning for a patient with mechanical respirator" was slightly early in 3rd grade students, and the appropriate timing was shown to be for 4th grade students. Principal component analysis extracts two principal components: "Balance between learning content difficulty and motivation (Achievability)" and "Balance between learning time, cost, and learning effect (Feasibility)". These two factors were thought to be the promoting and inhibiting factors when introducing a simulator. The future challenge is to popularize the simulator education program which is both achievable and feasible to improve the quality of care for children with home-ventilators and their families.

Objective

In Japan, the Ministry of Health, Labour and Welfare estimates that the number of children requiring medical care, such as tracheal suction and ventilators, has doubled from 10,702 in 2011 to 20,155 in 2021 (Nara, 2022). However, even among those holding a nursing license, there are cases where they are reluctant to provide care depending on the clinical department in which they have experience. One contributing factor is that the acquisition of skills for ventilator care is primarily done through On-the-Job Training (OJT).

As part of our support for children (and individuals) requiring medical care, we developed the Simmar+ESTE-SIM simulator, which enables training for the multitask of 'endotracheal suctioning while on a ventilator.' This simulator integrates the Simmar app, which simulates a ventilator's touchscreen panel (Figure 1, Ninomiya, et.al. 2023), and the ESTE-SIM (Endotracheal Suctioning Training Environment Simulator), which uses dynamic projection mapping technology to visually display a patient's facial expressions, changes in complexion, and other physiological changes based on the quality of catheter manipulation during suctioning (Figure 2, Colley et al. 2023, Komizunai et al., 2023). However, there can be barriers to implementing simulators. Therefore, this study conducted a multifaceted evaluation targeting students and instructors to assess the learning effectiveness of Simmar+ESTE-SIM and to identify criteria for deciding on the introduction of new simulators.

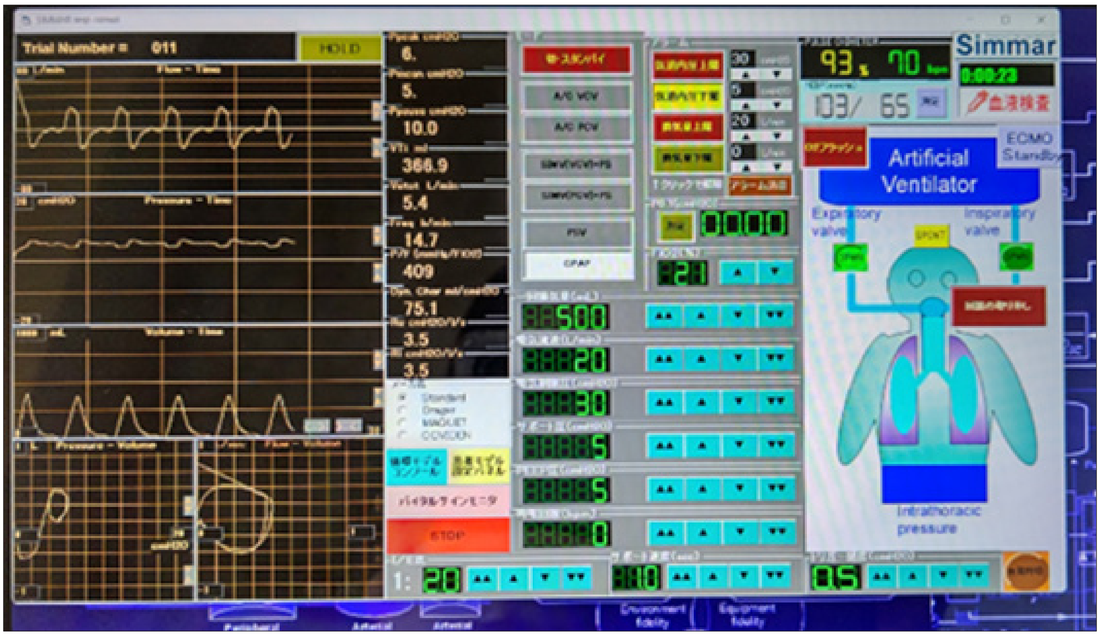

Figure 1: Mechanical Ventilator Training App: Simmar

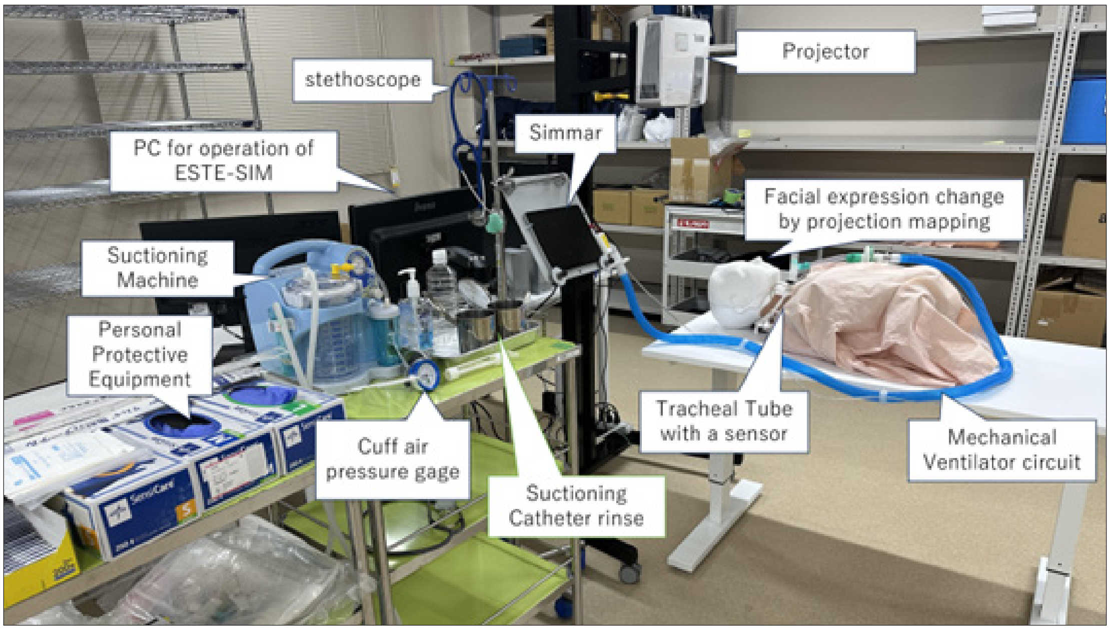

Figure 2: Simmar+ESTE-SIM

Subjects and Methods

Subjects

The study participants were seven faculty members and nine fourth-year students in the emergency nursing course at a university in Japan that specializes in nursing.

Questionnaire Items

Two types of questionnaires were created: one for faculty and one for students. The questions in the faculty questionnaire were:

1) basic attributes (years of clinical experience, years of experience in ventilator care, whether or not they hold qualifications related to respiratory care, and the models and number of ventilators they have used),
2) the learning effects and start date of the ventilator training app Simmar (hereafter referred to as Simmar),
3) the learning effects and appropriate timing of the endotracheal suction projection mapping simulator (Endotracheal Suctioning Training Environment – SIMulator: ESTE-SIM, hereafter referred to as ESTE-SIM),
4) content that should be learned in undergraduate education, and
5) difficult points in learning about ventilators.

The questionnaire for students with no clinical experience included only 2, 3, and 4. It did not include questions asking about the level of understanding of ventilators. Regarding 2) and 3), the learning effect (ease of doing things, realism, effect on increasing motivation to learn, time required, balance between time required and learning) and the timing of the course (whether it is appropriate as learning content for third-year students, whether it is appropriate as learning content for fourth-year students) were asked using a 4-point scale with "strongly agree (4 points)," "agree (3 points)," "disagree (2 points)," and "strongly disagree (1 point)." Regarding 4), the scope of knowledge that should be acquired in undergraduate education was asked using a 4-point scale for six items: how to deal with minor troubles in relation to the mechanical ventilator care, ventilator management, the fact that names of breathing modes etc. differ depending on the mechanical ventilators, assembling and setting up the ventilator, the mechanism of the mechanical ventilator, and emergency judgment regarding starting the ventilator.

Regarding 2), 3), and 4), in order to extract criteria to measure the decision to introduce a simulator, we used principal component analysis (PCA), which is used as a dimensionality reduction method in multivariate analysis. Python 3.11.6 and Microsoft Excel for Microsoft 365 MSO were used as analysis software. Prior to conducting the study, the study was approved by the Hokkaido University Graduate School of Health Sciences Ethics Committee (22-59), and written consent was obtained from the subjects.

Patient settings

The patient profile presented to the research collaborators in the simulator training was as follows:

Taro (pseudonym), 42-year-old male. Visited the hospital with fever. He had a fever of 38°C and fatigue for the past 3 days, and his family reported that he was "drowsy and seemed to be having difficulty breathing." At the time of admission, his fever was 38.5°C, SpO_2 was 95%, pulse rate was 88 beats/min, and respiratory rate was 30 breaths/min. His extremities felt cool, and his skin was moist. His medical history included cerebral palsy and recurrent aspiration pneumonia and decreased food intake, so he underwent a tracheotomy at the age of 10, had a tracheal cannula placed, and was started on continuous saliva suction and nasogastric tube feeding. He continued to suffer from recurrent pneumonia, and from the age of 12, his feeding schedule was changed to small amounts orally, as well as tube feeding (semi-solid) via a gastrostomy. After admission, the patient's oxygen saturation decreased further and oxygen administration was initiated, but due to worsening blood gas results, a mechanical ventilator was introduced to support his respiratory function.

Training tasks for Simmar+ESTE-SIM

The following tasks were set as learning objectives, and were explained by one of the co-researchers, who acted as an instructor, during the demonstration.

"Judge whether Taro (not his real name) needs sputum suction based on his vital signs and lung sounds, and if necessary, perform endotracheal suction (open system). When the ventilator is disconnected, a low-pressure alarm will sound on the ventilator (app), so please press the 'alarm silence button' before disconnecting the ventilator circuit. Please also observe the lung sounds after endotracheal suctioning."

When explaining the training tasks, the instructor explained where the SpO_2 and respiratory rate are displayed on the screen, the location of the alarm silence button, that the alarm silence button should be pressed every time an alarm sounds during endotracheal suctioning to prevent the patient from becoming anxious, and the use of personal protective equipment such as goggles and aprons.

Results

Basic Properties

We received responses to the questionnaire from eight fourth-year students and seven faculty members. Using G*power 3.1.9.7, we calculated the power of the independent two-group t-test with sample sizes of group 1 = 8, group 2 = 7, and effect size = 0.8, which was 0.69 (Table 1).

The years of clinical experience of the university faculty ranged from 8 to 32 years (average 17.7 years). Of the years of clinical experience, the number of years involved in ventilator care was less than 1 year (2 people), 3 to 5 years (1 person), 5 to 10 years (2 people), and more than 20 years (2 people). One person had a qualification related to respiratory care (NCPR: neonatal resuscitation). The types of ventilators/respiratory therapies they had used were Servo (5 people), Bennett (2 people), LTV (1 person), Nasal-DPAP (infant flow), HFNC (high flow nasal cannula), and Trilogy (1 person) (multiple answers allowed). The faculty survey suggested that there are situations in which it is necessary to be able to handle multiple types of ventilators in clinical practice depending on the age and condition of the patient.

Table 1: Result of the post hoc test by G*Power 3.1.9.7

t tests - Means: Difference between two independent means (two groups)

Analysis : Compromise: Compute implied α & power

Input: Tail(s)	=	Two
Effect size d	=	0.8
β/α ratio	=	1
Sample size group 1	=	8
Sample size group 2	=	7
Output: Noncentrality parameter δ	=	1.5457469
Critical t	=	1.0650752
Df	=	13
α err prob	=	0.3062248
β err prob	=	0.3062248
Power (1-β err prob)	=	0.6937752

Survey Results on Learning Effectiveness

The survey results (Tables 2 and 3) show that all items were highly rated, with an average score of 3.0 or more. For both the student and faculty groups, high ratings were generally given to the realism of the simulator, the effect of improving motivation to learn, the appropriateness of the time required, the balance between the time required and the learning effect, and the appropriateness as a fourth-year learning content. Questions with low ratings were as follows: for Simmar, the student group rated the ease of experience at 3.250±0.661 points, and the faculty group rated it at 3.429±0.728 points.

For the question about the appropriateness as a third-year learning content, the student group rated it at 3.375±0.484 points, and the faculty group rated it at 3.143±0.833 points. For ESTE-SIM, the student group rated the ease of experience at 3.375±0.696 points, and the faculty group rated it at 3.143±0.639 points, which was low, but the other items were rated at 3.5 or more. This indicates that a certain amount of training is necessary in operating the simulator. Although no statistical tests were conducted because the purpose was not to compare the proficiency levels of students and faculty, it became clear that many participants considered the difficulty of the patient settings and training tasks used in this study to be "appropriate for fourth-year learning content."

Table 2: Learning Effects of Simmar (Mean±SD)

Questions	Students	Faculty members
It was Handy	3.250±0.661	3.429±0.728
It was Real	3.625±0.484	3.571±0.495
It increased motivation to learn	3.750±0.433	3.714±0.452
Training time length was appropriate	3.625±0.484	3.714±0.452
Good Balance of time and learning contents	3.625±0.484	3.571±0.495
It was suitable for 3rd year students	3.375±0.484	3.143±0.833
It was suitable for 4th year students	3.875±0.331	3.571±0.728

Table 3: Learning Effects of ESTE-SIM (Mean±SD)

Questions	Students	Faculty members
It was Handy	3.250±0.661	3.429±0.728
It was Real	3.625±0.484	3.571±0.495
It increased motivation to learn	3.750±0.433	3.714±0.452
Training time length was appropriate	3.625±0.484	3.714±0.452
Good Balance of time and learning contents	3.625±0.484	3.571±0.495
It was suitable for 3rd year students	3.375±0.484	3.143±0.833
It was suitable for 4th year students	3.875±0.331	3.571±0.728

What should be learned in undergraduate education?

The average scores for each group were calculated for six areas that should be covered in undergraduate education on ventilator care (how to deal with problems, ventilator management, differences in names for breathing modes depending on the model, assembling and setting the ventilator, the mechanism of the ventilator, and emergency decisions regarding starting ventilation) (Figure 3). All students who responded answered that all items should be learned in undergraduate education, indicating that they participated with high motivation. On the other hand, the result of an unpaired t-test was $p=0.002$ ($t=5.538$, $df=14$), indicating that university faculty are statistically significantly more cautious than students about educating undergraduates about ventilator care.

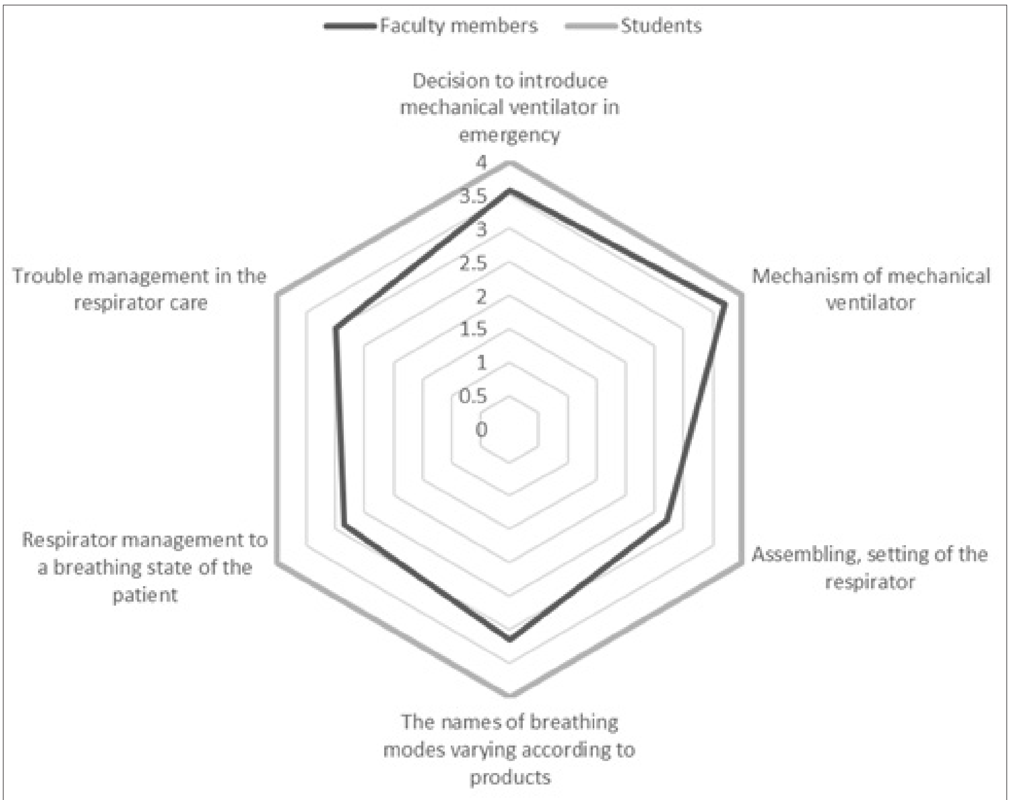

Figure 3: Results of Scope of Learning for Undergraduate course

Criteria for Deciding on Simulator Implementation

A principal component analysis was conducted using the results of the student and faculty questionnaires) the learning effect and start date of Simmar) the learning effect and start date of ESTE-SIM) the content that should be acquired in undergraduate education. Figure 4 shows the contribution of the observed variables.

As shown in Figure 4, in the first principal component, “Suitable as learning content for fourth-year students (B4)” for both Simmar and ESTE-SIM was located to the right of “Suitable as learning content for third-year students (B3),” with “Mechanism of MV” being the rightmost, and therefore difficulty of the educational contents was thought to be related to the first principal component. Regarding the second principal component, “Balance between time required and learning content” for Simmar and ESTE-SIM was located at the top of Figure 4, and “Understanding of Respiratory Circuit” was located at the bottom of Figure 4. As “assembly and setting of ventilator circuit” was not included in the tasks performed this time, it was inferred that feasibility of experience was the second principal component.

Based on the above, the first principal component was named “Balance between the difficulty of the learning content and motivation (achievability),” and the second principal component was named “Balance between learning time, cost, and learning effect (feasibility).” In the future, further investigation into related factors is necessary to improve motivation and learning effect during simulation education.

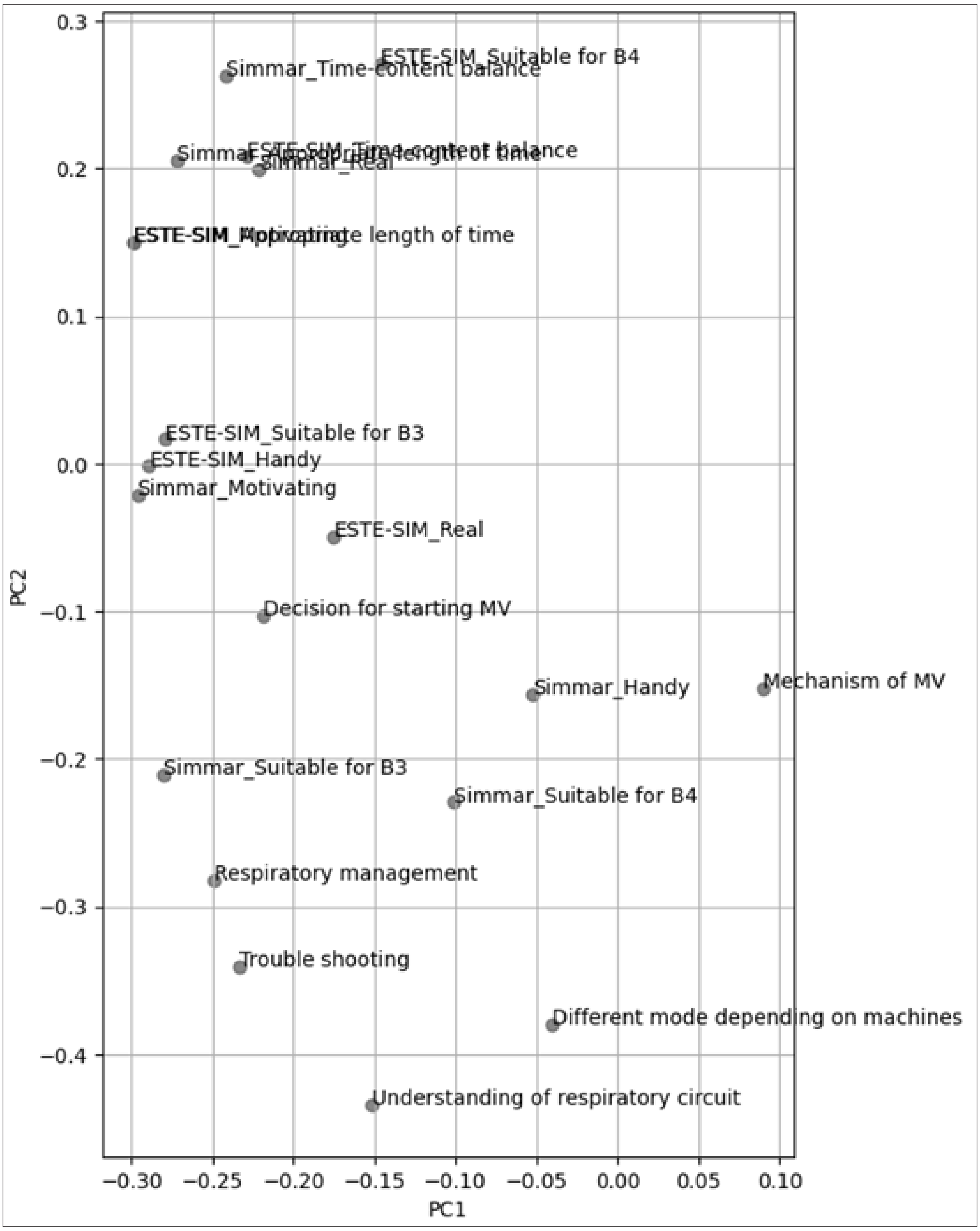

Figure 4: Results of Principal Component Analysis

Difficulties in Learning Ventilator Care

Regarding the difficulties in learning ventilator care through OJT, the university faculty gave the following responses: "(Understanding) the meaning of each setting according to the patient's condition, how to deal with troubles," "Procedures that do not cause discomfort to the patient. Distinguishing between sterility and non-sterile," "Observation items taking into account each disease," "Understanding the ventilator circuit, position of the artificial airway, meaning of alarm," "Types of ventilators," and "Understanding how the equipment works." In addition to descriptions of the difficulties of ventilator care, such as "I couldn't understand much even after looking at the textbook. I was able to understand little by little by attending study sessions and watching actual practice," challenges were also mentioned regarding the learning method.

However, there were many comments about the benefits of simulator education, such as "I think that being able to experience clinical situations without being in the actual situation is a very effective method of on-campus experiential learning in undergraduate education, and it was great to be able to experience that," "In emergency situations, particularly since multiple professionals are providing care at the same time, the simulator allows you to see the whole picture," "I think it was good that the students were able to enjoy the learning experience (2 people)," "It felt like they were actually performing the procedure, and I thought it would be a good practical learning experience for the students, including the assessment process. I think if it was incorporated into practical classes, it would help reduce the reality shock when they start working as novice nurses," and "It's realistic, easy to understand, and it's easy to stimulate interest of students."

In the free comments from the students, perhaps because the content of the training tasks had been coordinated in advance with the faculty of University B, many positive opinions were expressed, such as "By actually trying out the simulation myself, it was easier to understand what I should observe," "I was able to practice as if I was in a real-life situation," "The facial expressions and coughing were realistic, so I was able to practice in a situation close to reality (3 people)," "It was good to be able to learn things and techniques that I couldn't learn in the practical training," and "I thought it was a very interesting way to study."

On the other hand, there were comments from students who noticed things that they could not have noticed without actually touching the actual device, such as, "I found it difficult to know with the ventilator because the connecting the ventilator circuit to the tracheal tube would either fit or not fit depending on the amount of force used," "It was difficult to think about what to observe before reporting to the doctor," "The ventilator technique," and "It was difficult to assess and make a judgment." They also noticed the difficulty of reporting to the doctor and making assessments and judgments.

Features you would like to see added to the Simulator

In the free-form comments about simulators that the students group would like to have added, only two students wrote "tracheal intubation," but the faculty group requested that "the area where breath sounds can be auscultated be expanded," "I think the effectiveness of the simulation would be improved if the suction simulator were to add the feeling of actually suctioning sputum using simulated sputum," "a communication simulator with positive and negative symptoms," and "observation of consciousness level" be added to the patient settings used in Simmar+ESTE-SIM, as well as functions related to nursing techniques other than ventilator care, such as "nursing for midwifery assistance during childbirth" and "facial expressions in response to words spoken to."

Discussion

The results obtained in this study will be considered from two perspectives: "The current state of ventilator simulation education" and "The direction of curriculum development using new simulators in pediatric nursing."

Current Status of Ventilator Simulation Education

Murata et al. (2022), who investigated the current state of simulation education in the field of adult nursing, pointed out that the greatest effect of simulation education is "visualization of patients and nursing practice.Even in everyday life without the COVID-19 pandemic, it is not easy for nursing students to obtain the opportunity to provide care, especially to severely ill patients on ventilators, so the quality of education depends on how faithfully important aspects of clinical practice can be reproduced on campus and an environment in which learning can be created. In addition, in practical training, the required level of learning often differs depending on the severity of the patient, and students are forced to rely on the subjective evaluation of clinical instructors. On the other hand, simulation education allows multiple people to learn simultaneously for the same patient scenario, making it possible to develop standard evaluation measures. Furthermore, there is no loss of learning opportunities due to the presence or absence of enthusiasm of students or the timing of patient examinations and treatments, as is often the case in practical training. In addition, the study also lists another benefit: "The environment in which touch and repetition lead to understanding the observation items necessary for the subject and acquiring observation techniques." (Murata, et.al., 2022).

A previous study in which ventilator care was used as a training task was conducted by Sakuma et al. (2022). A three-phase simulation was set up as an integrated exercise in the second semester of the fourth year, and simulation education was provided to 145 students. The learning objectives were Phase 1 "Physical assessment of subjects with respiratory distress," Phase 2 "Information collection, assessment and response (including reporting) required in the event of an emergency," and Phase 3 "Insertion of a bladder catheter in the event of an emergency." As a result of evaluating the achievement of 142 nursing skills and the ARCS evaluation (Attention, Relevance, Confidence, Satisfaction) as the learning objective achievement level, the achievement level of the learning objectives was high at 3 or more out of 4 in all phases, indicating the validity of the goal setting. It was also reported that the ARCS evaluation was 4 or more out of 6. Another advantage of simulation education is that it is possible to provide education under the same patient scenario, learning environment, and conditions, even if there are more than 100 students.

Nishimura et al. (2022), who investigated student learning in ventilator simulation education, conducted simulation education as a fourth-year integrated nursing training and found nine categories: [opportunity to perform self-evaluation], [acquire necessary knowledge in emergency nursing], [recognize the importance of the team], [realize the importance of assessment], [lead to acquiring the ability to practice care], [be able to share information with medical professionals], [increase the significance of expressing one's own thoughts], [put oneself in the position of the person receiving care], and [improve ethical sensitivity in care]. In this study, a scenario that did not involve multiple professions was used, so no questionnaire descriptions regarding team medical care or information sharing were found, but it is believed that it is possible to develop an educational program that allows these learnings by creating a scenario.

Simulation education is also attracting attention in the education of clinical engineers. Omori (2017) warns that one drawback of OJT, "mistakes leading to medical accidents," should not be overlooked8). As a concrete example of simulation education that overcomes this drawback, 33 hospitals belonging to the National Federation of National Public Service Mutual Aid Associations (hereafter the Federation) have introduced KS-lab as a project of the academic organization "Kyosai Igakukai." KS-lab offers a course on responding to ventilator alarms, and aims to train nurses, interns, clinical engineers, and physical therapists to distinguish ventilator alarms, assess patients and check their vital signs, and to make appropriate judgments and take action regarding symptoms and pathology. Training results are managed on the cloud, and "learners can review and learn (post-learning) at any time at any Federation hospital nationwide without relying on a dedicated device". In this way, in addition to establishing a system to improve the effectiveness of simulation education in hospitals as part of postgraduate education, future challenges include sharing trainees' readiness by utilizing their training records and portfolios, creating an environment for pre- and post-learning in clinical settings, and developing methods for sharing educational materials.

Direction of Curriculum Development

In this study, we had fourth-year students and university faculty experience Simmar+ESTE-SIM and conducted a questionnaire survey. The results showed that both the student and faculty groups rated it highly in terms of learning effects (realism of the simulator, effect on improving motivation to learn, appropriateness of the time required, balance between the time required and learning effects, and appropriateness as learning content for fourth-year students). Two questions received low ratings: ease of experience and appropriateness as learning content for third-year students. It was shown that the training task set in this study, "endotracheal suction while attached to a ventilator," is a little too fast for third-year students and is appropriate as simulation education content for fourth-year students.

Regarding the scope of study, the students in this study were highly motivated and wanted to become emergency nurses, which was one of the reasons for the high overall evaluation. Therefore, when teaching all first-year students in acute care nursing practice or integrated nursing practice, it is essential to create a scenario that matches the students' areas of interest and the diversity of the subjects, such as an educational program that crosses subjects, such as home artificial ventilators (home care nursing and pediatric nursing), neonatal artificial ventilators (maternal nursing), and ethical judgments regarding the attachment and removal of artificial ventilators in palliative care. Nursing for children who require medical care requires knowledge and skills that cross multiple fields, such as not only pediatric nursing, but also maternal nursing, acute care nursing, chronic care nursing, home care nursing, psychiatric nursing, and family nursing.

In order to fulfill our mission as a nursing educator so that current students and future new nurses can provide better care to the patients they will encounter, we believe it is important to understand trends in medical needs in the local community and society, review the basic nursing education curriculum, develop a cross-disciplinary curriculum that transcends specialized areas to make ward training more effective, and ensure continuity between simulation education and OJT. Specifically, it is important to set the level of achievement at graduation in collaboration with medical faculty, faculty from other departments, such as Information Technology and Engineering, as well as the nursing department, to develop a curriculum based on research evidence.

In a book titled: The Future of Nursing 2020–2030: Charting a Path to Achieve Health Equity (The National Academies of Sciences, Engineering, and Medicine: NASEM, 2021), it is pointed out that nurses can play an important role as a change agent in creating systems that bridge the delivery of health care and social needs care in the community.

As mentioned in the introduction, the number of children receiving medical care who require endotracheal suctioning with/out mechanical respiration has doubled to 20,155 in the 10 years from 2011 to 2021. In particular, the number of children on mechanical respirators has increased by about 19 times, from 264 to 5,017 between 2005 and 2020 (Nara, 2022) in Japan. In order to respond to such a sudden social change in demand for home services, the Act on Support for Technology-Dependent Children and Their Families was enacted in 2021, and the establishment of a system to support children receiving medical care, including mechanical respirators, and their families is an urgent issue. In addition, it is difficult to consider increasing the number of NICUs, which are places for on-the-job training (OJT), due to the declining birthrate and aging population. In order to fundamentally solve this problem, educational shift based on the social demand to introduce artificial respirator training from informal education such as OJT to formal education such as undergraduate education will commence celebrating a rapid integration of healthcare science and AI technology. Our future challenge would be to develop a curriculum that includes a "sequential ventilator training program that allows for the acquisition of minimum knowledge and skills" to contribute to patient safety.

Conclusion

In this study, skills training was conducted for both Simmar and ESTE-SIM, and questionnaire surveys were conducted on faculty and students, which showed a high learning effect for obtaining skills for endotracheal suctioning for a patient with a mechanical ventilator. In terms of the timing of the course, it was suggested that the training task of "endotracheal suctioning while on a ventilator" is a little too early for third-year students, and that it would be appropriate as simulation education content for fourth-year students.

From principal component analysis of the questionnaire, the following criteria were extracted for introducing a simulator: "balance between the difficulty of the learning content and motivation (achievability)" and "balance between learning time, cost, and learning effect (feasibility of implementation)." Using these as reference, it was considered that a future challenge would be to improve the simulator education system. In the future, we would like to clarify the minimum requirements for safe ventilator management, not only provide an overly packed curriculum, but also expand the venue where people interested in simulation education and development can gather and aim to create an "open space for interdisciplinary communication" to solve social issues, such as through multi-professional collaboration and cross-disciplinary development.

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Conflict of Interest

There are no conflicts of interest to disclose.

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