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ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES
INTERDISCIPLINARY EUROPEAN ACADEMY OF SCIENCES

Lundi 12 Juin 2023 (en format mixte présence-distance) :

« Développer une posture de recherche dans les métiers de l'humain et en intelligence collective : émergences, cheminements et constructions de savoirs »

Muriel FRISCH

Professeure en sciences de l'éducation et de la formation
Université de Reims Champagne-Ardenne / Laboratoire Cérep

Notre Prochaine séance aura lieu le lundi 11 Septembre 2023 de 14h30 à 17h
Salle Annexe Amphi Burg
Institut Curie, 12 rue Lhomond – 75005 Paris

Elle sera consacrée :

- **à 14h30, à l'examen de la candidature du Pr. Wolfgang ELSÄSSER à l'AEIS**
- **à 15h précises, à la conférence de notre collègue le Pr. Nguyen TRAN :**

« Contribution relative du métavers et de la réalité virtuelle en formation médico-chirurgicale de haut niveau »

Nguyen TRAN

Professeur, Section 66, Physiologie,
Faculté de Médecine, Université de Lorraine

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TABLE DES MATIERES

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Séance du Lundi 12 Juin 2023 mixte présence-distance

La séance est ouverte à 15h, **sous la Présidence de Victor MASTRANGELO**

- **Étaient présents physiquement nos Collègues membres titulaires de Paris** : Gilbert BELAUBRE, Anne BURBAN, Jean-Felix DURASTANTI, Françoise DUTHEIL, Michel GONDRAN, Irène HERPE-LITWIN, Paul-Louis MEUNIER, Denise PUMAIN, René PUMAIN, Jean SCHMETS, Jean-Pierre TREUIL.
- **Était présent physiquement notre Collègue membre correspondant** : Jacky ROUSSELLE
- **Étaient connectés à distance nos Collègues** : Jean-Louis BOBIN, Eric CHENIN, Jacques FLEURET, Abdel KENOUFI, Christian GORINI, Jacques PRINTZ, Enrico SARTORI.

Compte-rendu de la conférence du 12 juin

Développer une posture de recherche dans les métiers de l'humain et en intelligence collective : émergence, cheminements et construction de savoirs.

Par Muriel Frisch, professeure des universités en sciences de l'éducation et de la formation INSPE de Reims

(Compte-rendu rédigé par notre collègue Anne Burban)

Constats problématiques
Deux conséquences directes du confinement dû à la pandémie de la Covid 19 :
- l'explosion du recours au numérique dans l'acte de formation-apprentissage ;
- la nécessité de concevoir des formations dites hybrides pour les professionnels de l'éducation, de la formation et de la recherche.

Ces deux effets ont entraîné une désincarnation des relations sociales alors même que l'on attend aujourd'hui une implication plus forte de la recherche dans des questions de nature sociale et professionnelle. Parallèlement à ces effets dus au recours aux formations à distance par voie numérique, on assiste à plusieurs phénomènes :
- une certaine forme de standardisation aboutissant à une vision simplificatrice des compétences et à une lecture réductrice des savoirs et du rapport au savoir ;
- un contexte de normalisation visant imposer de « bonnes pratiques » ;
- un amalgame entre information, savoir et connaissance.
- des résistances fortes à travailler de nouvelles formes de complexité, d'interdisciplinarité et de construction de savoirs.

Pour faire face à ces constats, de nouveaux enjeux …

Ces nouveaux enjeux sont caractérisés par :
- la préservation d'une forme de complexité et l'articulation entre recherche, éducation, formation et professionnalisation ;
- la garantie d'un avenir scientifique pour des recherches en didactique des disciplines ;

- l'intégration de la recherche dans l'action de « praticiens ».

… à investir par plusieurs champs de recherche

Les différents champs de recherche du laboratoire dirigé par Muriel Frisch portent sur :

- la didactique de l'information-documentation ;
- plus largement, les didactiques des différentes disciplines ;
- les métiers de l'humain.

Le choix de l'information-documentation repose sur le fait que cette discipline offre des situations permettant d'identifier assez facilement ce que l'on apprend en cherchant. La didactique de l'information-documentation, qui s'appuie sur de grandes figures comme celle de Suzanne Briet, a d'ailleurs fait l'objet d'un colloque de l'UNESCO en 2017, intitulé *Histoire et épistémologie de l'information-documentation*.

La pratique de l'information-documentation permet de développer une posture de recherche transversale tout au long de la vie et à travers différents niveaux de posture : la posture de l'élève-chercheur, la posture de l'étudiant-chercheur, celle du stagiaire-chercheur, celle de l'enseignant-formateur et enfin, celle de l'enseignant-chercheur.

Elle permet de concevoir l'activité d'apprentissage à travers un média, le document, servant à la fois de point de départ de la connaissance et d'outil de pensée. Par ailleurs, l'activité d'information-documentation met en jeu plusieurs processus de production : processus d'interprétation, de valorisation, de normalisation.

Mais les travaux de Muriel Frisch dépassent le cadre de la seule didactique de l'information-documentation. Ils relèvent aussi des sciences de l'éducation et de la formation et des métiers de l'humain, revendiquant le triple héritage d'une épistémologie constructiviste (Astolfi, Legroux, Monteil), d'une optique multi-référentielle inspirée par Jacques Ardoino et de la didactique des sciences (Gérard Vergnaud, Lev Vigotsky, Michel Develay, Jean-Pierre Astolfi).

Les lignes directrices de ses recherches portent sur les émergences, les cheminements et les constructions de savoirs et de didactiques pour les métiers de l'humain, en intelligence collective. Petit à petit, un réel travail de problématisation a permis d'établir une définition propre de cette nouvelle didactique qui se qualifie comme l'étude des conditions des transmissions, des médiations, des appropriations et des constructions des enseignements et des apprentissages. L'approche méthodologique est double : parallèlement à la transposition classique (modèle top-down) est menée une contre-transposition (modèle bottom-up), qui peut prendre par exemple la forme d'analyses de blogs ou de discours.

Parmi les sujets supports des recherches, on peut citer des questions vives comme le lien à établir entre l'école et la société pour essayer de faire culture commune.

À titre d'exemple relevant des métiers de l'humain, Muriel Frisch présente l'étude des complexités du métier de clown en établissement de soin.

Ce sujet est révélateur du caractère interdisciplinaire de la démarche puisque le projet convoque à la fois les arts du spectacle, la sociologie, la psychologie, la philosophie, les sciences de l'éducation et de la formation. Il montre aussi comment il permet d'articuler différentes postures : celle du praticien (le clown) et celle du chercheur.

Un espace numérique d'intelligence collective : la plateforme IDEKI (conçue en 2009)

Ouvert aux professionnels, aux scientifiques, aux usagers comme aux praticiens ou encore aux étudiants issus de domaines variés, l'espace numérique IDEKI est un espace d'intelligence collective, de dialogue des savoirs, de partage de connaissances et d'évolution des pratiques professionnelles.

Le choix des lettres qui constituent l'acronyme illustre les objectifs visés par cet espace numérique :
I= information ;

D = didactiques, documentations ;
E = enseignement ;
K= knowledge ;
I= ingénierie/ innovation.

Les chercheurs qui œuvrent au sein d'IDEKI créent une dynamique de travail collectif fondé sur une démarche de recherche-action-formation, en lien avec les acteurs des métiers de l'humain (éducation, formation, médiation, soin, etc.). Ils organisent des manifestations bisannuelles favorisant l'émergence d'idées dans le but de construire de nouveaux savoirs dans les domaines des didactiques et des métiers de l'humain, en intelligence collective.

Cette démarche collective se situe dans le processus de travail original qui correspond à la ligne éditoriale dirigée par Muriel Frisch, cheminements et constructions de savoirs, aux éditions L'Harmattan. Elle a par exemple permis l'émergence et la formalisation de concepts comme ceux de *reliance*, à relier à celui d'interdépendance, ou d'*efficacité réflexive*, déclinée selon douze critères destinés à estimer l'efficacité en matière d'éducation.

En conclusion de sa conférence, Muriel Frisch rappelle que, dans la construction de la professionnalité et dans le développement professionnel, il ne faut jamais renoncer aux savoirs, au rapport aux savoirs et aux processus de conceptualisation.

Parallèlement à la conceptualisation de ces savoirs, la réussite de la construction de la professionnalité se fonde aujourd'hui sur un travail en réseaux pluri-catégoriels et le déploiement d'une stratégie partenariale.

L'enregistrement intégral de présentation de la conférencière, de sa conférence, et des riches échanges qui ont suivi, est disponible sur le site de l'AEIS dans la rubrique des comptes-rendus des conférences mensuelles.

REMERCIEMENTS

Nous tenons à remercier vivement M. Yann TRAN et Mme Annabelle POIRIER de l'Institut Curie pour la qualité de leur accueil.

Conférence du 11 Septembre :

« Contribution relative du métavers et de la réalité virtuelle en formation médico-chirurgicale de haut niveau »

Par le Professeur Nguyen TRAN :

Professeur, Section 66, Physiologie,
Faculté de Médecine, Université de Lorraine

Titre et résumé

- Version française :

Titre : Contribution relative du métavers et de la réalité virtuelle en formation médico-chirurgicale de haut niveau

Résumé : Dans cette intervention, nous examinerons la contribution significative du métavers et de la réalité virtuelle à la formation de haut niveau des professionnels de santé. Le métavers, cet ensemble d'espaces virtuels interconnectés et habités en temps réel par des entités numériques, est une avancée technologique remarquable. Couplé à la réalité virtuelle immersive, il révolutionne la formation médicale et chirurgicale, offrant des possibilités sans précédent. Les professionnels de santé peuvent maintenant s'entraîner à réaliser des procédures complexes dans un environnement sûr et contrôlé, loin du stress et des risques de l'environnement clinique réel. Avec des feedbacks instantanés sur leurs actions, ils ont la possibilité de répéter les procédures jusqu'à leur maîtrise parfaite. Ces simulations améliorées contribuent à l'apprentissage par la pratique et à l'acquisition d'une expertise précise et efficace. De plus, le métavers transcende les limites géographiques, facilitant la collaboration à distance entre professionnels de santé, offrant la possibilité de consultations d'expertise et de formation continue sans contraintes de distance. Ces technologies sont ainsi devenues des outils essentiels dans la transformation de la formation de haut niveau en santé, remodelant notre approche de l'éducation médicale et la rendant plus accessible, flexible et efficace.

- English version:

Title: Relative Contribution of the Metaverse and Virtual Reality to High-Level Medical-Surgical Training

Abtract: In this intervention, we will delve into the significant contribution of the metaverse and virtual reality to the high-level training of health professionals. The metaverse, an interconnected collection of virtual spaces inhabited in real-time by digital entities, is a remarkable technological advancement. Combined with immersive virtual reality, it is revolutionizing medical and surgical training, offering unprecedented opportunities. Health professionals can now practice performing complex procedures in a safe and controlled environment, away from the stress and risks of the real clinical environment. With instant feedback on their actions, they have the ability to repeat procedures until they are perfectly mastered. These enhanced simulations contribute to hands-on learning and the acquisition of precise, efficient expertise. Furthermore, the metaverse transcends geographical boundaries, facilitating remote collaboration between health professionals, offering the possibility of expert consultations and continuing education without distance constraints. These technologies have thus become essential tools in the transformation of high-level health training, reshaping our approach to medical education, and making it more accessible, flexible, and effective.

Candidature du Professeur Wolfgang ELSÄSSER à l'AEIS

Dans un courriel du 19 Juillet dernier, le Pr. ELSÄSSER a manifesté le souhait de devenir membre de notre société savante.

Le Pr. Wolfgang ELSÄSSER enseigne à l'université de Darmstadt ; il est aussi Professeur adjoint au Trinity College de Dublin, et membre de l'Institut d'électronique et d'ingénierie de l'information et des télécommunications de Turin.

La candidature du Pr. ELSÄSSER, appuyée sur son CV et une lettre de motivation, sera examinée par les membres de l'AEIS lors de la séance du 11 Septembre prochain. CV et lettre de motivation seront présentés en séance.

Annexe 1 : publication récente de notre collègue Jacques FLEURET

Notre collègue Jacques Fleuret a émis le souhait que son article *"Expansion Force as a Bohmian Quantum effect on elementary particles"* soit diffusé aux membres de l'AEIS. L'auteur propose une courte introduction ci-dessous, et le corps de l'article suit.

"*Expansion Force as a Bohmian Quantum effect on elementary particles*", Jacques Fleuret, HADRONIC JOURNAL 46, 135 - 142 (2023)

Une nouvelle *force d'expansion* a été précédemment introduite afin d'expliquer les mouvements des étoiles dans les galaxies sans faire appel à la "matière sombre".

Dans un récent article, cette force est apparue comme une conséquence de la Mécanique Quantique Bohmienne appliquée à la cosmologie (la MQB considère qu'à tout élément matériel - déterministe - est associée une onde pilote, régie par l'équation de Schrödinger).

Ce nouvel article examine la question au niveau de l'interaction de deux particules élémentaires soumises à une force quelconque variant en carré inverse de leur distance (gravité, électromagnétisme). Il y est démontré que la force d'expansion est encore une conséquence de la Mécanique Quantique Bohmienne appliquée à cette micro-échelle. Ce résultat confère à cette force une validation plus fondamentale et plus étendue, ainsi qu'un nouveau champ d'expérimentations probatoires.

Lien vers l'article : https://www.fleuretjacques.com/travaux-scientifiques

Article in extenso à partir de la page suivante.

HADRONIC JOURNAL 46, 135 - 142 (2023)

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EXPANSION FORCE AS A BOHMIAN QUANTUM EFFECT ON ELEMENTARY PARTICLES

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ABSTRACT

The new expansion force, which has been proposed to explain flat rotation curves without Dark Matter, is shown to be a consequence of Bohmian Quantum Mechanics applied to elementary particles in an inverse-square interaction.

This gives a new fundamental validation of this expansion force and opens the way to a new field of experimental verifications.

KEYWORDS

Expansion force, gravity, Bohmian Quantum Mechanics, inverse-square interaction

1. Introduction

Ten years ago, I proposed a new expansion dynamics paradigm [1], introducing a "cosmic expansion acceleration" to explain the galactic flat rotations curves [2] with unchanged Newton's gravity and without Dark Matter. This acceleration has been proposed to be proportional to the velocity vector $\vec{v}$ according to :

$$\vec{\gamma} = \frac{\dot{r}}{r}\vec{v} \tag{1}$$

Where the coefficient $\frac{\dot{r}}{r}$ is the local expansion rate.

This paradigm has been applied to different phenomena, such as the question of planar structures of satellite galaxies [3] and to large scale cosmic evolutions [4, 5].

Considering a nonhomogeneous radially symmetrical universe, I have shown that this new acceleration can be deduced from the solution of Einstein's equation, thus being validated in General Relativity [4]. According to this point of view, gravity appears to be a dual process, including the unchanged (inward) Newton's acceleration plus the outward expansion acceleration (which is very small in common experience). Negative masses are needed for this cosmologic model and the positive and negative mass repartitions have been computed [5].

Meanwhile, the same idea has been reintroduced by a Chinese team [6] with a lagrangian approach (applied to the radial acceleration only, and with a different coefficient in eq. (1)).

Incidentally, when this paradigm is restricted to the radial part only, it can be compared to the MOND approach [7], where the radial acceleration of a circular trajectory is supposed to be modified, through a threshold procedure. The new expansion acceleration has often been wrongly assimilated to MOND, in spite of the two important differences:

- The proposed expansion acceleration (1) is simply added to Newtons's one, which is not modified.
- It has also a lateral part: $\gamma_l = \frac{\dot{r}}{r} r\dot{\theta} = \dot{r}\dot{\theta}$ (2)

In fact, this lateral part is absolutely needed in our paradigm, so as to modify the *lateral* velocity of the flat rotation curves [1]. But (unlike MOND), it was not absolutely necessary to add a radial acceleration. It was assumed by induction, to have the same form as the lateral one:

$$\gamma_r = \frac{\dot{r}}{r}\dot{r} = \frac{\dot{r}^2}{r} \tag{3}$$

leading to the vectorial formulation (1).

Up to this point, this new paradigm has not found deep justifications.

In 2015, I proposed that it could be generated by a mass erosion process [8].

More recently, such a vectorial additional acceleration has also been proposed by Maeder [9], based on quite different arguments (scale invariance of the macroscopic empty space).
Meanwhile, I searched for theoretical justifications in Bohmian Quantum Mechanics [10, 11], studying a far-away galaxy as a "particle" submitted to the pilot wave of the total mass of the universe [12]. This approach results in an infinitely expanding and contracting universe (no Big Bang) and allows to deduce the observed variations of the Hubble Constant and acceleration coefficient.
The present contribution is focused on the same Bohmian Quantum Mechanics approach, but at the probably more fundamental level of elementary particle interactions.

2. Bohmian Quantum interaction of two elementary particles

Let-us consider a couple of two identical microscopic particles submitted to a central inverse-square interaction (which could be gravitational or electromagnetic). In a first step, we restrict their movement to a 1D. non-rotating straight line space. Each particle (supposed to have the same mass m) can be considered, in the mass center system, to be submitted to a potential energy, noted as:

$$V = -m\frac{A}{r} \tag{4}$$

where r represents the distance between the two particles and A is a constant (positive for gravity, but a-priori, it could also be negative).

Each particle has a mass m and, due to the reduced mass $\frac{m}{2}$, their acceleration in the central mass system is equal to $-\frac{2A}{r^2}$.

The pilot wave associated to each particle is supposed to be Gaussian. In order to satisfy Schrödinger's equation and normalization, it must be written, in amplitude R and phase $\frac{S}{\hbar}$ as [13]:

$$\psi(r,t) = R(t)e^{i\frac{S(r,t)}{\hbar}} \qquad \text{with} \qquad \frac{S}{\hbar} = \frac{r^2}{4Д^2\left(1+\frac{t^2}{\tau^2}\right)\tau} - \frac{Vt}{\hbar} \tag{5}$$

where $Д$ is the width of the initial wave packet and τ represents the time scale parameter:

$$\tau = \frac{2mД^2}{\hbar} \tag{6}$$

According to the pilot wave theory [10, 11], the particle velocity is obtained by:

$$m\frac{dr}{dt} = \frac{\partial S}{\partial r} = \left(\frac{\hbar r}{2Д^2\left(1+\frac{t^2}{\tau^2}\right)\tau} - \frac{\partial V}{\partial r}\right)t \tag{7}$$

For an elementary particle, such as an electron, the time-scale τ is extremely small (equal to 10^{-26}s. for $Д \sim 10^{-15}$m.). At this point, our problem differs from the cosmic evolution of a galaxy, where τ was extremely high [12].

Now, from (6) and $t \gg \tau$, eq. (7) can be approximated by:

$$m\frac{dr}{dt} = m\frac{r}{t} - m\frac{At}{r^2} \tag{8}$$

This equation can be solved (thru the variable change $u = \frac{r}{t}$), resulting in:

$$r^3 = 3At^2 + Ct^3 \tag{9}$$

where C is a constant of integration.

For $A > 0$ (attractive potential, gravity) a positive value of C is needed for large time. The relative weight of the two right-side terms in eq. (9) depend on the value of:

$$t_0 = \frac{3A}{C} \tag{10}$$

which is very small for common velocities ($A = mG \sim 10^{-40}$ for an electron). In this case, a quasi-linear movement is rapidly obtained.

For zero energy particles, the velocity at infinity tends to zero. This implies $C = 0$, and eq. (9) becomes:

$$r^3 = 3At^2 \tag{11}$$

[For this equation, free fall is represented by t going from $-\infty$ to 0.]

Successive derivation allows to compute $\dot{r}$ and $\ddot{r}$:

$$r^2\dot{r} = 2At \tag{12}$$

Noting that, from (11) and (12):

$$\frac{\dot{r}^2}{r} = \frac{4}{3}\frac{A}{r^2} \tag{13}$$

the acceleration can be finally written as:

$$\ddot{r} = -\frac{2A}{r^2} + \frac{\dot{r}^2}{r} \tag{14}$$

The first term on the right is the classical inverse-scare acceleration. The second term represents the additional expansion acceleration:

$$\gamma_r = \frac{\dot{r}^2}{r} = \frac{\dot{r}}{r}\dot{r} \tag{15}$$

This radial acceleration is clearly a consequence of Bohmian Quantum dynamics applied to the particles and their pilot waves.

3. Where the lateral part comes from

Let-us now suppose that the preceding straight line is turning around a perpendicular central axis, generating a planar trajectory. We choose the particular angular velocity:

$$\Omega = \frac{v_0}{r} \tag{16}$$

Where $v_0 = r\dot{\theta}$ has been chosen to be a constant lateral velocity in order to represent the flat rotation curve observations.

Due to the acceleration transformation law between the initial line space and the rotating line, the two following lateral terms (usually called tangential and Coriolis terms) must be added to the acceleration:

$$\overrightarrow{\gamma_l} = \frac{\partial \vec{\Omega}}{\partial t} \wedge \vec{r} + 2\vec{\Omega} \wedge \frac{\partial \vec{r}}{\partial t} \tag{17}$$

In the case of the rotation velocity (16), it is easy to show that:

$$\gamma_{l} = \frac{\dot{r}}{r} v_0 \tag{18}$$

(the - non mentioned here - centrifugal term $\frac{{v_0}^2}{r}$ does also appear as usual).

Eq. (18) is nothing else than the lateral additional expansion acceleration to be added in order to guarantee the flat rotation curve.

This result confirms our initial choice of an expansion acceleration proportional to the vectorial velocity and local expansion rate, as it is clear for the lateral part (eq. (18)) and for the additional radial part (eq.15).

Finally, the lateral part (which explains flat rotation curves) simply results from the rotation dynamics, whenever the radial part is a consequence of Bohmian Quantum Mechanics applied to the considered particles.

4. Comments on Universe expansion and possible experimental verifications

Of course, this very simple 2 particle interaction model cannot predict by itself what happens for the expansion of the Universe. However, for instance, it can be envisioned that – in the case of a homogeneous infinite Universe – the Newton's contribution tends to be strongly reduced, due to symmetric cancellations. In this case, eq. (14) should be reduced to its expansion term, leading to a quasi-exponential expansion.

More complex configurations would produce various expansion dynamics, depending on the mass repartition in the Universe.
Going back to our simple 2 particle model with a far-away zero velocity, the expansion rate can be easily computed from (12):

$$\frac{\dot{r}}{r} = \frac{2}{3t} \tag{19}$$

It is notable that this does not depend on A: the expansion force produces a natural repulsive tendency for particles, even when they are attractive. And, according to eq. (13), the closer are the two particles, the more important is the repulsive expansion force.
Another interesting result is that, from (11), the second derivative can also be written as:

$$\ddot{r} = -\frac{2A}{3r^2} \tag{20}$$

So, when compared to pure Newton's gravity, the "Bohmian free-fall" of a zero energy particle just happens as if A was divided by 3. Practically, it can be seen from (12) that, at a given place in the fall (*t* and *r* given), the local velocity should be divided by 3 for the Bohmian free fall, due to the opposite effect of the expansion force. This can be a possible benchmark for future experimental verifications.
More generally, eq. (9) is the one to be verified. The possibility of a non-zero constant velocity v_∞ at infinite time leads to $C = {v_\infty}^3$. In this case, due to the third degree of the curve (9), a bounce effect should be observed (where $\dot{r} = 0$) at time $t_B = -\frac{2A}{C}$ and radius:

$$r_B = \sqrt[3]{4}\frac{A}{{v_\infty}^2} \tag{21}$$

In the far-away zone, simple developments lead tot

$$\dot{r} - v_\infty \simeq \frac{A^2}{{v_\infty}^3 r^2} \tag{22}$$

to be compared with the equivalent development for a purely Newtonian interaction:

$$\dot{r} - v_\infty \simeq \frac{A}{v_\infty r} \tag{23}$$

Due to the r^{-2} variation in (22), the fall's acceleration is of course reduced in case of a (repulsive) expansion, and this reduction is more important for large velocities.
Furthermore, for the second derivative (deduced from (22), a r^{-3}variation is obtained for large r:

$$\ddot{r} = -2\frac{A^2}{{v_\infty}^2 r^3} \tag{24}$$

Which can be another benchmark for future experimental verifications.

Let-us recall that our paradigm concerns not only gravity but also any inverse-square force, since A can be negative. Comparable observations can be made in this case (no rebound effect happens in this case, due to the negative value of (21).

5. Conclusion

Our present results confirm the proposal of a "fifth force" as a consequence of Bohmian Quantum Mechanics, since it has been found to be there at the cosmic level of galaxy expansions [12] and here, at the more fundamental level of elementary particles. As it was originally stated [1, 8], it is a general dynamics principle, assumed to be valid not only for the problem of flat rotation curves. Incidentally, it seems to be there for any central inverse-square - attractive or repulsive – force: gravity and electromagnetism.

The MOND radial modification is equivalent to an additional attractive acceleration, which can be thought of as due to an added positive (dark) matter. According to this point of view, dark matter is nothing else than a mathematical equivalence of a ad-hoc radial gravity modification.

In our paradigm, the added radial (expansion) acceleration is equivalent to additional negative matter. Since anti-matter does exist, it seems that it could be more promising to seek negative matter [12, 14] rather than dark matter, even though its repartition in the universe is not well understood. Up to now, the negative mass repartitions corresponding to the expansion force has been computed for the simple case of nonhomogeneous symmetrical universes [5, 12]. These simulations suggest that positive masses do predominate in our surroundings, while there should be an excess of negative masses in far-away regions [12, 14]. This could be in conformity with the present observations of large-scale regions.

Furthermore, this mass repartition can be related to the spatial evolution curve of the Hubble Constant [12], which gives another benchmark for future verifications related to the present data from the Hubble constant measurements.

These preliminary results will have to be confronted to observations and/or simulations in order to be accepted or not as a support for reality. Our present contribution increases the field of experiences and simulations to be done to the domain of elementary particles.

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Annexe 2 : deux articles connexes à la conférence du Pr. Nguyen TRAN

Afin de vous familiariser avec le thème de la conférence du Pr. Nguyen TRAN, nous vous proposons ci-après deux articles qu'il nous a conseillés :

"Educational applications of metaverse: possibilities and limitations", Bokyung Kye, Nara Han, Eunji Kim, Yeonjeong Park, Soyoung Jo, Journal of Educational Evaluation for Health Professions 2021;18:32, https://doi.org/10.3352/jeehp.2021.18.32.

"Virtual Reality for Health Professions Education: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration", Kyaw et al, JOURNAL OF MEDICAL INTERNET RESEARCH.

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Educational applications of metaverse: possibilities and limitations

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This review aims to define the 4 types of the metaverse and to explain the potential and limitations of its educational applications. The metaverse roadmap categorizes the metaverse into 4 types: augmented reality, lifelogging, mirror world, and virtual reality. An example of the application of augmented reality in medical education would be an augmented reality T-shirt that allows students to examine the inside of the human body as an anatomy lab. Furthermore, a research team in a hospital in Seoul developed a spinal surgery platform that applied augmented reality technology. The potential of the metaverse as a new educational environment is suggested to be as follows: a space for new social communication; a higher degree of freedom to create and share; and the provision of new experiences and high immersion through virtualization. Some of its limitations may be weaker social connections and the possibility of privacy impingement; the commission of various crimes due to the virtual space and anonymity of the metaverse; and maladaptation to the real world for students whose identity has not been established. The metaverse is predicted to change our daily life and economy beyond the realm of games and entertainment. The metaverse has infinite potential as a new social communication space. The following future tasks are suggested for the educational use of the metaverse: first, teachers should carefully analyze how students understand the metaverse; second, teachers should design classes for students to solve problems or perform projects cooperatively and creatively; third, educational metaverse platforms should be developed that prevent misuse of student data.

Keywords: Augmented reality; Communication; Educational personnel; Medical education; Virtual reality

Introduction

Background

The metaverse concept first appeared in 1992 in the science fiction novel Snow crash by American novelist Neal Stephenson. The characters in *Snow crash* become avatars and work in a 3-dimensional (3D) virtual reality, and this 3D virtual reality is called the metaverse. The metaverse refers to a virtual reality existing beyond reality. It is a compound word of "meta", meaning transcendence and virtuality, and "universe", meaning world and universe. This term refers to the digitized earth as a new world expressed through digital media such as smartphones and the internet [1]. After the concept of the metaverse appeared, extensive efforts and research were carried out to make the metaverse a re-

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ality. The Acceleration Studies Foundation (ASF), a representative metaverse research organization, announced the metaverse roadmap in 2006. It presented the concept of the metaverse and the 4 types of the metaverse and proposed thinking about the metaverse as a connection point or combination of the real world and virtual reality.

Go et al. [2] defined the metaverse as "a 3D-based virtual reality in which daily activities and economic life are conducted through avatars representing the real themselves." Here, daily activities and economic life are extensions of reality, and it is seen that the real world is combined with the virtual space, and reality is expanded into the virtual space. In other words, the avatar in the metaverse is identified with one's real self. The avatar engages in social, economic, and cultural activities in the metaverse world. In addition, Lee [3] stated that "metaverse means a world in which virtual and reality interact and co-evolve, and social, economic, and cultural activities are carried out in it to create value." This is not a simple combination of the world and virtual reality, but an interaction; furthermore, the metaverse can denote a world in which daily life and economic activities are conducted in a unified way.

As the metaverse began to be introduced into present life rapidly, some metaverse applications have already been used in education. Therefore, it is necessary to understand the concept and types of the metaverse and examples of its educational applications.

Objectives

This review aims to define the 4 types of the metaverse and explain the potential and limitation of the educational applications of the metaverse. Specifically, the characteristics of the 4 types of metaverse are described with examples. The merits of applications of the metaverse in the educational field are presented. Furthermore, the limitation and disadvantages of the use of the metaverse are discussed. Thus, this review will be able to provide basic insights into the concept of the metaverse for applying it in education.

Four types of the metaverse

In the ASF's metaverse roadmap, 2 axes were presented to explain the types of the metaverse [4]. One is 'augmentation versus simulation', and the other is 'intimate versus external' (Fig. 1). Augmentation technology refers to a technology that adds a new function to an existing real system. In the metaverse, augmentation technology superimposes further information on the physical environment that we perceive. Simulation technology, which contrasts with augmented technology, refers to technology that provides a unique environment by modeling reality. Simulation in the metaverse includes various techniques for realizing the simulated world as a place for interaction. In short, augmented technology and simulation can be divided according to whether the information will be implemented in physical reality or virtual reality.

Meanwhile, the metaverse is divided into an inner world and an external world. The inner world focuses on the identity and behavior of an individual or object. Technology is used to achieve completion of the inner world in the metaverse. Individuals or

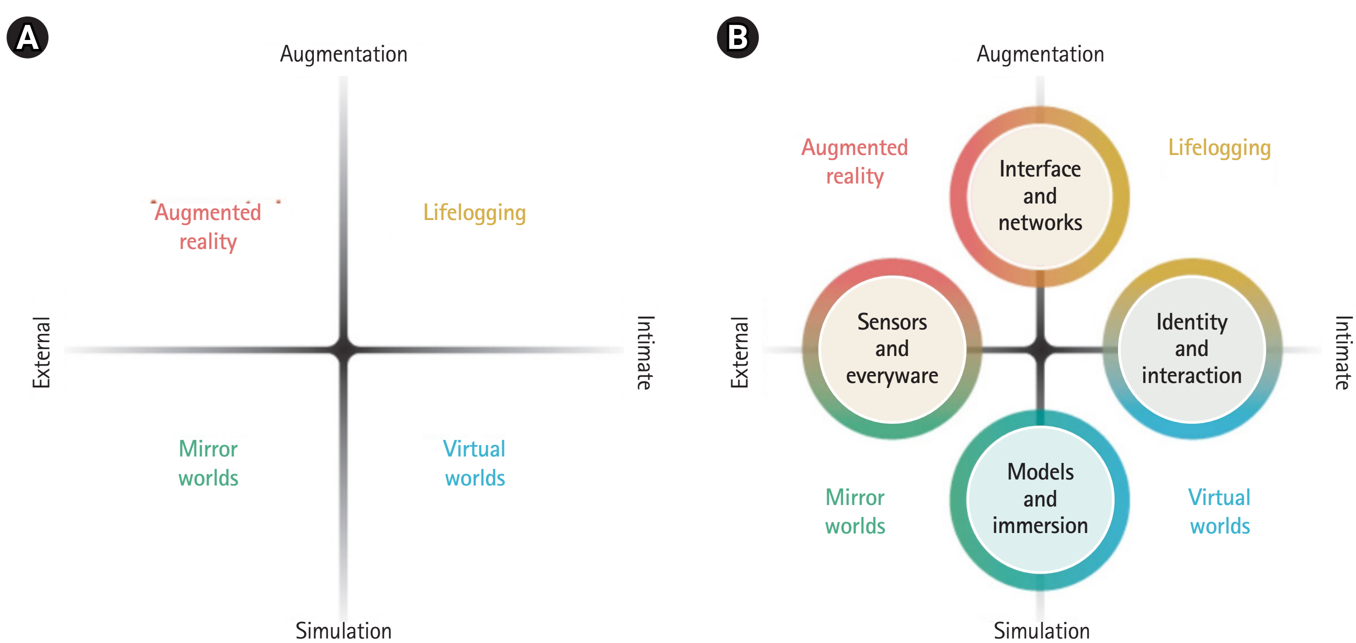

Fig. 1. (A, B) Diagram of 4 types of the metaverse [4].

things act using an avatar or digital profiles or act directly in the system, whereby the user has agency in that environment. In contrast, the external world usually focuses on aspects of external reality centered on the user, the subject of the metaverse. Therefore, it includes technology related to displaying information about the user's surrounding world and how to control it. These internal and external frameworks become another axis for dividing applications based on whether metaverse technology is focused on the user's inner world or the surrounding world.

The metaverse roadmap categorizes the metaverse into 4 types: augmented reality, lifelogging, mirror world, and virtual reality based on these 2 axes. Table 1 summarizes the definitions, characteristics, application fields, and use cases of each type.

Augmented reality

Augmented reality is a type of augmentation of the external world. It refers to a form of technology that expands the real physical world outside an individual by using a location-aware system and interface with added and layered networked information on spaces we encounter daily [4]. The interfaces that augment the world are divided into Global Positioning System (GPS)-based, marker-based, and see-through-based [5,6]. By utilizing the built-in GPS and Wi-Fi in a mobile device, augmented reality provides linkage information suitable for the user's location information or recognizes a marker in a QR (quick response) code to augment already extant information. In addition, the real world and virtual graphics can be mixed and viewed in real-time through glasses or lenses. Augmented reality has been evaluated to be effective in learning material that is difficult to observe directly or explain in text, fields that require continuous practice and experience, and fields with high costs and high risk [5]. For example, Cruscope's Virtuali-Tee is an augmented reality T-shirt that allows students to examine the inside of the human body as if it were an anatomy lab [7] (Fig. 2). Augmented reality simulation content as a representative educational case is related to augmented reality. Simulation plays a role in linking abstract visuals to concrete objects by connecting the context of the real world and virtual objects. In the medical field, various examples of augmented reality technology

Table 1. Four types of the metaverse

	Augmented reality	Lifelogging	Mirror world	Virtual reality
Definition	Building a smart environment by utilizing location-based technologies and networks.	Technology to capture, store, and share everyday experiences and information about objects and people.	It reflects the real world as it is, but integrates and provides external environment information.	A virtual world built with digital data
Features	Building a smart environment using location-based technology and networks	Recording information about objects and people using augmented technology	Virtual maps and modeling using GPS technology	Based on interaction activities between avatars that reflect the user's ego
Applications	Smartphones, vehicle HUDs	Wearable devices, black boxes	Map-based services	Online multiplayer games
Use cases	Pokemon Go, Digital Textbook, Realistic Content	Facebook, Instagram, Apple Watch, Samsung Health, Nike Plus	Google Earth, Google Maps, Naver Maps, Airbnb	Second Life, Minecraft, Roblox, Zepeto

From Lee S. Log in Metaverse: revolution of human×space×time (IS-115) [Internet]. Seongnam: Software Policy & Research Institute; 2021 [cited 2021 Nov 29]. Available from: https://spri.kr/posts/view/23165?code=issue_reports [3]; Smart J, Cascio J, Paffendorf J. Metaverse roadmap: pathway to the 3D web [Internet]. Ann Arbor (MI): Acceleration Studies Foundation; 2007 [cited 2021 Nov 29]. Available from: https://metaverseroadmap.org/MetaverseRoadmapOverview.pdf [4].

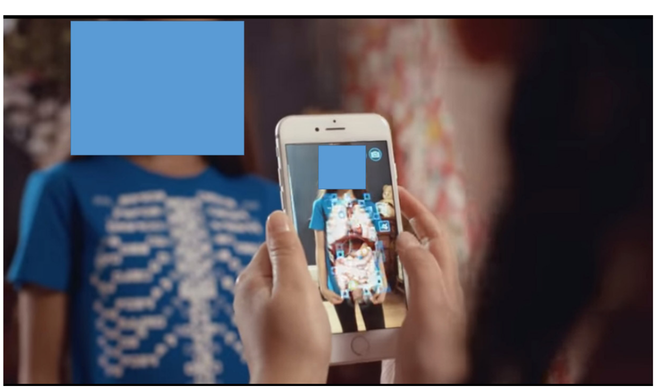

Fig. 2. Virtuali-Tee: augmented reality T-Shirt [7].

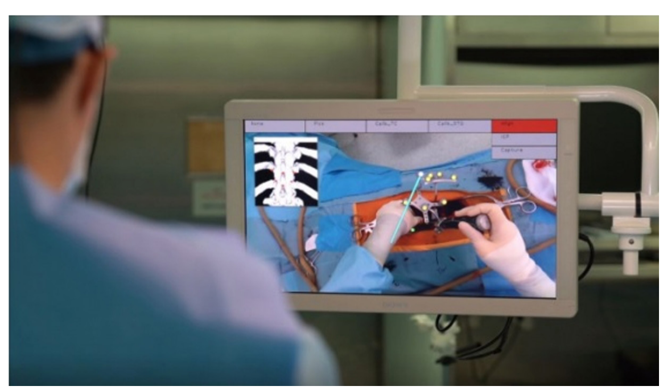

Fig. 3. Augmented reality-based spine surgery platform [8].

are emerging. Recently, a research team in a hospital in Seoul developed a spinal surgery platform that applied augmented reality technology in collaboration with university laboratories. This platform uses a real-time projection of a pedicle screw used for spinal fixation on a human body structure as an overlay graphic based on augmented reality [8]. In addition, based on this technology, a spinal surgery education program will be developed to implement an effective education system that can be applied to actual surgery (Fig. 3).

Lifelogging

Lifelogging is a type of augmentation of the inner world. In the world of lifelogging, people use smart devices to record their daily lives on the internet or smartphones. Typical examples of lifelogging include Twitter, Facebook, and Instagram. Recently, there have been services that utilize biometric information stored through wearable devices in the medical field. Some devices link sensors such as Nike Plus to record the amount of exercise or location. This is also a kind of lifelogging. As a representative example, the Classting artificial intelligence (AI) system in Korea is an online class community application called an educational social networking service (SNS). In particular, Classting AI analyzes students' learning achievements and provides customized learning by level in all subjects [9] (Fig. 4).

Mirror world

The mirror world is a type of simulation of the external world that refers to an informationally enhanced virtual model or "reflection" of the real world [4]. The mirror world is a metaverse where the appearance, information, and structure of the real world are transferred to virtual reality as if reflected in a mirror. However, the expression "efficient expansion" is more appropriate than describing these systems as reproducing the real world [1]. All activities in the real world can be done through the internet or mobile applications, and a mirror world metaverse is a place that makes life in the real world convenient and efficient. Examples of representative mirror worlds used in education include "digital laboratories" and "virtual educational spaces" created in various mirror worlds.

Digital labs

The mirror world metaverse was further activated by the coronavirus disease 2019 (COVID-19) pandemic. In other words, the biggest contributor to enabling the mirror world is the user. Users meet and play games with physically distant people in the mirror world and perform meaningful tasks. The Foldit platform provides an opportunity for all participants to contribute to scientific research through games. David Baker's team at the University of Washington, which studies protein structure, has used this digital lab to have people fold protein amino acid chains. Through this game, where the protrusion structure matches well, and the player gets points and ranks up if they succeed, the protein structure is found for an AIDS (acquired immunodeficiency syndrome) treatment, and the achievement of 60,000 participants in 10 days was described in a journal publication [10] (Fig. 5).

Virtual educational spaces

A representative example of the mirror world is video conferencing systems such as Zoom, Webex, Google Meet, and Teams. These video conferencing systems are playing the role of the class-

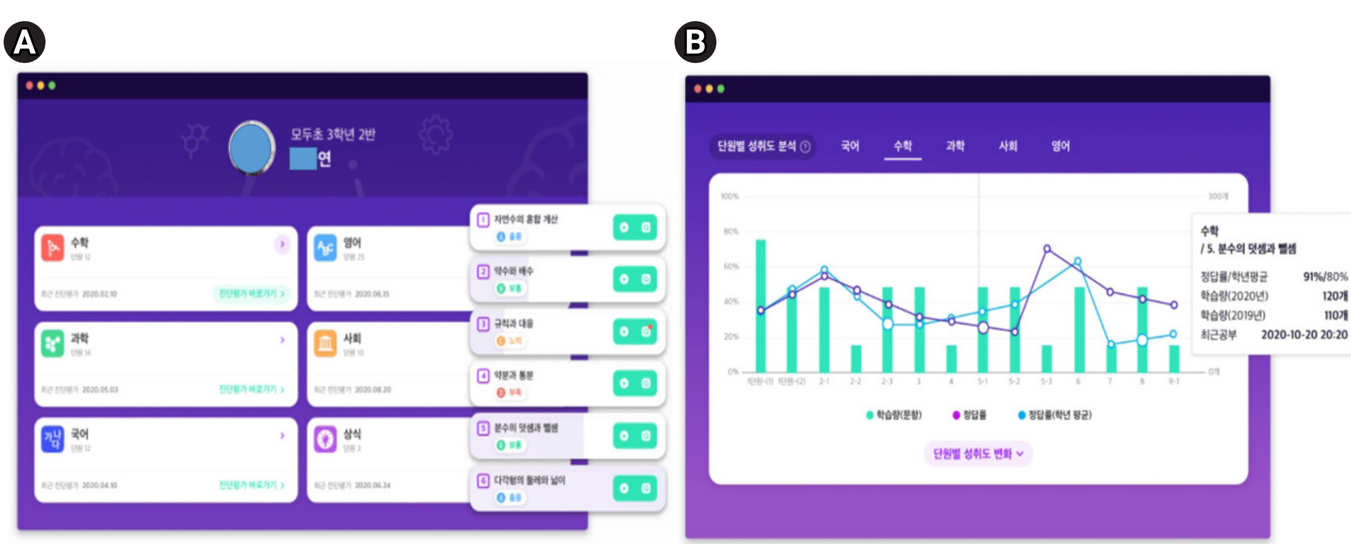

Fig. 4. (A, B) Artificial intelligence analysis screen for all subjects and distribution table of achievement changes by unit [9].

Fig. 5. (A, B) Foldit platform as a mirror world example [10].

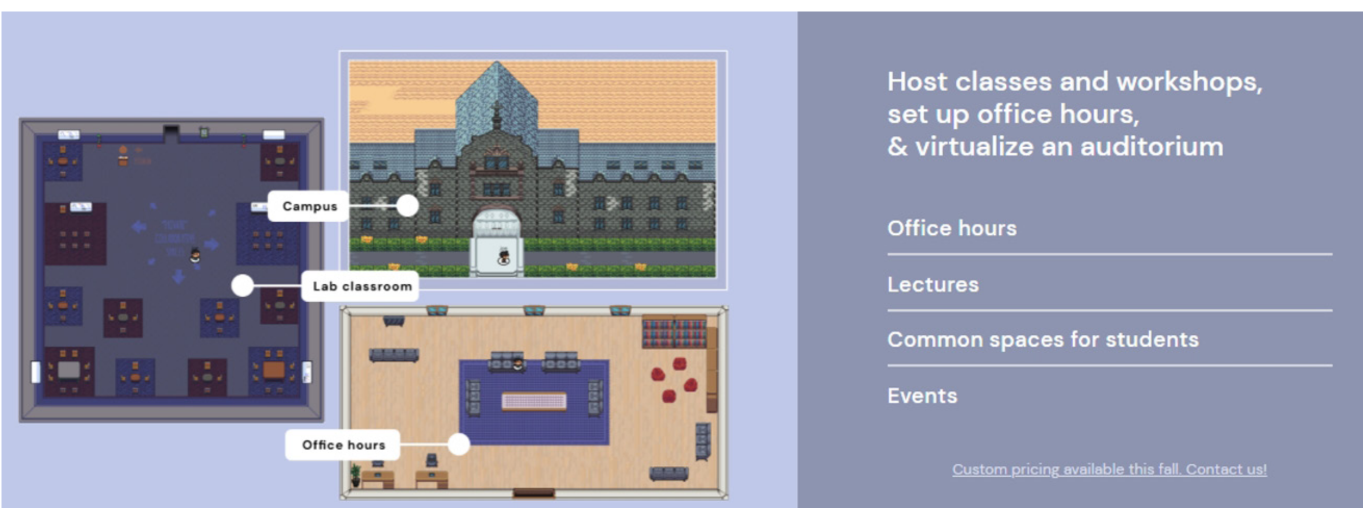

Fig. 6. Classroom in Gathertown [11].

room in the real-time operation of non-face-to-face remote classes in the post-COVID-19 era. Gathertown is an online video conferencing platform that supports conversation and business in a virtual space [11]. Its main functions include chatting, interworking with external links, and decorating spaces (Fig. 6). The mirror world metaverse has great educational potential as a way to efficiently expand the information and functions required for learning while showing the real world exactly as if reflected in a mirror [1].

Virtual reality

Virtual reality is a type of the metaverse that simulates the inner world. Virtual reality technology includes sophisticated 3D graphics, avatars, and instant communication tools. It is a world where users feel that they are entirely in a virtual reality. Virtual reality is often described as the other end of the spectrum containing mixed reality and augmented reality [12]. However, virtual reality makes us see a flat image in 3 dimensions based on the working principle of our eyes [6]. It is also characterized as an internet-based 3D space that multiple users can access simultaneously and participate by creating an avatar that expresses the user's self [13].

In this virtual reality metaverse, the space, cultural background, characters, and institutions are designed differently from in reality. The avatar that acts on behalf of the user explores a virtual space with AI characters, communicates with other players, and achieves the goal. Virtual reality is also called the metaverse in the narrow sense in that the real body moves, touches something, and daily and economic activities take place in the virtual space. Zepeto and Roblox are examples of virtual reality [14,15]. Zepeto is a 3D avatar-based interactive service that has recently appeared, and Roblox is a platform where anyone can create virtual reality and create games by themselves to enjoy with friends and engage in various creative experiences [16].

Zepeto is an augmented reality avatar service operated by Naver Z, and is a representative metaverse platform in Korea. Zepeto, launched in 2018, creates a "3D avatar" using facial recognition, augmented reality, and 3D technology to communicate with other users. It allows users to experience various virtual realities. When anyone takes a picture or loads an image saved in his or her smartphone, a character that resembles the user is created through

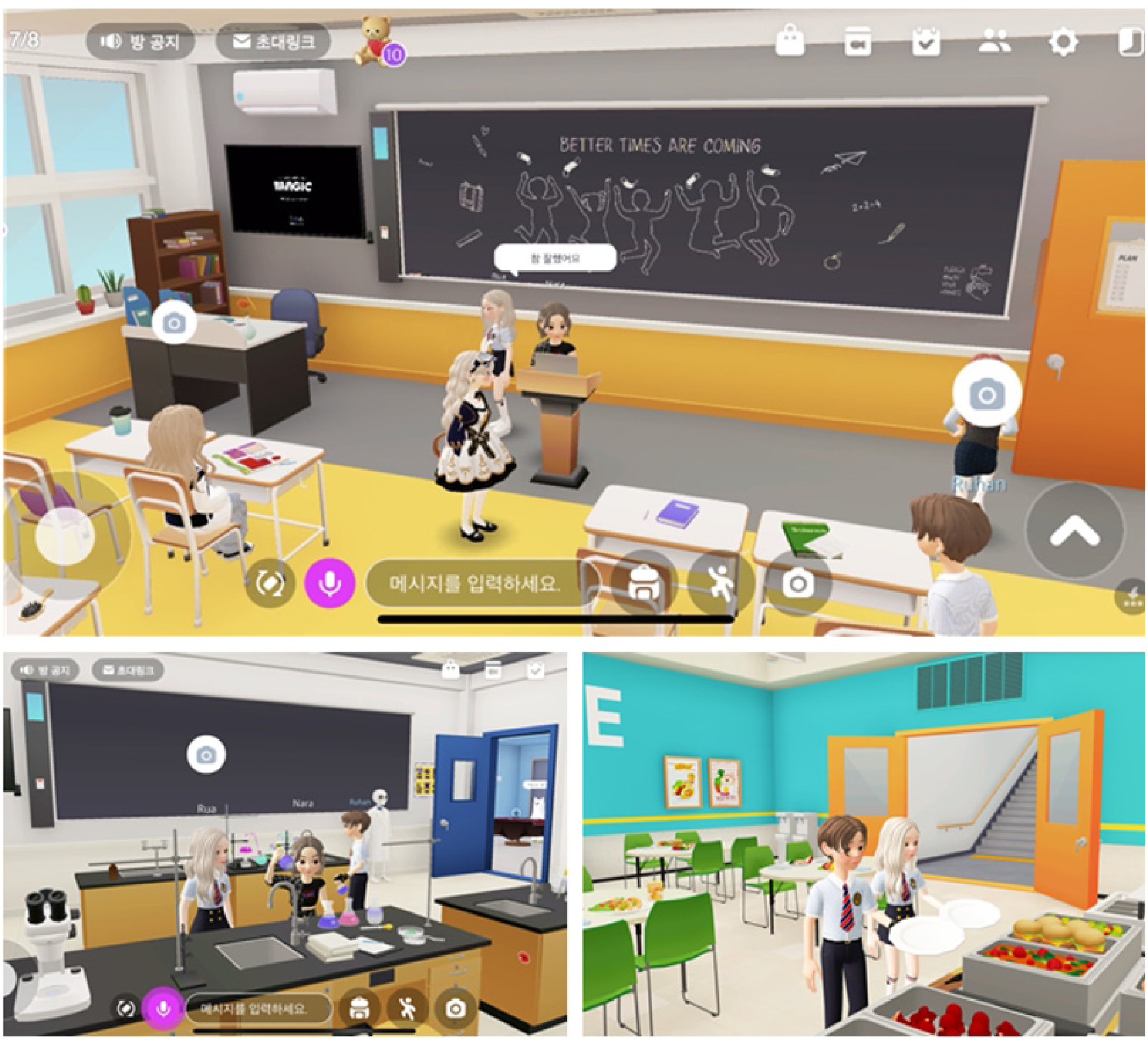

Fig. 7. Class 2 map in Zepeto. From Snow Corp. Zepeto [Internet]. Seongnam: Snow Corp.; c2021 [cited 2021 Nov 29]. Available from: https://zepeto.me/ [14].

AI technology. They can customize skin color, features, height, facial expression, gestures, and fashion style as they like. Since the SNS function is also incorporated, it is possible to follow other people and to exchange messages by text or voice [14]. Various activities such as games and educational role-plays can be performed through multiple maps. For example, a teacher can select a classroom map, open a room, invite students, and interact with each other by voice or message on the classroom map [14] (Fig. 7).

Roblox is a virtual reality platform launched in 2006, where one can create one's own space and enjoy games in real-time. Lee and Han [17] explain that Roblox is a "second real world" in which the virtual currency "Robux" is used, and the economic ecosystem is completed. It is characterized by users being able to make games on their own in virtual reality using the Lego-shaped

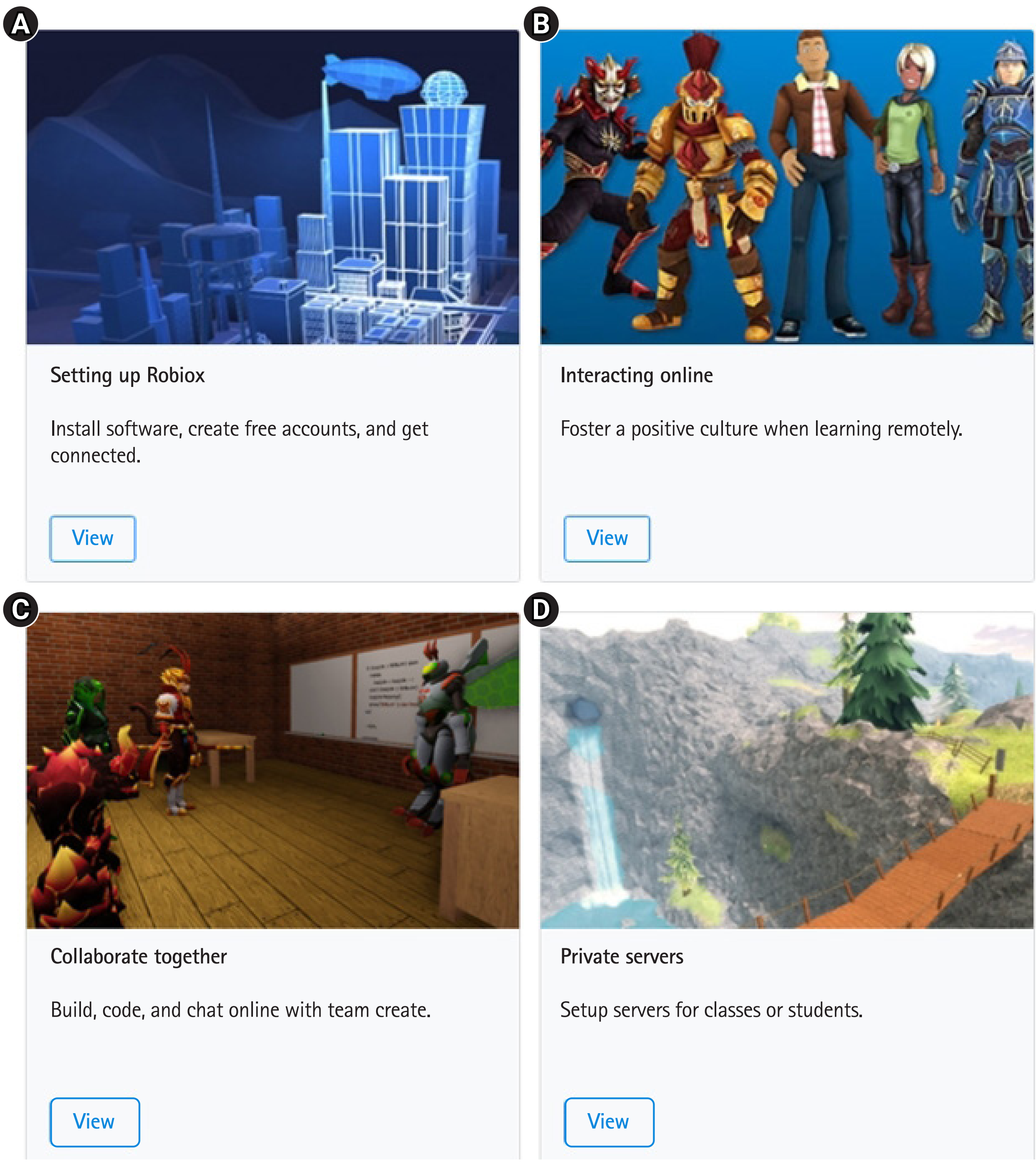

Fig. 8. (A-D) Roblox remote education tool (https://education.roblox.com/ko-kr/resources/roblox-remote). From Roblox Corp. Roblox [Internet]. San Mateo (CA): Roblox Corp.; c2021 [cited 2021 Nov 29]. Available from: https://www.roblox.com [15].

avatar or to enjoy games made by others [15] (Fig. 8).

Convergence and complexity of the metaverse

We have looked at the characteristics and examples of each of the 4 types of the metaverse. The metaverse can be organized as a space in which the real world is augmented by virtual reality. The real world is connected to virtual reality, the real world is replicated in virtual reality, or the virtual reality becomes another world. From a functional point of view, the metaverse integrates information retrieval, SNS, and game elements. From an evolu-

Table 2. Main technical characteristics of the metaverse and educational implications

Type	Technological characteristics	Educational implications
Augmented reality	- Overlay virtual objects in the real world to make the object 3D and real (e.g., paper birthday cards are augmented to appear as 3D video cards).	- Learn invisible parts visually and 3-dimensionally through virtual digital information, and effectively solve problems
	- Adding fantasy to the thread (e.g., Pokémon Go on the street, Zepeto, which recognizes faces and creates 3D avatar)	- In-depth understanding of content that is difficult to observe or explain in text, and learners can construct knowledge through experience
	- Effectively emphasizing information and promoting convenience (e.g., HUD presented on the car glass)	- Interactive experiences such as reading, writing, and speaking are possible while immersed in the learning context.
Lifelogging	- One's daily life and thoughts are productively contented and shared through social media and SNS (e.g., blogs, YouTube, Wikis, etc.).	- Review and reflect on one's daily life, improve the ability to represent and implement information in an appropriate direction, and feedback from others on social networks leads to reinforcement and rewards.
	- Network technology forms relationships with others online, communicates quickly, and records various social activities (Facebook, Band, Twitter, etc.).	- Critically explore various information on the lifelogging platform, and creatively reconstruct information through collective intelligence.
	- Personal activity information is accumulated and analyzed through various sensors of the internet of things and wearable devices to create added value (e.g., health tracking including Nike Plus).	- Reflect on learning and improve it based on analytics data related to learning (e.g., dashboard).
		- Teachers promote learning in a customized direction based on students' learning log data, provide appropriate support, and prevent dropouts.
Mirror world	- Expanding the real world by combining GPS and networking technology (e.g., Google Earth, various map applications, etc.)	- Overcoming the spatial and physical limitations of teaching and learning, learning takes place in the metaverse of the mirror world.
	- Implementation of the real world into the virtual world as if reflected in a mirror for a specific purpose (e.g., Airbnb, Minerva School, food ordering app, taxi call, bus route guidance, parking lot finder app, etc.)	- Conduct online real-time classes through online video conferencing tools and collaboration tools (Zoom, WebEx, Google Meet, Teams), which are representative mirror worlds.
	- However, it does not contain everything in reality. In other words, it effectively expands the real world to increase fun and play, flexibility in management and operation, and collective intelligence (e.g., Minecraft, Upland, Digital Lab, etc.).	- Through the mirror world, learners can realize "learning by making" (e.g., in Minecraft, students build and restore historical structures—Bulguksa, Gyeongbokgung, Cheomseongdae, Taj Mahal, Eiffel Tower, etc. Users can experience their digital heritage and deepen their understanding of history and culture.
Virtual reality	- Through sophisticated computer graphics work, especially in a virtual environment implemented with 3D technology, users enjoy various games through a seamlessly connected interface (e.g., various 3D games including Roblox).	- Practice can be performed through virtual simulation in environments that are difficult to produce due to high costs and high risk (e.g., fire scenes, flight control, dangerous surgery, etc.).
	- In a space, era, culture, and characters designed differently from reality, they act as avatars rather than their original self, and have multiple personas.	- Users can have immersive experiences of times and spaces that cannot be experienced in reality, such as the past or future era.
	- Chat and communication tools are included in virtual reality to communicate and collaborate with AI characters and others (e.g., multiplayer online games).	- Through 3D virtual world-based games (according to the characteristics and types of designed games), users improve strategic and comprehensive thinking skills, problem-solving skills, and learn skills necessary for the real world.

The technical features are summarized by referring to the content and examples of Kim [1].
3D, 3-dimensional; HUD, head-up display; SNS, social networking service; GPS, Global Positioning System; AI, artificial intelligence.

tionary point of view, the metaverse is a mixture of the internet with 5G and virtual convergence technology, reflecting a world that has been spread and developed in response to the COVID-19 pandemic. From a technical point of view, the metaverse is a complex of virtual reality technologies [2]. Socially, it is a space where members of the digital native generation leave traces in their daily life and economic life with their various appearances (personas, avatars) in the 3D-based internet world. Table 2 summarizes the characteristics and educational implications of each type of metaverse discussed above.

The core of the metaverse can be seen as "extension" and "connection." The 4 types of the metaverse were developed independently in the beginning. Nonetheless, they have recently been evolving into a new kind of convergence/composite service by interacting while breaking down boundaries. For example, Ghost Pacer, presented as lifelogging, combines augmented reality and lifelogging service [3]. In addition, the virtual conference service Roomkey [18] introduced in a mirror world is an example of the fusion of lifelogging, the mirror world, and virtual reality. Existing non-face-to-face meetings such as video conferences and webinars have the disadvantage that there is no proper way to measure performance other than the number of simultaneous users. In this service that combines virtual reality and lifelogging concepts in a mirror world, all activities such as meetings and networking are measured after the performance.

Characteristics of the virtual reality metaverse in education

Among the 4 types of the metaverse, the most diverse and actively used technology in education is virtual reality. In particular, the recent non-face-to-face (untact) era has been characterized by the frequent the utilization of virtual reality, , which can be accessed from anywhere regardless of distance or space. Go et al. [2] presented 5 characteristics of the virtual reality metaverse that distinguish it from existing platform services as the "5 Cs" as follows: first, as a canon, the space-time of the metaverse is created and expanded by designers and participants together; second, a creator (anyone in the metaverse) can create content; third, as a digital currency, production and consumption are possible through the production of various contents; fourth, the continuity of everyday life is guaranteed through the metaverse; and fifth, the metaverse connects the real and the virtual, connects the metaverse worlds, and connects people (avatars).

Book [19] also suggested 6 characteristics of virtual reality as follows: first, as a shared space, virtual reality should be a space where multiple users can participate at the same time; second, with a graphical user interface, virtual reality is visually expressed and implemented in a 2-dimensional (2D) or 3D environment; third, immediacy means that interactions between users in the virtual reality occur in real-time; fourth, interactivity allows users to interact with various contents of the virtual reality, such as transforming or developing contents; fifth, the virtual reality is persistently maintained regardless of the access of individual users; and sixth, with socialization/community, a community that can perform various social actions in the virtual reality can be formed.

Potential of the metaverse as an educational environment

The recent metaverse craze has started again, according to the transition to an untact society due to the COVID-19 pandemic. The 4 existing metaverse types—augmented reality, lifelogging, mirror world, and virtual reality—are accelerating the utilization of the metaverse as it evolves into a new type of convergence service. It also breaks down the boundaries between these types of the metaverse. As face-to-face communication becomes difficult due to the spread of COVID-19, activities that were thought to be only possible offline are being converted to virtual reality and are rapidly expanding into various fields such as education, medical care, fashion, and tourism.

A space for new social communication

Due to the prolonged COVID-19 pandemic, it is not easy to have private meetings of many people or eat together in a restaurant. However, in the metaverse, hundreds of thousands or tens of millions of people can gather to hold a festival or watch a concert by their favorite singer. Virtual reality metaverses such as Roblox and Zepeto provided people who could not go out due to COVID-19 with a new social space for meeting and relaxation.

When schools were closed due to COVID-19 and students could not attend school, the "Classroom Map" among various 3D maps in Zepeto was the most popular. Instead of going to the real classroom, the students went to the Zepeto classroom. They met and communicated with their friends. The idol group *Blackpink* held a virtual fan signing event through Zepeto when they could not hold a fan signing event face-to-face due to COVID-19. *Blackpink* also released a choreography music video for "Ice cream" that they reproduced with their avatar [20] (https://gweb.zepeto.io/user/post/97321663). More than 46 million users attended Blackpink's virtual fan signing event to get autographs and take selfies with their favorite singers. The idol group *BTS* also held a showcase by releasing the choreography version of the music video for "Dynamite" on Fortnite for the first time [21]. Users who attended the event forgot about COVID-19 and enjoyed the event by dancing together or sharing their impressions.

A higher degree of freedom to create and share

Some may believe the metaverse to be merely online games, but it is an evolved concept. In online games, service users have no choice but to perform limited missions according to the goals set by the platform provider. However, in the metaverse, ultimately, anything the user wants is possible without a pre-determined mission. Based on the perfect degree of freedom, users can experience various things in the real world, such as study, shopping, performances, exhibitions, and tourism. They can also share events that are difficult to experience easily due to physical restrictions in the real world, such as flying in the sky and going to space. Alternatively, users can get away from their busy lives and enjoy the leisurely life of fishing, picking fruits, or traveling to a friend's island all day without the task of solving the metaverse. Everything is the user's choice.

By actively utilizing the characteristics of the metaverse, it will be possible to design learning activities that can expand students' freedom and experience to an infinite extent. Students will conduct self-directed learning that allows them to explore their questions based on their endless autonomy. They can refer to the ideas of countless people across time and space and take the initiative in finding their original answers.

Providing new experiences and high immersion through virtualization

The metaverse is attracting attention as an alternative to overcome the limitations of existing 2D-based online and remote classes. It can provide a differentiated experience value from the current internet era due to the complex use of various technologies. Furthermore, the metaverse makes it possible to design a new experience that transcends time and space. Metaverse-based education enables the use of infinite space and data and has the advantage of allowing interaction at the level of face-to-face education [3].

Limitations of the metaverse in educational application

The metaverse has made users "social connection" possible by providing a place where people with hobbies and interests can gather and communicate even under real-world restrictions such as "social distancing" in response to the COVID-19 pandemic. However, these social connections in the metaverse are weaker than interactions in the real world. In metaverse, rather than showing "me as I am," information that one does not want to share is deleted to create "me I want to show." In addition, privacy infringement is also a problem that needs to be considered in social activities in the metaverse, where various information that was not generated in real-world interactions is collected and processed in real-time.

The high degree of freedom, which is an advantage of the metaverse, makes metaverse users more dangerous than users of existing online services and games. The administrator cannot predict all the actions of users due to the high degree of freedom. Due to the essential characteristics of the metaverse—virtual space and anonymity—people's sense of guilt about crimes is reduced. There is a concern that new crimes that are more vicious and sophisticated than the real world may appear. The 'I' participating in the virtual world may have a similar appearance and self as an extension of reality, but may participate as a self with a different appearance and worldview. The term sub-character (additional character) can be interpreted as the concept of an avatar. As life in which the virtual world and reality are combined become commonplace, the degree of freedom in people's identities is expected to increase gradually in a virtual space where one's identity is not exposed at all. People can be recognized in a limited way compared to reality. They should be careful because they can be more easily exposed to criminal activities in the metaverse with a higher level of anonymity. In a metaverse that values freedom, the countless amounts of data created and shared by users worldwide cannot be censored one by one. Therefore, there is a possibility that it will become a lawless zone. In this case, caution is needed because it can be a significant risk to young adolescents with little social experience and whose identity has not been established. Furthermore, ethics education for cultivating citizenship in the virtual world will be required.

As the distinction between the virtual and the real world becomes blurred, users may experience confusion regarding their "real me" identity. They may not be able to adapt to virtual reality properly appropriately. If one is too immersed in human relationships in the virtual reality or satisfied with human relationships in virtual reality, there is a danger that neglecting one's relationships in the real world can make them worse, or it can make it difficult to establish relationships (Table 3).

Conclusion

The characteristics of 4 types of the metaverse, the possibility of educational applications, the convergence and complex characteristics of the types of the metaverse, and the potential and limitations of the metaverse for educational applications were de-

Table 3. Characteristics of the metaverse, and merits and shortcomings in its educational applications

Metaverse characteristics	Merits	Shortcomings
New social communication space	Even in the case of school closures due to coronavirus disease 2019, students can socially connect beyond the limitations of reality.	When forming a relationship with others, one forms a relationship centered on play that is weaker than the interaction in the real world, and privacy problems occur due to the collection and processing of various personal information.
High degree of freedom	Expanding student autonomy in the learning process by providing experiences from content consumers to creators	Due to the high degree of freedom, platform administrators cannot predict all the actions of users, and they can be exposed to various crimes due to the virtual space and anonymity of the metaverse.
Through virtualization high immersion	By providing a new experience that transcends time and space, it is possible to increase student interest and immersion to expand students' active participation in learning.	It can cause identity confusion, escape from reality, and maladaptation to the real world for students whose identity has not been established.

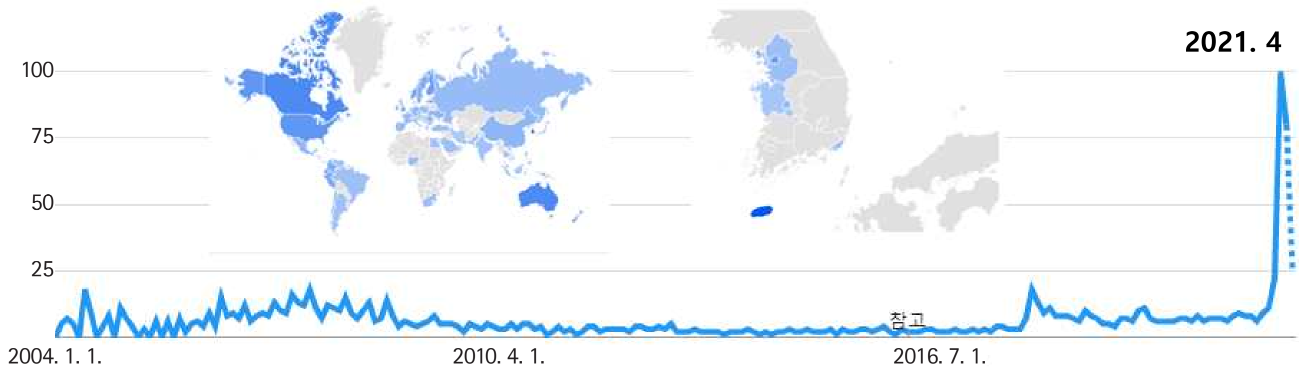

Fig. 9. Trends of interest in the metaverse in Google Trends over time. From Google Trends. Metaverse [Internet]. Mountain View (CA): Google; 2021 [cited 2021 Nov 29]. Available from: https://trends.google.com/trends/explore?date=all&q=metaverse [22].

scribed. The metaverse is predicted to change our daily life and economy beyond the realm of games and entertainment. Furthermore, all social, cultural, and economic activities are moving to the metaverse's new platform. The metaverse has infinite potential as a new social communication space. It provides a high degree of freedom for creation and sharing and provides a unique and immersive experience [22] (Fig. 9). Since the metaverse is expected to grow rapidly during and after the COVID-19 pandemic, it also has risk factors that do not have appropriate regulations. The following are suggested as future tasks for the educational use of the metaverse.

First, it is necessary to carefully analyze how students understand the metaverse, what they want to do there, why they like it, and what value they attach to their avatar in virtual reality. It is necessary to study students' activity patterns, level of immersion in the metaverse, and its positive and negative effects on students' learning activities.

Second, an effective and attractive aspect of the metaverse is that it allows us to experience events that would be impossible or limited in the real world. However, there is room for uncritically accepting the intentions of content developers or service designers rather than students' cognitive abilities and imagination. Therefore, instructional designers and instructors who want to utilize the metaverse for education need to properly understand each type of metaverse's technical characteristics and design classes so that they can solve problems or perform projects collaboratively and creatively.

Third, developing an educational metaverse platform to prevent the misuse of student data is required. Evaluation studies on data collection to support teaching and learning are also required.

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Authors' contributions

All work was done by all authors.

Conflict of interest

Bokyung Kye, Na-Ra Han, Eun-Ji Kim, and So Young Jo have been employees of the Korea Education and Research Information Service. However, this review article is not an official opinion of the Korea Education and Research Information Service, but rather reflects the authors' opinions. Otherwise, no potential conflict of interest relevant to this article was reported.

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Data availability

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Supplementary materials

Supplementary files are available from Harvard Dataverse: https://doi.org/10.7910/DVN/0KUSGC
Supplement 1. Audio recording of the abstract.

Editors' note

The metaverse is a new and unique environment in health education. Although the application of the metaverse in health education is still uncommon, there have already been some cases of its application. The evaluation of metaverse applications is another emerging topic, the relevance of which was accelerated by the COVID-19 pandemic. This review article can serve as an introductory guide for health educators to the metaverse's possibilities for educational applications.

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Review

Virtual Reality for Health Professions Education: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration

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Abstract

Background: Virtual reality (VR) is a technology that allows the user to explore and manipulate computer-generated real or artificial three-dimensional multimedia sensory environments in real time to gain practical knowledge that can be used in clinical practice.

Objective: The aim of this systematic review was to evaluate the effectiveness of VR for educating health professionals and improving their knowledge, cognitive skills, attitudes, and satisfaction.

Methods: We performed a systematic review of the effectiveness of VR in pre- and postregistration health professions education following the gold standard Cochrane methodology. We searched 7 databases from the year 1990 to August 2017. No language restrictions were applied. We included randomized controlled trials and cluster-randomized trials. We independently selected studies, extracted data, and assessed risk of bias, and then, we compared the information in pairs. We contacted authors of the studies for additional information if necessary. All pooled analyses were based on random-effects models. We used the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) approach to rate the quality of the body of evidence.

Results: A total of 31 studies (2407 participants) were included. Meta-analysis of 8 studies found that VR slightly improves postintervention knowledge scores when compared with traditional learning (standardized mean difference [SMD]=0.44; 95% CI 0.18-0.69; I^2=49%; 603 participants; moderate certainty evidence) or other types of digital education such as online or offline digital education (SMD=0.43; 95% CI 0.07-0.79; I^2=78%; 608 participants [8 studies]; low certainty evidence). Another meta-analysis of 4 studies found that VR improves health professionals' cognitive skills when compared with traditional learning (SMD=1.12; 95% CI 0.81-1.43; I^2=0%; 235 participants; large effect size; moderate certainty evidence). Two studies compared the effect of VR with other forms of digital education on skills, favoring the VR group (SMD=0.5; 95% CI 0.32-0.69; I^2=0%; 467 participants; moderate effect size; low certainty evidence). The findings for attitudes and satisfaction were mixed and inconclusive. None of the studies reported any patient-related outcomes, behavior change, as well as unintended or adverse effects of VR. Overall, the certainty of evidence according to the GRADE criteria ranged from low to moderate. We downgraded our certainty of evidence primarily because of the risk of bias and/or inconsistency.

Conclusions: We found evidence suggesting that VR improves postintervention knowledge and skills outcomes of health professionals when compared with traditional education or other types of digital education such as online or offline digital education. The findings on other outcomes are limited. Future research should evaluate the effectiveness of immersive and interactive forms of VR and evaluate other outcomes such as attitude, satisfaction, cost-effectiveness, and clinical practice or behavior change.

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KEYWORDS

virtual reality; health professions education; randomized controlled trials; systematic review; meta-analysis

Introduction

Adequately trained health professionals are essential to ensure access to health services and to achieve universal health coverage [1]. In 2013, the World Health Organization (WHO) estimated a shortage of approximately 17.4 million health professionals worldwide [1]. The shortage and disproportionate distribution of health workers worldwide can be aggravated by the inadequacy of training programs (in terms of content, organization, and delivery) and experience needed to provide uniform health care services to all [2]. It has, therefore, become essential to generate strategies focused on scalable, efficient, and high-quality health professions education [3]. Increasingly, digital technology, with its pervasive use and relentless advancement, is seen as a promising source of effective and efficient health professions education and training systems [4].

Digital education (also known as eLearning) is the act of teaching and learning by means of digital technologies. It is an overarching term for an evolving multitude of educational approaches, concepts, methods, and technologies [5]. Digital education can include, but is not limited to, online and offline computer-based digital education, massive open online courses, virtual reality (VR), virtual patients, mobile learning, serious gaming and gamification, and psychomotor skills trainers [5]. A strong evidence base is needed to support effective use of these different digital modalities for health professions education. To this end, as part of an evidence synthesis series for digital health education, we focused on one of the digital education modalities, VR [6].

VR is a technology that allows the user to explore and manipulate computer-generated real or artificial three-dimensional (3D) multimedia sensory environments in real time. It allows for a first-person active learning experience through different levels of immersion; that is, a perception of the digital world as real and the ability to interact with objects and/or perform a series of actions in this digital world [7-9]. VR can be displayed with a variety of tools, including computer or mobile device screens, and VR rooms of head-mounted displays. VR rooms are projector-based immersive 3D visualization systems simulating real or virtual environments in a closed space and involve multiple users at the same time [10]. Head-mounted displays are placed over the user's head and provide an immersive 3D environmental experience for learning [7]. VR can also facilitate diverse forms of health professions education. For example, it is often used for designing 3D anatomical structure models, which can be toggled and zoomed into [11]. VR also enables the creation of virtual worlds or 3D environments with virtual representations of users, called avatars. Avatars in VR for health professions education can represent patients or health professionals. By enabling simulation, VR is highly conducive to clinical and surgical procedures-focused training.

We found several reviews focusing primarily on the development of technical skills as part of surgical and clinical procedures-focused training, mostly calling for more research on the topic [12-15]. However, VR also offers a range of other educational opportunities, such as development of cognitive, nontechnical competencies [13-18]. Our review addresses this gap in the existing literature by investigating the effectiveness of VR for health professions education.

Methods

Systematic Review

We adhered to the published protocol [6] and followed the Cochrane guidelines [19]. The review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [20]. For a detailed description of the methodology, please refer to the study by Car et al [5].

Study Selection

We included randomized and cluster-randomized controlled trials that compared any VR intervention with any control intervention, for the education of pre- or postregistration health professionals. We included health professionals with qualifications found in the Health Field of Education and Training (091) of the International Standard Classification of Education. VR interventions could be delivered as the only mode of education intervention or blended with traditional learning (ie, blended learning). We included studies on VR for cognitive and nontechnical health professions education, including all VR delivery devices and levels of immersion. We included studies that reported VR as an intervention for healthcare professionals without the participant using any additional physical objects or devices such as probes or handles for psychomotor or technical skill development. We included studies that compared VR or blended learning with traditional learning, other types of digital educations, or another form of VR intervention.

We differentiated the following types of VR: 3D models, virtual patient or virtual health professional (VP or VHP) within VR and surgical simulation. Although we included studies including virtual patients in a VR, studies of virtual patient scenarios outside VR were excluded and are part of a separate review looking at virtual patients alone (simulation) [10]. We excluded studies of students and/or practitioners of traditional, alternative, and complementary medicine. We also excluded studies with cross-over design because of the likelihood of a carry-over effect.

We extracted data on the following primary outcomes:

- Learners' knowledge postintervention: Knowledge is defined as learners' factual or conceptual understanding measured using change between pre- and posttest scores.
- Learners' skills postintervention: Skills are defined as learners' ability to demonstrate a procedure or technique in an educational setting.
- Learners' attitudes postintervention toward new competences, clinical practice, or patients (eg, recognition of moral and ethical responsibilities toward patients): Attitude is defined as the tendency to respond positively or negatively toward the intervention.
- Learners' satisfaction postintervention with the learning intervention (eg, retention rates, dropout rates, and survey satisfaction scores): This can be defined as the level of approval when comparing the perceived performance of digital education with one's expectations.
- Change in learner's clinical practice or behavior (eg, reduced antibiotic prescriptions and improved clinical diagnosis): This can be defined as any changes in clinical practice after the intervention which results in improvement of the quality of care as well as the clinical outcomes.

We also extracted data on the following secondary outcomes:

- Cost and cost-effectiveness of the intervention
- Patient-related outcomes (eg, patient mortality, patient morbidity, and medication errors)

Data Sources, Collection, Analysis, and Risk of Bias Assessment

We developed a comprehensive search strategy for MEDLINE (Ovid), Embase (Elsevier), Cochrane Central Register of Controlled Trials (CENTRAL; Wiley), PsycINFO (Ovid), ERIC (Ovid), CINAHL (Ebsco), Web of Science Core Collection, and clinical trial registries (ClinicalTrial.gov and WHO ICTRP). Databases were searched from January 1990 to August 2017. The reason for selecting 1990 as the starting year for our search is that before this year, the use of computers and digital technologies was limited to very basic tasks. There were no language or publication restrictions (see Multimedia Appendix 1).

The search results from different bibliographic databases were combined in a single Endnote library, and duplicate records were removed. Four authors (BMK, NS, JV, and CKN) independently screened the search results and assessed full-text studies for inclusion. Any disagreements were resolved through discussion between the authors. Study authors were contacted for unclear or missing information.

Five reviewers (BMK, NS, JV, CKN, and UD) independently extracted data using a structured data extraction form. Disagreements between review authors were resolved by discussion. We extracted data on the participants, interventions, comparators, and outcomes. If studies had multiple arms, we compared the most interactive intervention arm with the least interactive control arm.

Two reviewers (BMK and NS) independently assessed the risk of bias for randomized controlled trials using the Cochrane *risk of bias* tool [19,21], which included the following domains: random sequence generation, allocation concealment, blinding of outcome assessors, completeness of outcome data, and selective outcome reporting. We also assessed the following additional sources of bias: baseline imbalance and inappropriate administration of an intervention as recommended by the Cochrane Handbook for Systematic Reviews of Interventions [21]. Studies were judged at high risk of bias if there was a high risk of bias for 1 or more key domains and at unclear risk of bias if they had an unclear risk of bias for at least 2 domains.

Data Synthesis and Analysis

Studies were grouped by outcome and comparison. Comparators included traditional education, other forms of digital education, and other types of VR. We included postintervention outcome data in our review for the sake of consistency as this was the most commonly reported form of findings in the included studies. For continuous outcomes, we summarized the standardized mean differences (SMDs) and associated 95% CIs across studies. We were unable to identify a clinically meaningful interpretation of SMDs specifically for digital education interventions. Therefore, in line with other evidence syntheses of educational research, we interpreted SMDs using the Cohen rule of thumb: <0.2 no effect, 0.2 to 0.5 small effect size, 0.5 to 0.8 medium effect size, and >0.80 a large effect size [22,22]. For dichotomous outcomes, we summarized relative risks and associated 95% CIs across studies. We employed the random-effects model in our meta-analysis. The I^2 statistic was employed to evaluate heterogeneity, with I^2<25%, 25% to 75%, and >75% to represent a low, moderate, and high degree of inconsistency, respectively. The meta-analysis was performed using Review Manager 5.3 (Cochrane Library Software, Oxford, UK). Where sufficient data were available, summary SMD and associated 95% CIs were estimated using random-effects meta-analysis [21].

We prepared *Summary of Findings* tables to present a summary of the results and a judgment on the quality of the evidence by using Grading of Recommendations, Assessment, Development and Evaluations methodology. We presented the findings that we were unable to pool, because of lack of data or high heterogeneity, in the form of narrative synthesis.

Results

Results of the Search

The searches identified 30,532 unique references; of these, 31 studies (33 reports; 2407 participants) fulfilled the inclusion criteria [11,24-53] (see Figure 1).

Characteristics of Included Studies

All included studies were conducted in high-income countries. Moreover, 21 studies included only preregistration health professionals. A range of VR educational interventions were evaluated, including 3D models, VP or VHP within virtual worlds, and VR surgical stimulations. Control group interventions ranged from traditional learning (eg, lectures and textbooks) to other digital education interventions (online and offline) and other forms of VR (eg, with limited functions, noninteractivity, or nontutored support; see Multimedia Appendix 2). Although they met the inclusion criteria, some studies did not provide comparable outcome data. Out of the 24 studies assessing knowledge, 1 did not provide any comparable data to estimate the effect of the intervention [44]. Likewise, 2 out of 12 studies assessing skills [29,49], 4 out of 8 studies assessing attitude [38,40,46,50], and 8 out of 12 studies assessing satisfaction [24,29,33,37,48,49,52,53] did not provide comparable data.

Risk of Bias

Overall, studies were judged at unclear or high risk of bias (see Figure 2). Most studies lacked information on randomization, allocation concealment, and participants' baseline characteristics. Studies were mostly at low risk of bias for blinding of outcome assessment as they provided detailed information on blinding of outcome measures and/or used predetermined assessment tools (multiple choice questions, survey, etc). We judged the studies to be at low risk of detection bias in comparison with traditional education as blinding of participants was impossible because of the use of automated or formalized outcome measurement instruments. However, most of these instruments lacked information on validation. Most studies were judged to be at low risk of attrition and selection bias. Overall, 6 studies were judged at high risk of bias because of reported significant baseline differences in participant characteristics or incomplete outcome data.

Figure 1. Study flow diagram. RCT: randomized controlled trial.

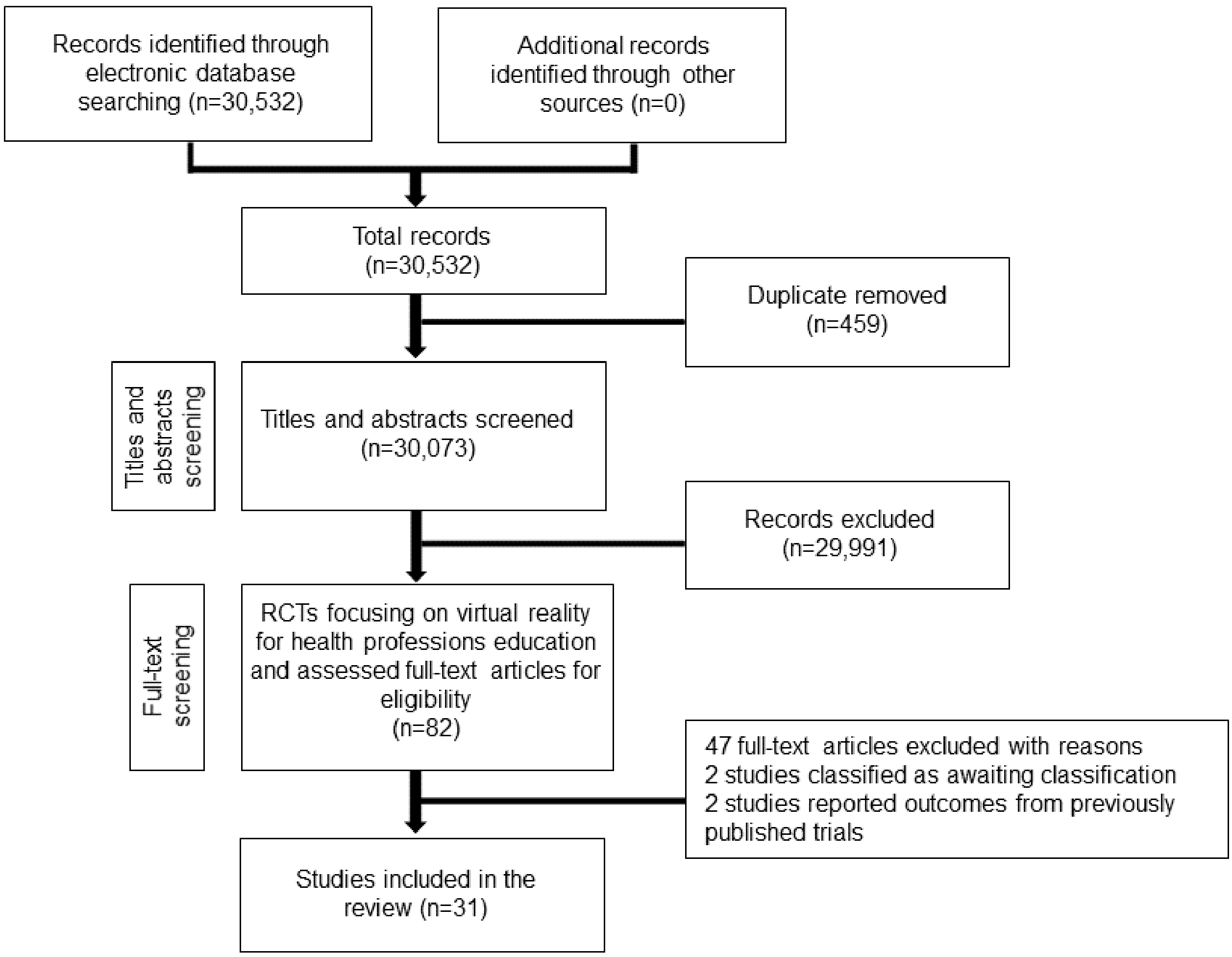
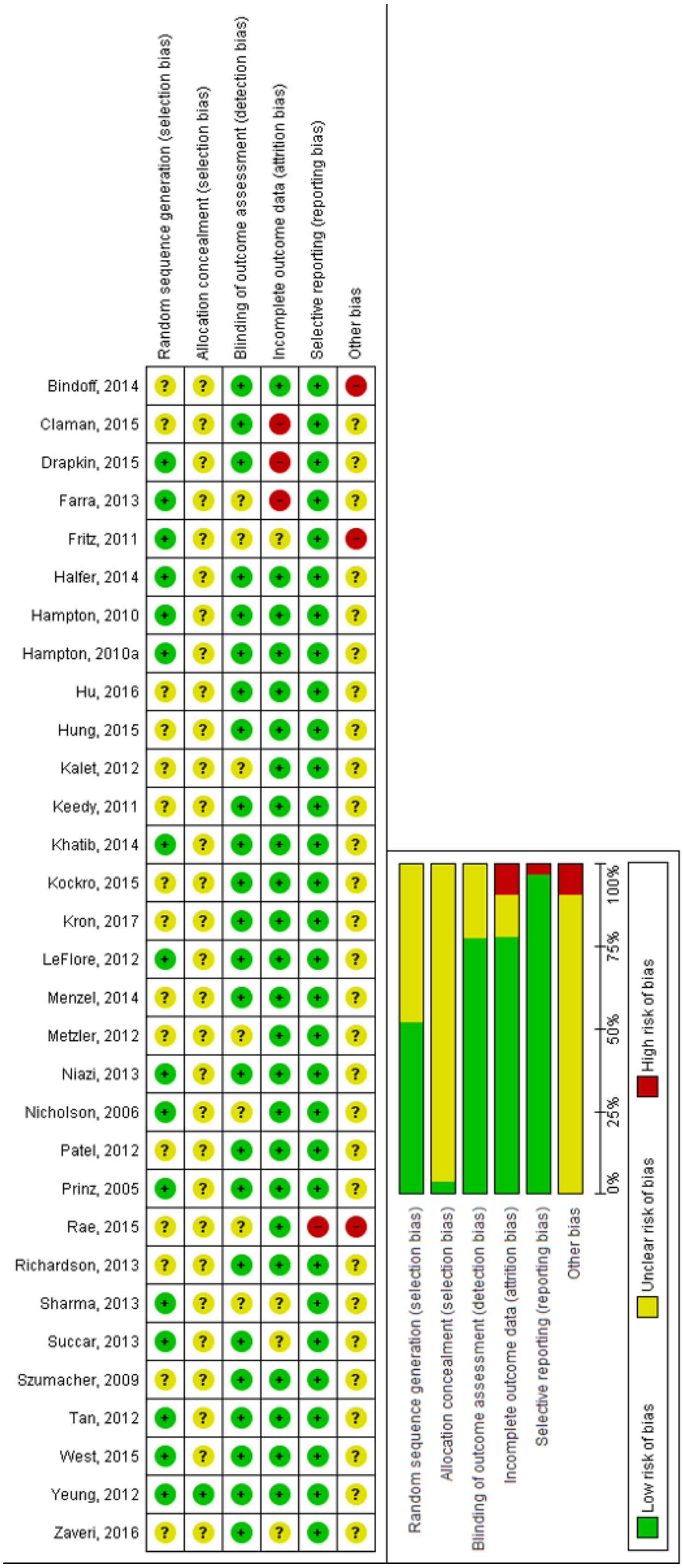


Figure 2. Risk of bias graph and summary.



Primary Outcomes

Knowledge Outcome

A total of 24 studies (1757 participants) [11,24,26-28,30-32,34-37,39,41-44,46-48,50-53] assessed knowledge as the primary outcome. Of them, 6 studies focused on postregistration health professionals [30,42,46,47,50,53] and all others focused on preregistration health professionals.

The effectiveness of VR interventions was compared with traditional learning (via two-dimensional [2D] images, textbooks, and lectures) in 9 studies (659 participants) [24,30,32,36,39,43,47,48,52] (Table 1). Overall, studies suggested a slight improvement in knowledge with VR compared with traditional learning (SMD=0.44; 95% CI 0.18-0.69; I^2=49%; 603 participants [8 studies]; moderate certainty evidence; see Figure 3).

A total of 10 studies (812 participants) compared VR with other forms of digital education (comprising 2D images on a screen, simple videos, or Web-based teaching) [11,27,28,35,37,41,44,46,50,53] (see Table 2). The overall pooled estimate of 8 studies that compared different types of VR (such as computer 3D model and virtual world) with different controls (ie, computer-based 2D learning or online module or video-based learning) reported higher postintervention knowledge scores in the intervention groups over the control groups (SMD=0.43; 95% CI 0.07-0.79; I^2=78%; 608 participants; low certainty evidence; see Figure 3). Additionally, 4 studies compared 3D models with different levels of interactivity (243 participants) [26,34,42,51]. Models with higher interactivity were associated with greater improvements in knowledge than those with less interactivity. The overall pooled estimate of the 4 studies reported higher postintervention knowledge score in the intervention groups with higher interactivity compared with the less interactive controls (SMD=0.60; 95% CI 0.05-1.14; I^2=66%; moderate effect size; low certainty evidence; see Figure 3). A total of 3 studies could not be included in the meta-analysis: 1 study lacked data [44], whereas the other 2 studies reported a mean change score, favoring the VR group [36] or other digital education intervention [53].

Table 1. Summary of findings table: virtual reality compared with traditional learning.

Outcomes[a]	Illustrative comparative risks (95% CI)	Participants (n)	Studies (n)	Quality of evidence (GRADE[b])	Comments
Postintervention knowledge scores: measured via MCQs[c] or quiz. Follow-up: immediate postintervention only	The mean knowledge score in the intervention group was 0.44 SDs higher (0.18 to 0.69 higher) than the mean score in the traditional learning group	603	8	Moderate[d]	1 study [36] reported mean change scores within the group, and hence, the study data were excluded from the pooled analysis
Postintervention skill scores: measured via survey and OSCE[e]. Follow-up duration: immediate postintervention only	The mean skill score in the intervention group was 1.12 SDs higher (0.81 to 1.43 higher) than the mean score in the traditional learning group	235	4	Moderate[d]	3 studies were excluded from the analysis as 1 study reported incomplete outcome data [29], 1 study assessed mixed outcomes [36], and 1 study reported self-reported outcome data [24]
Postintervention attitude scores: measured via survey. Follow-up duration: immediate postintervention only	The mean attitudinal score in the intervention group was 0.19 SDs higher (−0.35 lower to 0.73 higher) than the mean score in the traditional learning group	83	2	Moderate[d]	N/A[f]
Postintervention satisfaction scores: measured via survey. Follow-up duration: immediate postintervention only	Not estimable	100	1	Low[d,g]	5 studies [24,29,33,48,52] reported incomplete outcome data or lacked comparable data. Therefore, these studies were excluded from the analysis.

[a]Patient or population: health professionals; settings: universities and hospitals; intervention: virtual reality; comparison: traditional learning (face-to-face lecture, textbooks, etc).

[b]GRADE (Grading of Recommendations, Assessment, Development and Evaluations) Working Group grades of evidence. High quality: further research is very unlikely to change our confidence in the estimate of effect; moderate quality: further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate; low quality: further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate; and very low quality: we are very uncertain about the estimate.

[c]MCQs: multiple choice questions.

[d]Downgraded by 1 level for study limitations: the risk of bias was unclear or high in most included studies (−1).

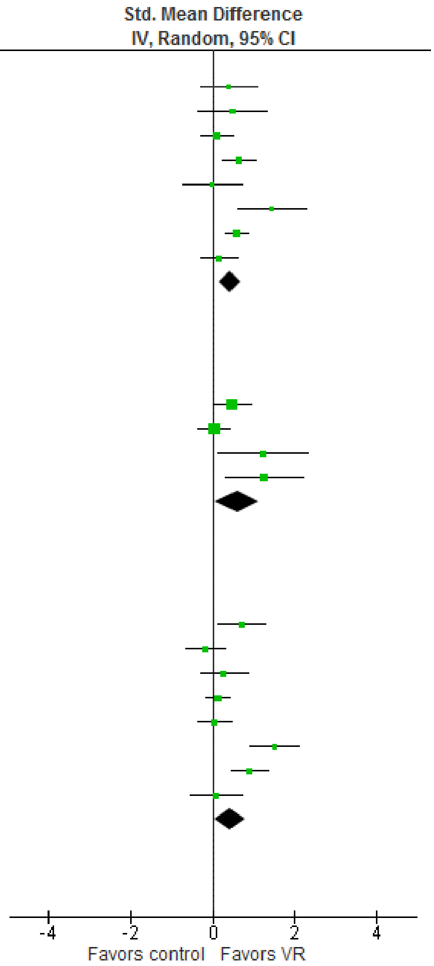
[e]OSCE: objective structured clinical examination.

[f]N/A: not applicable.

[g]Downgraded as results were obtained from a single small study (−1).

Figure 3. Forest plot for the knowledge outcome (postintervention). df: degrees of freedom; IV: interval variable; random: random effects model; VR: virtual reality.

Study or Subgroup	VR Mean	VR SD	VR Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
VR versus traditional learning								
Bindoff, 2014	6.7	1.23	16	6.1	1.66	17	9.1%	0.40 [-0.29, 1.09]
Hampton, 2010a	14.5	1.22	12	13.5	2.51	11	7.0%	0.50 [-0.34, 1.33]
Hu, 2016	14.2	2.8	49	13.9	3.4	51	16.8%	0.10 [-0.30, 0.49]
LeFlore, 2012	83.9	15	46	75	12	47	16.0%	0.65 [0.23, 1.07]
Patel, 2012	34.2	3.73	15	34.2	4.88	15	8.7%	0.00 [-0.72, 0.72]
Sharma, 2013	59	10	14	44	10	14	6.8%	1.46 [0.61, 2.30]
Succar, 2013	16	1.8	95	14.8	2.2	93	20.5%	0.60 [0.30, 0.89]
Yeung, 2012	42.7	10.5	43	41	11.6	35	15.0%	0.15 [-0.29, 0.60]
Subtotal (95% CI)			**290**			**283**	**100.0%**	**0.44 [0.18, 0.69]**
Heterogeneity: Tau² = 0.06; Chi² = 13.62, df = 7 (P = 0.06); I² = 49%								
Test for overall effect: Z = 3.36 (P = 0.0008)								
VR (more interactive) versus VR								
Drapkin, 2015	70.8	17.9	41	61	23	32	31.7%	0.48 [0.01, 0.95]
Kalet, 2012	14	2.11	51	13.9	1.91	50	34.2%	0.05 [-0.34, 0.44]
Niazi, 2013	10.5	3.57	8	5.8	3.57	8	15.4%	1.24 [0.15, 2.34]
West, 2015	19.5	1.53	10	16.7	2.51	12	18.7%	1.27 [0.33, 2.20]
Subtotal (95% CI)			**110**			**102**	**100.0%**	**0.60 [0.05, 1.14]**
Heterogeneity: Tau² = 0.19; Chi² = 8.76, df = 3 (P = 0.03); I² = 66%								
Test for overall effect: Z = 2.15 (P = 0.03)								
VR versus other digital education								
Farra, 2013	17.6	1.72	22	16.2	2.13	25	11.4%	0.71 [0.11, 1.30]
Fritz, 2011	14.3	2.2	30	14.7	2.4	32	12.6%	-0.17 [-0.67, 0.33]
Keedy, 2011	74	34.38	22	64	34.38	24	11.6%	0.29 [-0.30, 0.87]
Kockro, 2015	5.4	2.16	89	5.1	2.12	80	14.9%	0.14 [-0.16, 0.44]
Metzler, 2012	6.6	1.4	47	6.5	1.8	47	13.7%	0.06 [-0.34, 0.47]
Nicholson, 2006	12.5	1.7	28	9.8	1.8	29	11.4%	1.52 [0.93, 2.11]
Richardson, 2013	72	9.05	40	63	10.36	49	13.3%	0.91 [0.47, 1.35]
Tan, 2012	15.7	2	21	15.5	2.3	19	11.1%	0.09 [-0.53, 0.71]
Subtotal (95% CI)			**299**			**305**	**100.0%**	**0.43 [0.07, 0.79]**
Heterogeneity: Tau² = 0.20; Chi² = 31.26, df = 7 (P < 0.0001); I² = 78%								
Test for overall effect: Z = 2.33 (P = 0.02)								



Skill Outcome

A total of 12 studies (1011 participants) assessed skills as an outcome [24,29,33,34,36,38,39,42,43,45,49,53]. Of which, 7 studies compared VR-based interventions with traditional learning (comprising paper- or textbook-based education and didactic lectures; 354 participants) [24,29,33,36,39,43,45], and the overall pooled estimate of 4 studies showed a large improvement in postintervention cognitive skill scores in the intervention groups compared with the controls (SMD=1.12; 95% CI 0.81-1.43; I^2=0%, 235 participants; large effect size; moderate certainty evidence; see Figure 4 and Table 1). Additionally, 3 studies compared the effectiveness of different types of VR on cognitive skills acquisition (190 participants) [34,42,49]. We were able to pool the findings from 2 studies favoring more interactive VR (SMD=0.57; 95% CI 0.19-0.94; I^2=0%; moderate effect size; low certainty evidence). Two studies compared VR with other forms of digital education on skills, favoring the VR group (SMD=0.5; 95% CI 0.32-0.69; I^2=0%; 467 participants; moderate effect size; low certainty evidence; see Table 2). A total of 4 studies could not be included in the meta-analysis: 2 studies reported incomplete outcome data [29,49], 1 study assessed mixed outcomes [36], and 1 study reported self-reported outcome data [24].

Attitude Outcome

A total of 8 studies (762 participants) [25,30,31,38,40,43,46,50] assessed attitude as an outcome. Of them, 2 studies comparing VR-based interventions with traditional learning (small group teaching and didactic lectures; 83 participants) [30,43] reported no difference between the groups on postintervention attitude scores (SMD=0.19; 95% CI−0.35 to 0.73; I^2=0%; moderate certainty evidence; see Table 1). One study compared blended learning with traditional learning (43 participants) [30] and reported higher postinterventional attitude score (large effect size) toward the intervention (SMD=1.11; 95% CI 0.46-1.75). Additionally, 5 studies (636 participants) [25,38,40,46,50] that compared VR with other digital education interventions reported that most of the studies had incomplete outcome data.

Table 2. Summary of findings table: virtual reality compared with other digital education interventions.

Outcomes[a]	Illustrative comparative risks (95% CI)	Participants (n)	Studies (n)	Quality of evidence (GRADE[b])	Comments
Postintervention knowledge score: measured via MCQs[c] and questionnaires. Follow-up duration: immediate postintervention to 6 months	The mean knowledge score in the intervention group was 0.43 SDs higher (0.07 to 0.79 higher) than the mean score in the other digital education interventions	608	8	Low[d,e]	1 study (32 participants) presented mean change score and favored VR group compared with the control group [53], and 1 study (172 participants) compared VR with computer-based video (2D) and presented incomplete outcome data [44]
Postintervention skills score: measured via scenario-based skills assessment. Follow-up duration: immediate postintervention only	The mean skill score in the intervention group was 0.5 SDs higher (0.32 to 0.69 higher) than the mean score in the other digital education interventions	467	2	Moderate[d]	N/A[f]
Postintervention attitude: measured via survey and questionnaire. Follow-up duration: immediate postintervention only.	Not estimable	21	1	Low[d,g]	4 studies [38,40,46,50] reported incomplete outcome data or lacked comparable data. Therefore, these studies were excluded from the analysis.
Postintervention satisfaction: measured via MCQs, survey, and questionnaire. Duration: immediate postintervention only	The mean satisfaction score in the intervention group was 0.2 SDs higher (−0.71 lower to 1.11 higher) than the mean score in the other digital education interventions	218	2	Low[d,e]	2 studies [37,53] reported incomplete outcome data or lacked comparable data. Therefore, these studies were excluded from the analysis.

[a]Patient or population: Health professionals; Settings: Universities and hospitals; Intervention: Virtual reality; Comparison: Other digital education interventions (such as online learning, computer-based video, etc).

[b]GRADE (Grading of Recommendations, Assessment, Development and Evaluations) Working Group grades of evidence. High quality: Further research is very unlikely to change our confidence in the estimate of effect; Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate; Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate; and Very low quality: We are very uncertain about the estimate.

[c]MCQs: multiple choice questions.

[d]Downgraded by 1 level for study limitations (−1): the risk of bias was unclear or high in most included studies.

[e]Downgraded by 1 level for inconsistency (−1): the heterogeneity between studies is high with large variations in effect and lack of overlap among confidence intervals.

[f]N/A: not applicable.

[g]Downgraded as results were obtained from a single small study (−1).

Satisfaction Outcome

A total of 12 studies (991 participants) [24,26,29,32,33,35,37,44,48,49,52,53] assessed satisfaction, mostly only for the intervention group. Only 4 studies compared satisfaction in the intervention and control groups and largely reported no difference between the study groups.

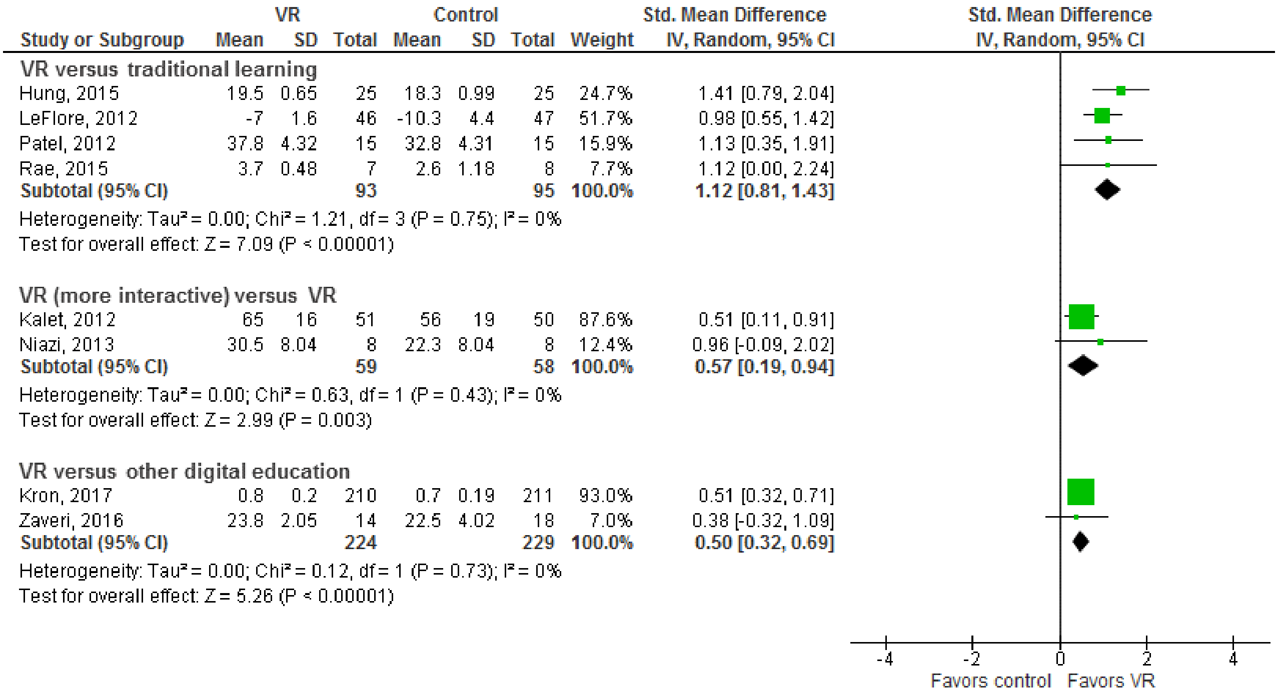
Secondary Outcomes

Halfer et al (30 participants) [29] assessed the use of VR versus traditional paper floor plans of the hospital to prepare nurses for wayfinding in a new hospital building. A cost analysis showed that a virtual hospital-based approach increased development costs but provided increased value during implementation by reducing staff time needed for practicing wayfinding skills. The paper describes that the real-world paper floor plan approach had a development cost of US $40,000 and the implementation cost was US $530,000, bringing the total cost to US $570,000. In comparison, the virtual world would cost US $220,000 for development and US $201,000 for implementation, bringing the total to US $421,000.

Zaveri et al (32 participants) [53] assessed the effectiveness of a VR module (Second Life, Linden Lab) in teaching preparation and management of sedation procedures, compared with online learning. Development of the module occurred over 2 years of interactions with a software consultant and utilized a US $40,000 grant to create VR scenarios. Cost of the control group (online training) was not presented, and hence, no formal comparison was made.

No information on patient-related outcomes, behavior change, and unintended or adverse effects of VR on the patient or the learner were reported in any of the studies.

Figure 4. Forest plot for the skills outcome (postintervention). df: degrees of freedom; IV: interval variable; random: random effects model; VR: virtual reality.



Discussion

Principal Findings

This systematic review assessed the effectiveness of VR interventions for health professions education. We found evidence showing a small improvement in knowledge and moderate-to-large improvement in skills in learners taking part in VR interventions compared with traditional or other forms of digital learning. Compared with less interactive interventions, more interactive VR interventions seem to moderately improve participants' knowledge and skills. The findings for attitude and satisfaction outcomes are inconclusive because of incomplete outcome data. None of the included studies reported any patient-related outcomes, behavior change, as well as unintended or adverse effects of the VR on the patients or the learners. Only 2 studies assessed the cost of setup and maintenance of the VR as a secondary outcome without making any formal comparisons.

Overall, the risk of bias for most studies was judged to be unclear (because of a lack of information), with some instances of potentially high risk of attrition, reporting, and other bias identified. The quality of the evidence ranges from low to moderate for knowledge, skills, attitude, and satisfaction outcomes because of the unclear and high risks of bias and inconsistency, that is, heterogeneity in study results as well as in types of participants, interventions, and outcome measurement instruments [54].

The fact that no included studies were published before 2005 suggests that VR is an emerging educational strategy, attracting increasing levels of interest. The included studies were mainly conducted among doctors, nurses, and students pursuing their medical degree. Limited studies on pharmacists, dentists, and other allied health professionals suggest more research is needed on the use of VR among these groups of health professionals. Additionally, the majority of interventions studied were not part of a regular curriculum and none of the studies mentioned the use of learning theories to design the VR-based intervention or develop clinical competencies. This is an important aspect of designing any curriculum, and hence, applicability of the included studies might only be limited to their current setting and may not be generalizable to other geographic or socioeconomic backgrounds. Furthermore, most studies evaluated participants' knowledge, and skills assessed may not translate directly into clinical competencies.

Although the included studies encompassed a range of participants and interventions, a lack of consistent methodological approach and studies conducted in any one health care discipline makes it difficult to draw any meaningful conclusions. There is also a distinct lack of data from low- or middle-income countries, which reduces applicability to those contexts that are most in need of innovative educational strategies. In addition, only 2 studies assessed the cost of setup and maintenance of the VR-based intervention, whereas none of the included studies assessed cost-effectiveness. Thus, no conclusions regarding costing and cost-effectiveness can be made at this point either. There was also a lack of information on patient-related outcomes, behavior change, and unintended or adverse effects of VR on the patients as well as the learner, which needs to be addressed.

Majority of the included studies assessed the effectiveness of nonimmersive VR, and there is a need to explore more on the effects of VR with different level of immersion as well as interactivity on the outcomes of interest. In our review, most of the studies assessing attitude and satisfaction outcomes reported incomplete outcome or incomparable outcome data, and there is a need for primary studies focusing on these outcomes. Finally, there is a need to standardize the methods for reporting meaningful and the most accurate data on the outcomes as most of the included studies reported postintervention mean scores rather than change scores on the outcomes, which limits the accuracy of the findings for the reported outcomes.

Strengths and Limitations

Our review provides the most up-to-date evidence on the effectiveness of different types of VR in health professions education. We conducted a comprehensive search across different databases including gray literature sources and followed the Cochrane gold standard methodology while conducting this systematic review. Our review also has several limitations. The included studies largely reported postintervention data, so we could not calculate pre- to postintervention change or ascertain whether the intervention groups were matched at baseline for key characteristics and outcome measure scores. We were also unable to perform the prespecified subgroup analysis because of limited data from the primary studies.

Conclusions

As an emerging and versatile technology, VR has the potential to transform health professions education. Our findings show that when compared with traditional education or other types of digital education, such as online or offline digital education, VR may improve postintervention knowledge and skills. VR with higher interactivity showed more effectiveness compared with less interactive VR for postintervention knowledge and skill outcomes. Further research should evaluate the effectiveness of more immersive and interactive forms of VR in a variety of settings and evaluate outcomes such as attitude, satisfaction, untoward effects of VR, cost-effectiveness, and change in clinical practice or behavior.

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Authors' Contributions

LTC and NZ conceived the idea for the review. BMK, NS, and LTC wrote the review. LTC and PP provided methodological guidance, drafted some of the methodology-related sections, and critically revised the review. JV, PPG, IM, UD, AAK, CKN, and NZ provided comments on and edited the review.

Conflicts of Interest

None declared.

Multimedia Appendix 1

MEDLINE (Ovid) search strategy.

[PDF File (Adobe PDF File), 45KB-Multimedia Appendix 1]

Multimedia Appendix 2

Characteristics of included studies.

[DOCX File, 44KB-Multimedia Appendix 2]

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Abbreviations

2D: two-dimensional
3D: three-dimensional
GRADE: Grading of Recommendations, Assessment, Development and Evaluations
MCQ: multiple choice question
OSCE: objective structured clinical examination
SMD: standardized mean difference
VHP: virtual health professional
VP: virtual patient
VR: virtual reality
WHO: World Health Organization

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