The impact of using virtual patients in preclinical pharmacology teaching

Persoulla A. Nicolaou1,2 and Mamoun El Saifi3

1 Department of Basic and Clinical Sciences, University of Nicosia Medical School, Nicosia, Cyprus; 2 Division of Population Health Sciences & Education, St. George’s University of London, London, United Kingdom; and 3 MBBS Programme, St. George’s University of London, London, United Kingdom and the University of Nicosia Medical School, Nicosia, Cyprus

Submitted 21 January 2020; accepted in final form 27 May 2020

HOW WE TEACH | Classroom and Laboratory Research Projects

INTRODUCTION

Impact of Medication Errors

Reducing errors arising from the use of medicinal products remains a significant socioeconomic challenge. In fact, the European Medicines Agency (EMA) has referred to medication errors as a “major public-health burden” (15). It is striking that 106,000 and 197,000 deaths have been attributed to adverse drug reactions in the United States (US) and Europe, respectively (25). The financial burden is evident across the globe. In the United Kingdom (UK), it has been reported that £770 million were wasted in the National Health System in 2007 due to adverse drug reactions (16), whereas, in the US, medication errors were estimated to cost $21 billion annually (10). Importantly, some of these errors may be preventable. EMA has estimated that 18.7–56% of adverse drug reactions in hospitalized patients may be preventable (15), whereas, in the US, preventable medication errors are estimated to harm 7 million people annually (10).

Challenges in Preparing Future Prescribers

An important contributor to medication errors is irrational prescribing. It has been reported that, in Europe, 11% of patients have been prescribed wrong medication (33). There is a need to “nurture the early development of desired attitudes, which foster safe and rational drug prescribing” (17), and this may contribute to addressing the unmet need of reducing medication errors. Irrational prescribing may stem, at least partially, from a poor understanding of principles of drug action, adverse effects, contraindications, and potential drug–drug interactions (29). Indeed, it remains a challenge for medical educators to prepare medical students to become effective and safe prescribers. Accordingly, Kwan (24) has stated that “deficiency in the learning of pharmacological sciences in medical education has been a continuous plague in the system,” with many medical students complaining about their gap in pharmacology knowledge. Indeed, 75% (19) and 65.5% (36) of medical school graduates in the UK and Slovakia, respectively, did not feel confident enough in pharmacology for their future clinical practice.

The teaching of pharmacology is challenging because it requires students to integrate knowledge across disciplines, including physiology, pathology, and biochemistry. Furthermore, the vast number of drugs available on the market as well as the rapidly increasing development of new drugs make teaching and learning pharmacology a challenge. Traditionally, pharmacology has been taught using didactic, lecture-based learning (5), which often lacks clinical relevance and may predispose the learner to information overload. Furthermore, this method of teaching may promote a culture of passive learning.

Virtual Patients in Medical Education

To address the limitations of traditional teaching, educators have advocated the use of virtual patients (VPs) in medical education. A VP is an “interactive computer simulation of real-life clinical scenarios for the purpose of medical training, education or assessment” (13). VP branching case scenarios allow learners to emulate the role of healthcare professionals...
and make decisions about how to proceed in the care of the presented patient (2, 4, 14, 30, 40). In this way, they represent a more dynamic learning tool that involves more active learning. In fact, Begg and colleagues (1) proposed that branched VPs allow learners to move toward more abstract or higher thinking, as defined by Bloom’s taxonomy. Importantly, the use of VPs is aimed at helping students gain and apply knowledge in a safe, simulated environment, which they can subsequently apply to real clinical practice.

Even though much of the published literature is limited by virtue of design, lack of rigorous outcomes, absence of comparator groups, and lack of preintervention data (2, 7–9), recent systematic reviews and meta-analyses are consistent with beneficial effects of VPs. Specifically, Cook and colleagues (9) conducted the first systematic review and meta-analysis in 2010 and noted positive gains in knowledge outcomes, clinical reasoning, and other skills, compared with no intervention, whereas there was no significant difference compared with noncomputer instruction. A subsequent meta-analysis conducted 2 yr later noted a positive overall effect on communications skills, ethical reasoning, and clinical reasoning, when VPs were used as either an additional or alternative method (8). Similarly, in a more recent scoping review, Duff et al. (11) showed that virtual simulation was superior or comparable to traditional methods in promoting diagnostic reasoning.

Interestingly, VP scenarios are generally used in clinical years to encompass a range of skills needed by a junior doctor, including differential diagnosis, investigations, and management in a range of disciplines, such as geriatrics (32), surgery (21–23), anesthesia (26), and rheumatology (12). Even though scholars have advocated the use of VPs in preclinical teaching (2, 11), the use of VPs in preclinical years and in specific preclinical disciplines, including pharmacology, is not well-described in the literature.

Study Objectives

The present study aimed to explore the impact of introducing VP-based tutorials, to supplement traditional teaching, in a medical pharmacology course taught in preclinical years. The effect of this intervention on knowledge outcomes and student satisfaction and perceptions was investigated, compared with traditional case-based discussion and single-best-answer tutorials. The findings of the present study have the potential to inform modernization of traditional basic pharmacology curricula, which use predominantly lecture-based teaching. In fact, a recent study reported that 75% of basic pharmacology teaching in Europe is lecture based (5).

METHODS

Study Population

All year 3 students, in an undergraduate 6-yr medical program at the University of Nicosia Medical School, were invited to participate in the study. The study was carried out in two different cohorts during the academic years of 2017–2018 and 2018–2019 (in the study. The study was carried out in two different cohorts during the University of Nicosia Medical School, were invited to participate cohort 2 names during the study. Was maintained by using student identification numbers, rather than participation in the study. Participation was voluntary, and confidentiality (45%) female students in male students in academic year 2018–2019 attended four CBD/SBA-based tutorials and six VP tutorials. Our medical school has recently published one of the branched VP cases developed (30), which was delivered via the e-learning platform OpenLabyrinth (31). The curriculum content and delivery were equivalent in cohorts 1 and 2, just in two different academic years. It should be noted that when the study was repeated in cohort 2, the Scheme of Assessment in our medical program had changed; therefore, cohort 2 did not have a midterm examination.

The impact of VPs was assessed by 1) examination performance in the midterm versus the final examination in cohort 1; 2) examination performance in the final examination, which was comprehensive and included material from the entire semester, on items related to teaching using CBD/SBA-based tutorials, compared with VP-based tutorials (cohorts 1 and 2); and 3) student satisfaction and perceptions (35), using a validated, modified questionnaire (cohorts 1 and 2). The study design is shown schematically in Fig. 1.

The naturalistic study design was chosen for the study, rather than alternative study designs, such as a randomized control trial or a crossover study, to ensure that the academic ability of different students did not impact the results. Additionally, since our hypothesis

Study Design

This was a naturalistic, prospective study. The study was carried out as part of the course entitled, Systematic Pharmacology I. Specifically, this course was delivered, using a lecture-based format (3 h/wk). Learning was supported by a 1-h tutorial weekly. Lectures were delivered once to the entire cohort. For the tutorials, students were separated into two groups to allow more interactivity. There was a total of 10 tutorials in the semester.

Cohort 1 students (enrolled in year 3 in academic year 2017–2018) were taught during the first four tutorials using case-based discussion and single-best-answer questions (CBD/SBAs-control) before their midterm exam and VPs for the next six tutorials leading up to the final exam. Similarly, cohort 2 (enrolled in year 3 in academic year 2018–2019) attended four CBD/SBA-based tutorials and six VP tutorials. Our medical school has recently published one of the branched VP cases developed (30), which was delivered via the e-learning platform OpenLabyrinth (31). The curriculum content and delivery were equivalent in cohorts 1 and 2, just in two different academic years. It should be noted that when the study was repeated in cohort 2, the Scheme of Assessment in our medical program had changed; therefore, cohort 2 did not have a midterm examination.

The impact of VPs was assessed by 1) examination performance in the midterm versus the final examination in cohort 1; 2) examination performance in the final examination, which was comprehensive and included material from the entire semester, on items related to teaching using CBD/SBA-based tutorials, compared with VP-based tutorials (cohorts 1 and 2); and 3) student satisfaction and perceptions (35), using a validated, modified questionnaire (cohorts 1 and 2). The study design is shown schematically in Fig. 1.

The naturalistic study design was chosen for the study, rather than alternative study designs, such as a randomized control trial or a crossover study, to ensure that the academic ability of different students did not impact the results. Additionally, since our hypothesis

![Fig. 1. Study design. Students were taught during the first four tutorials using case-based discussion and single-best-answer questions (CBD/SBAs-control) before their midterm exam and virtual patients (VPs) for the next six tutorials leading up to the final exam. Similarly, cohort 2 attended four CBD/SBA-based tutorials and six VP tutorials. The impact of VPs was assessed by the following: 1) performance in the midterm (control) versus the final examination in cohort 1; 2) examination performance in the final examination, which was comprehensive and included material from the entire semester, on items related to teaching using CBD/SBA-based tutorials, compared with VP-based tutorials (cohorts 1 and 2); and 3) student satisfaction and perceptions (35), using a validated, modified questionnaire (cohorts 1 and 2). The study design is shown schematically in Fig. 1.](http://advan.physiology.org)
was that VP-based tutorials would confer beneficial effects, learners in the control group in alternative study designs may have perceived receiving traditional teaching as disadvantageous to their learning, and this was an important reason for the chosen study design.

Examination performance. Knowledge of pharmacology was assessed via a written examination consisting of 30 SBAs (midterm: cohort 1), 60 SBAs (final: cohort 1) and 100 SBAs (final: cohort 2). These exam lengths yield good internal consistency and reliability, as determined via the Kuder-Richardson 20 (KR-20) coefficient.

The examinations were constructed to assess application of knowledge rather than simple recall. Specifically, the questions were constructed to include a clinical scenario to contextualize information, followed by a lead-in question and five homogeneous options. As part of the internal evaluation process of examinations, questions not conforming to the basic principles of SBAs were flagged and either reworded or replaced.

To investigate whether performance of the students was dependent on the difficulty of the topic/item, we performed standard setting on all assessments used in this study, using the well-established standard-setting method of Angoff (4). This method is reliable and has been widely used to determine the pass-mark for high-stakes examinations.

Student satisfaction and perceptions. Student satisfaction and perceptions were evaluated using a 25-item questionnaire (35). This is a modified version of a tool that was shown to be valid when assessing perceptions of medical students regarding VPs. Students were asked to rate their extent of agreement with 25 statements, using a 5-point Likert scale. The questionnaire was divided into four different domains: 1) acquisition and maintenance of knowledge; 2) facilitation of learning; 3) inauthenticity of learning; and 4) disadvantages of learning. A high score in domains 1 and 2 denotes high perceived acquisition/maintenance of knowledge and facilitation of learning, whereas a low score in domains 3 and 4 signifies that learners perceived the cases to be authentic and that the mode of delivery was not disadvantageous to their learning.

Data Analysis

Statistical analysis was performed using the statistical software package SPSS 21.0 to identify any differences between the control and experimental group. Analysis of comparison data was determined by using t test. Significance was set at $P \leq 0.05$.

RESULTS

Examination Performance

All students (cohort 1: $n = 31$; cohort 2: $n = 44$) participated in this part of the study, as this was a mandatory component of the course.

Examination Performance in Cohort 1: Midterm versus Final Examination

As shown in Fig. 2, cohort 1 students performed significantly better in the final exam, compared with the midterm examination [midterm: 57.6% (SD 14.0); final: 62.8% (SD 11.3); $P = 0.04$]. It should be noted that both examinations showed good internal consistency and reliability, as determined by the KR-20 coefficient (midterm KR20 = 0.68; final KR20 = 0.75).

To investigate whether VP-based tutorials have differential beneficial effects on students, based on academic ability, as determined by a student’s grade point average (GPA), the performance of students with a GPA between 3 and 4 and students with a GPA <3 in the midterm and final exam was determined. As shown in Fig. 3, academic ability did not affect student performance in the midterm [GPA 3–4: 58.8% (SD 16.4); GPA <3: 55.8% (SD 7.9)], which utilized traditional teaching in tutorials. However, the performance of students with a higher GPA was significantly increased in the final examination, compared with students with a lower GPA [GPA 3–4: 66.4% (SD 10.2); GPA <3: 56.5% (SD 9.6); $P = 0.02$], suggesting that students with higher academic ability benefited more from the intervention, i.e., the VP-based tutorials.

To investigate whether increased academic performance between the midterm and final examination was related to nonspecific academic improvement, e.g., improved study technique and familiarity with the subject matter as the semester progressed, we investigated performance of students in the other written examinations of the same semester. The results showed that there was no significant change in performance in Medical Genetics between the midterm [64.7% (SD 12.3)] and the final examination [64.5% (SD 8.7)], while students showed lower performance in the final examination of Immunology [63.3% (SD 10.7)] and Pathology II [67.6% (SD 14.1)], compared with the midterm [Immunology: 68.4% (SD 17.7); Pathology II: 85.9% (SD 9.6); $P \leq 0.001$]. These results suggest that the increased performance in Pharmacology may be attrib-

Fig. 2. Examination performance in cohort 1. Students performed significantly better in the final exam, after the virtual patient-based tutorials, compared with the midterm exam. Values are means ± SD; $n = 31$ students. *$P = 0.04$, using paired $t$ test.

Fig. 3. Academic ability and examination performance in cohort 1. Academic ability, as determined by a student’s grade point average (GPA), did not affect student performance in the midterm, which utilized traditional teaching in tutorials. However, the performance of students with a higher GPA was significantly increased in the final examination, compared with students with a lower GPA. Values are means ± SD; $n = 19$ students (GPA 3–4); $n = 12$ students (GPA <3). *Final examination: GPA 3–4 and final examination GPA <3, $P = 0.02$, using unpaired $t$ test.
uted to the intervention (i.e., VP), rather than improved academic performance in general.

Another potential explanation for the increase in examination performance in the Pharmacology final examination, which was comprehensive and assessed material from the entire semester, could be mastery of material that was already assessed in the midterm. As shown in Fig. 4, there was no increase in the performance of items assessing midterm material in the final examination [midterm: 57.6% (SD 14.0); SBA/CBD in final examination: 57.8% (SD 18.0)], suggesting that the improved performance may be associated with VP-based tutorials rather than mastery of reassessed material.

Examination Performance in Final Examination: Cohorts 1 and 2

To further investigate the effect of VP-based tutorials on the final examination performance of both cohorts, we isolated student performance on the items taught via CBD/SBA-based tutorials, compared with items assessing material taught via VP-based tutorials. As shown in Fig. 4, performance on items taught via VP-based tutorials increased, compared with control items in both cohorts [cohort 1: SBA/CBD: 57.8% (SD 18.0); VP: 64.4% (SD 21.6); cohort 2: SBA/CBD: 53.4% (SD 20.1); VP: 58.7% (SD 16.8); cohorts 1 and 2: SBA/CBD: 54.7% (SD 19.6); VP: 61.2% (SD 19.2); P = 0.04]. Similar to the midterm examination and final examination in cohort 1, the final examination for cohort 2 also showed good internal consistency and reliability, as determined by the KR-20 coefficient (KR20 = 0.82).

Item Difficulty of Assessments

To investigate whether the improved performance of students on the items taught via VP-based tutorials was confounded by item difficulty in the examinations, standard setting was carried out on all assessments used in this study using the well-established standard-setting method of Angoff (4). Our results showed that all three examinations used in the study were of equivalent difficulty, as shown by similar determined pass marks (midterm: 54.0%; final examination cohort 1: 51.2%; final examination cohort 2: 50.9%). Importantly, the difficulty of the items in the final examinations of both cohorts assessing material in SBA/CBD- and VP-based tutorials was not significantly different (cohort 1: SBA/CBD: 51.0%; VP: 51.2%; cohort 2: SBA/CBD: 50.5%; VP: 51.3%). This suggests that the beneficial effects of VP-based tutorials are not attributed to easier topics or items.

Student Satisfaction and Perceptions

This part of the study was conducted on a voluntary basis. There were 52 (cohort 1: n = 26; cohort 2: n = 26) and 46 (cohort 1: n = 20; cohort 2: n = 26) students who filled out the questionnaire survey about CBD/SBAs and VPs, respectively (Fig. 5).

Dimension 1: Acquisition and maintenance of knowledge. Students perceived both types of tutorials to be effective in facilitating acquisition and maintenance of pharmacological knowledge, including understanding of pharmacological principles, mechanism of action, adverse drug reactions, and rational clinical use [control: 4.45 (SD 0.46); VPs: 4.46 (SD 0.50)].

Dimension 2: Facilitation of learning. Students perceived the VP-based tutorials to facilitate their learning to a higher extent, compared with the CBD/SBA tutorials [control: 3.49 (SD 0.76); VPs: 3.87 (SD 0.70); P = 0.01]. Specifically, students noted that VP-based tutorials facilitated teamwork more effectively during the sessions, while they were also an efficient learning tool for independent learning.

Dimension 3: Inauthenticity of learning. Students rated both types of tutorials favorably in terms of authenticity of learning and representation of cases they are likely to

![Fig. 4. Final examination performance in cohorts 1 and 2. Students in cohorts 1 and 2 performed significantly better on assessment items related to teaching in virtual patient (VP)-based tutorials, compared with single-best-answer question and case-based discussion (SBA/CBD)-based tutorials. Values are means ± SD; cohort 1: n = 31 students; cohort 2: n = 44 students. *Final cohorts 1 and 2: SBA/CBD, and final cohorts 1 and 2: VP. P = 0.04, using paired t test.](http://advan.physiology.org)
encounter in clinical practice [control: 1.67 (SD 0.67); VPs: 1.63 (SD 0.61)].

Dimension 4: Disadvantages of learning. Students did not perceive either type of tutorial to be disadvantageous to their learning. Specifically, learners found the tutorials to be of appropriate difficulty for their stage of learning, requiring an appropriate amount of time. Importantly, students did not feel disadvantaged by the differing role of the tutor, i.e., as a teacher in CBD/SBAs and a facilitator in VP tutorials [control: 1.53 (SD 0.54); VPs: 1.59 (SD 0.59)].

Linear regression analysis, using the coefficient of determination ($R^2$), was used to investigate a potential correlation between enhanced student performance in items assessing VP-based tutorials and student satisfaction. Our results showed that there was no correlation between student satisfaction and examination performance (data not shown).

DISCUSSION

Even though VPs have been predominantly used in clinical teaching, the results of the present study suggest that this is an efficacious tool that can be effectively incorporated into preclinical teaching, with enhancement of knowledge outcomes and facilitation of learning in Systematic Pharmacology.

Increased Knowledge Outcomes

The results of the present study suggest that the use of VPs has beneficial effects on acquisition and application of knowledge, as shown by the increased examination performance in the final examination, compared with the midterm examination in cohort 1. It is important to consider that our results may have been confounded by the testing effect.

In fact, scholars have shown that engaging in a test, in our case the midterm, may serve as a significant learning event, improving retention and recall, compared with studying (3, 34, 37). Thus the testing effect could have, at least partially, been responsible for the improvement in the final examination in cohort 1. However, when we compared performance in the final examination on the material previously assessed in the midterm, we did not observe an increase in performance in those items, suggesting that the increase in the final examination performance was not attributed to mastery of material reassessed in the midterm examination, which would be consistent with the testing effect.

Furthermore, when assessment items in the final examination of both cohorts were isolated to investigate student performance on items taught via CBD/SBA- compared with VP-based tutorials, a significant increase in performance was also noted, further suggesting that VP-based tutorials can enhance knowledge outcomes.

These findings are consistent with previous studies, which have shown improved knowledge outcomes in clinical courses. For example, Leung and colleagues (26) have showed that examination performance in the end-of-module multiple-choice question paper, the essay paper, and the end-of-year final surgery paper was significantly increased in final-year medical students exposed to branched VPs, compared with story-line VPs, in an anesthesia course. Similarly, students from four different medical schools in the US, who had completed clinical rotations in surgery-urology, showed increased test scores when using VPs, compared with traditional structured ward teaching (21). The positive effect of VPs is also supported by a study carried out at the University of Western Ontario in an undergraduate otolaryngology course, which compared VPs to internet-based learning, with positive effects on posttest results (20). It should be noted that some studies have suggested that VPs may not provide significant benefits. For example, the use of VPs, compared with no intervention, during a fourth-year surgical clerkship showed that, while there was improvement in history taking, there was no significant difference in appropriate use of diagnostic tests, differential diagnosis, and management plans, as evaluated by a seven-part, paper-based examination (38). However, an overall positive effect of VPs is starting to emerge, as indicated by recent meta-analyses and systematic reviews (8, 9, 11).

As far as efficacy of VPs in preclinical disciplines is concerned, there is a clear evidence gap in the literature. A recent study, in first-year undergraduate students at the University of Copenhagen, who had a single didactic session followed by a VP tutorial, showed increased knowledge in medical genetics counseling, as assessed by a pre- and posttest (27). However, this study only explored the effect of a single case and did not utilize a comparator group, thus making it difficult to compare VP-based teaching to traditional teaching methods. Importantly, the pre- and posttest questions were the same, which may have affected student performance. The present study utilized a longer intervention and written examinations with
high reliability, as exemplified by the KR-20 coefficients, which showed that VP-based tutorials had positive effects on learning outcomes, compared with traditional tutorials. As such, this study provides important insight into the efficacy of VPs in a preclinical discipline. It is interesting to note that, while our results on examination performance are indicative of positive effects on knowledge acquisition, this was not reflected in student perceptions, as assessed by the student survey (dimension 1). Students, in fact, perceived both tutorials to be equally effective in helping them acquire and maintain knowledge. However, it is important to note that students rated tutorials very highly, providing ratings of almost 4.5 on a 5-point Likert scale, for both types of tutorials.

Disadvantages of Learning and Authenticity of Teaching

While scholars have advocated for the use of VPs in earlier points in a medical curriculum, a potential concern raised is cognitive overload due to inappropriate levels of difficulty (17). Our findings suggest that students perceived the cases to be appropriately demanding for their stage in learning (dimension 4). Beyond the fact that the cases were written, with the learner’s background in mind, the fact that tutorials followed a didactic session may have been beneficial. In fact, Marei and colleagues (28) have recently shown that a VP tutorial delivered after a didactic lecture requires minimal investment of cognitive load.

Importantly, even though the cases did not follow the most widely used format of history taking, differential diagnosis, investigations, and management due to their early place in the curriculum, students perceived them to represent authentic teaching (dimension 3).

Facilitation of Learning

Several studies have shown that learners perceive VPs to be effective in facilitating their learning, due to time efficiency (20, 21, 28, 39) and collaborative teamwork (12, 18). Consistently, rigorous qualitative studies, evaluated as part of a recent systematic review and meta-analysis, identified efficiency and accommodation in a busy schedule, as well as group work as factors, which facilitated student learning (9). This review also identified student independence as an important emerging theme (9). These studies have been carried out primarily in clinical years. The results from our study suggest that VPs, when used in preclinical teaching, can facilitate learning to a greater extent, compared with traditional teaching, due to teamwork, independent learning, and time efficiency (dimension 2), in concordance with the aforementioned results in clinical teaching.

Limitations

While all year 3 students from two different cohorts were invited to participate (i.e., a total of 75 students), the response rate was moderate, with 52 of 75 students (69%) and 46 out of 75 students (61%) filling out the questionnaire survey about CBD/SBAs and VPs, respectively. It should be noted, however, that results in each dimension of the questionnaire were consistent in both cohorts, suggesting that the results are reproducible across cohorts. The results on the examination performance are limited by the fact that these were only obtained in cohort 1, since the Scheme of Assessment had changed and cohort 2 students did not have a midterm examination. It should be noted, however, that, since the exam was a compulsory part of the course, data from all cohort 1 students have been included in the present study. The fact that enhanced performance was only observed in the Pharmacology course, and not in Medical Genetics, Immunology, or Pathology, further supports the notion that the intervention (i.e., VPs) may support learning. Consistent with the beneficial effects of VP-based tutorials, increased performance was also noted on the final examination assessment items taught via VP-based tutorials, compared with those taught via CBD/SBA-based tutorials in both cohorts. Other study designs, such as randomized controlled trial and crossover design, may further corroborate the results.

Conclusion

It is not currently clear which learners at which stage of learning would benefit from VPs. The present study provides important insight into the use of VPs in a preclinical setting, with statistically significant advantages in 1) knowledge acquisition and application, as assessed by written exams; and 2) perceived advantages in facilitation of learning.

ACKNOWLEDGMENTS

Special thanks go to Sheetal Kaval for providing technical support for the use of OpenLabyrinth software. We are grateful to the course leads of Medical Genetics, Prof Adonis Ioannides, Immunology, Dr. Vicky Nikolaidou and Pathology, and Dr. Dimitrios Kanakis for the midterm and final examination results of their respective courses.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

P.N. conceived and designed research; P.N. and M.E.S. performed experiments; P.N. and M.E.S. analyzed data; P.N. and M.E.S. interpreted results of experiments; P.N. prepared figures; P.N. drafted manuscript; P.N. and M.E.S. edited and revised manuscript; P.N. and M.E.S. approved final version of manuscript.

REFERENCES

1. Begg M, Ellaway R, Dewhurst D, Macleod H. Transforming professional healthcare narratives into structured game-informed-learning activities. *Innovate J Online Educ* 3: 6, 2007.
2. Berman NB, Durning SJ, Fischer MR, Huwendiek S, Triola MM. The role for virtual patients in the future of medical education. *Acad Med* 91: 1217–1222, 2016. doi: 10.1097/ACM.0000000000001146.
3. Binks S. Testing enhances learning; A review of the literature. *J Prof Nurs* 34: 205–210, 2018. doi: 10.1016/j.profnurs.2017.08.008.
4. Brandon PR. Conclusions about frequently studied modified Angoff standard-setting topics. *Appl Meas Educ* 17: 59–88, 2004. doi: 10.1207/s15324818ame1701_4.
5. Brinkman DJ, Tichelaar J, Okorier M, Bissell L, Christiaens T, Likic R, Maculaitis R, Costa J, Sanz EJ, Tamba BI, Maxwell SR, Richir MC, van Agtmael MA; Education Working Group of the European Association for Clinical Pharmacology and Therapeutics (EACPT). Pharmacology and therapeutics education in the European Union needs harmonization and modernization: a cross-sectional survey among 185 medical schools in 27 countries. *Clin Pharmacol Ther* 102: 815–822, 2017. doi: 10.1002/cpt.682.
6. Cendan J, Lok B. The use of virtual patients in medical school curricula. *Adv Physiol Educ* 36: 48–53, 2012. doi: 10.1152/advan.00054.2011.
7. Consorti F, Manfuso R, Nocioni M, Piccolo A. Efficacy of virtual patients in medical education: a meta-analysis of randomized studies. *Comput Educ* 59: 1001–1008, 2012. doi: 10.1016/j.compedu.2012.04.017.
Advances in Physiology Education • doi:10.1152/advan.00009.2020 • http://advan.physiology.org