



Helyer, R., & Dickens, P. (2016). Progress in the utilisation of high-fidelity simulation in basic science education. *Advances in Physiology Education*, 40(2), 143-144. DOI: 10.1152/advan.00020.2016

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**Progress in the utilisation of high-fidelity simulation in basic science education**

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Running header

Simulation in basic science education

Disclosures

No conflicts of interest, financial or otherwise, are declared by the author(s)

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Contributions of authors

RH and PD equally contributed to the content of this discussion. RH drafted manuscript. PD revised manuscript. RH prepared final version.

Keywords

High-fidelity simulation basic science education

## **Abstract**

High-fidelity patient simulators are mainly used to teach clinical skills and remain under-utilised in teaching basic sciences. This article summarises our current views on the use of simulation in basic science education and identifies pitfalls and opportunities for progress.

## **Article**

High-fidelity patient simulators are normally defined as life-like, computer model-driven manikins that show realistic clinical signs, are responsive to interventions including drug administration, and may be used to display and record physiological data. They can be programmed to demonstrate medical conditions and emergencies, and are typically used to teach clinical skills. This teaching is usually delivered to student cohorts other than those in early years of undergraduate courses or those studying the basic sciences that underpin medicine such as physiology and pharmacology. It is now some 15 years since seminal papers by Euliano and others (2,3,4,13) first described the use of human patient simulators to teach key principles of normal human physiology. It is 10 years since adoption of the CAE Human Patient Simulator (HPS; CAE Inc.) at the University of Bristol in the teaching of early-years undergraduates in science programmes as well as medicine, and some 5 years since the Bristol approach was summarised by Harris et al. (5). This approach makes use of the underlying model of the high-fidelity simulator to teach aspects of normal homeostatic mechanisms and responses to perturbations. The emphasis is on observing, recording and analysing physiological data rather than treating the simulated patient.

In Bristol, over the past 10 years, we have continued to develop simulation as a core part of the curriculum embedded alongside traditional lecture, tutorial and practical class teaching (5). We currently use HPS to teach seven separate scenarios in physiology and pharmacology across three basic science and three professional programmes including medicine. These scenarios have been developed 'in-house' to demonstrate key principles, allowing students to record and analyse physiological parameters involved in homeostatic mechanisms. These values are derived from the model, and are often different from those obtained by palpation or by display on clinical monitors, e.g. real time changes in gas partial pressures and pH. Over 1000 students per year receive some form of simulation teaching in their first two undergraduate years. Final year basic-science students are also able to select 'laboratory' projects using simulators to explore in-depth aspects of integrated human physiology that would otherwise be impossible e.g. altitude and descent to depth, an approach similarly reported elsewhere (8).

Despite these exciting innovations, high-fidelity simulators with a functional physiological model are still under-utilised in basic science teaching, with only few reports in the literature (8,12). In fact, the converse is probably true in that these simulators are more typically utilised in teaching basic skills that do not require high-fidelity models – the 'fidelity trap' (9). Further, there may be a misconception as to what is actually being taught using simulation. Teaching that demonstrates generalised changes in heart rate and blood pressure during bleeding to nursing students, although clearly valuable, is far removed from using simulated physiological data to effectively demonstrate the action of Starling's law during haemorrhage in real-time. The latter is an example of teaching aimed at explaining complex principles that students may find difficult. The potential for using simulators in this type of teaching was first shown by (2,3,4) and further developed at Bristol (reviewed by 5) and a small number of locations elsewhere (including 12).

The question remains as to why high-fidelity simulation still remains under-utilised in teaching basic science despite this potential and the increased adoption among teaching hospitals and university departments for clinical teaching. A number of factors may be involved. First, developing physiologically accurate scenarios can be difficult and time consuming. Although high-fidelity simulators are made commercially available with pre-configured scenarios, these tend to be aimed at revealing clinical signs and values for display on clinical monitors. By contrast, underlying variables of key interest to a physiologist may be overlooked and lack fidelity. Therefore scenarios should be validated against published human data (5,10), which itself may be scarce, and the model subsequently modified in order to improve fidelity. Second, there are few simulators with an effective, integrated physiological model that produce data required for full exploration of physiological principles, and these are expensive in terms of basic cost and servicing. Other less expensive, commonly adopted simulators may fall short in terms of integration of even the most basic cardio-respiratory responses. Third, faculty may be wary of using simulator models versus traditional teaching or non-integrated computer simulations which may produce accurate, but limited, data in terms of homeostatic integration with other systems, e.g. an isolated heart model. In Bristol, concerns by faculty around the fidelity of pharmacological models of HPS vs stand-alone computer simulations for calculating dose-responses and drug interactions have hampered wider adoption. This is despite the attraction of being able to demonstrate effects across body systems. Finally the complexity of scenario creation may dissuade even the keenest developer. It is very easy to produce a simple model of, say, blood loss that can be demonstrated at a superficial level. It is very hard to develop one where all relevant physiological variables closely match published human data.

Matching data produced by scenarios with the literature is an example of the highly accurate, validated approach taken in Bristol. To add a further level of fidelity in terms of simulating homeostatic interactions, we adopted a 'dogma' that our scenarios should be exclusively 'model-driven'. In theory, this means that layers of changes and perturbations can be applied over the primary scenario. For example, in demonstrating the response to low inspired O<sub>2</sub>, rather than simply setting controllable variables to simulate the response data were entirely based on the actual response of the simulator via its 'lung' and in real-time. To do this, the basis must be a reasonably accurate model with responses that can be fine-tuned by applying gains and factors to variables, rather than overrides. Certainly simply presenting static data to students, for example when blood-gases are requested verbally, should be avoided. Achieving this, though, and ensuring values remain within published or accepted ranges adds considerable complexity to scenario development.

The question remains even for the teaching of basic science in some detail, is this level of model-driven fidelity required? Are even physiologists, who may be using simulation effectively, caught in the 'fidelity-trap'. Has this trap hampered wider utilisation of simulation in basic-science teaching? It is evidently far more practical to produce accurate data by applying overrides and 'fixes' to models to produce data at valid values in terms of the literature, and as importantly, what students might expect to see in a textbook. This approach is also repeatable, as data will be identical for each session – in the model-driven HPS equipped with a lung, respiratory data in particular vary from run to run and drift over time. Further, setting variables to fixed values avoids having to work within a complex model with feedback loops where changing one parameter will have knock-on consequences on another. In other words inconvenient homeostatic algorithms can be circumvented. Finally, we could ask why use a simulator at all? This question is beyond the scope of the current discussion.

The future for high-fidelity simulation in basic science education may be in finding a middle-way. Some lower-cost simulators without the ability of the HPS to effectively exchange gases or operate with a ventilator utilise similar physiological models (it should be noted that not all do, e.g. presentation of blood gas data, so careful choice of mid-range platform is required). In fact, a mixed-approach to producing teaching scenarios with some data produced by model-driven aspects of the scenario, and others determined by over-rides, can produce data where a dogmatic, purely model-driven approach fails. An example is the demonstration of the classic alveolar gas equation derived by Fenn, Otis and Rahn that shows the relationship between  $O_2$  and  $CO_2$  (learning opportunities described by 1). An accurate demonstration of this equation is not possible using a CAE HPS with a lung. However, using the HPS software-model alone, or with a manikin that does not have a lung, extremely accurate results can be obtained compared to published human data (6).

There is a final area of consideration for even the keenest adopter that remains a prevailing question. Does using high-fidelity simulation in basic science education improve learning outcomes? Here there is very little evidence. There is little doubt that simulation in the broadest sense is an effective tool in improving learning and outcomes in medical education (11). However, this is probably most apparent in disciplines assessed via achievement of skills and day-one competencies. In other areas, the relatively scarce evidence centres on improving student confidence or in preferential learning methods (5) rather than in measurable improvements in examination results. The wide adoption across programmes in Bristol provided an opportunity to evaluate improvements in learning using similar cohorts with and without simulation, but any measurable effect was small (7). This is not limited to simulation, as assessing impact on learning in terms of measurable outcomes is notoriously difficult. We may take some solace by consider whether this is really an

issue in a climate where student satisfaction and learning-method preference seems to be becoming a prevailing driver.

In the light of this discussion, we conclude that high-fidelity simulation in basic science education remains an under-developed resource with considerable potential. By careful matching of hardware and software to teaching and learning objectives, it remains a potentially highly-effective tool.



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