Richard Say[1] / Denis Visentin[2] / Vasiliki Betihavas[3] / Susannah Minutillo[4]

A Cognitive Load Theory Simulation Design to Assess and Manage Deteriorating Patients

[1] College of Health and Medicine, University of Tasmania, Sydney, New South Wales, Australia, E-mail: Richard.Say@utas.edu.au
[2] College of Health and Medicine, University of Tasmania, Sydney, New South Wales, Australia, E-mail: Denis.Visentin@utas.edu.au. https://orcid.org/0000-0001-9961-4384.
[3] Faculty of Medicine & Health, University of Sydney, Sydney, New South Wales, Australia, E-mail: vasiliki.betihavas@sydney.edu.au
[4] Australian Institute of Management, Sydney, New South Wales, Australia, E-mail: susannah.minutillo@gmail.com

Abstract:
Background: Cognitive load theory (CLT) uses an understanding of brain architecture for educational design, with implications for simulation. Since working memory is limited, minimising extraneous cognitive load improves learning of new tasks (intrinsic load) and use of existing knowledge (germane load). This study evaluates the effectiveness of low-fidelity simulation (LFS) utilising CLT principles in the assessment and management of the deteriorating patient (AMDP).
Method: CLT design principles informed the choice of LFS and simulation design. The self-rated ability of 13 undergraduate nurses across seven aspects of AMDP was measured in a pre-post design.
Results: Self-rated ability increased from 2.98 (SD = 0.19) to 4.47 (SD = 0.12) ($p < 0.001$), with improvements across all AMDP aspects.
Conclusion: This study indicates that CLT informed design has benefits for simulation. LFS may be preferred to high fidelity simulation for AMDP teaching and medical simulation for novice learners.

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Introduction

Despite the importance of early assessment and management of the deteriorating patient (AMDP), many nurses are underprepared to deal with these situations leading to deleterious patient outcomes (Purling & King, 2012). Undergraduate education is a key starting point to enable clinicians to manage the acutely ill patient effectively (Smith, Perkins, Bullock, & Bion, 2007), with a number of simulation education programs implemented to train pre-registration clinical students and junior nurses in AMDP (Purling & King, 2012; Smith et al., 2007). However, a trend towards high-fidelity simulation (HFS) as a teaching platform raises concerns about affordability and its capacity as a medium to achieve anticipated learning outcomes (Levett-Jones, Lapkin, Hoffman, Arthur, & Roche, 2011; Zendejas, Wang, Brydges, Hamstra, & Cook, 2013). While definitions of simulation fidelity are inconsistent, fidelity can be broadly defined as the extent a simulation represents a real-world scenario (Tun, Alinier, Tang, & Kneebone, 2015). The fidelity approach chosen and the design of specific simulation-based training need to be evidence based and optimally designed to achieve specific educational objectives. Cognitive Load Theory (CLT) provides important considerations for the design of simulation training (Reedy, 2015). While nursing literature tends to analyse simulation from a teaching perspective, the cognitive processes involved in learning must be considered in order to maximise students' development of skills, knowledge and dispositions (Kaakinen & Arwood, 2009). There are important educational frameworks from the field of CLT and elsewhere indicating that low fidelity simulation (LFS) may be a more appropriate alternative for the training of undergraduate nursing students in AMDP.

This paper presents a LFS intervention modelled on a design used in a UK medical school (Cave et al., 2007). A CLT framework is utilised to inform best practice to optimise learning for medical simulation (Fraser, Ayres, & Sweller, 2015). The impact of the intervention on the confidence of undergraduate nurses in AMDP was measured in a pre-post design.

Denis Visentin is the corresponding author.

Managing the deteriorating patient

Early recognition and management of deteriorating patients significantly reduces the incidence of cardiac arrest in hospital (Chan, Jain, Nallmothu, Berg, & Sasson, 2010). As the majority of cardiac arrests occur on medical/-surgical wards, ward nurses are in a pivotal position to identify and act on the early signs of deterioration (Gordon & Buckley, 2009; Odell, Victor, & Oliver, 2009).

Despite the important role expected of nurses in AMDP, many nurses are deficient and lack confidence in these skills (Odell et al., 2009). Pre-registration training is a key starting point for improving overall clinician performance. However, research has exposed significant deficits in the ability of final-year nursing students and graduate nurses to recognise and manage deteriorating patients (Purling & King, 2012).

Cognitive load theory

CLT is an instructional model describing how the brain, with a limited working memory and an effectively unlimited long-term memory, processes and stores new information. This understanding informs instructional design, which is improved when the extraneous cognitive load associated with learning is reduced. Learning can be defined as a change in long-term memory (Kirschner, Sweller, & Clark, 2006), by the incorporation of novel information, which is processed by working memory to develop and build on existing cognitive schemas. As working memory is only able to process a very limited number of elements simultaneously (Baddeley, 2012; Miller, 1956), the presentation and structure of instructional materials is of paramount concern when designing instructional materials (Sweller, 1999).

The total cognitive load relates to the amount of information that working memory can process at any one time, with this load coming in a number of forms. Three types of cognitive load have been identified: intrinsic load, germane load and extraneous load (Table 1). The intrinsic load is the required material to be learnt or task to be performed, the germane load is the pre-learnt knowledge which will aid the learner in learning the new information, while the extraneous load is the unnecessary cognitive load that adversely affects learning. It is this extraneous load, which relates to the presentation and design of learning activities, that educational designers can often manipulate to optimise learning (Chandler & Sweller, 1991).

Table 1: Types of cognitive load and examples from learning to read and AMDP simulation.

Cognitive load type	Definition	Learning to read	Assessing and managing the deteriorating patient simulation
Intrinsic	Required material to be learnt or task to be performed	Reading simple sentences	Applying a systematic approach. Identifying key signs of deterioration. Recognising and implementing appropriate interventions e.g. oxygen therapy, fluid administration, positioning.
Germane	Helpful pre-learnt knowledge needed for the required task	Phonemic awareness - the relationship between sounds and symbols	*Knowledge* of basic physical assessment e.g. taking vital signs, auscultation, palpation. Oxygen administration through simple oxygen masks, basic medicine administration.
Extraneous	Unnecessary cognitive load that adversely affects learning	Illustrations which are distracting and/or redundant to the task of reading	Aspects of simulated environment not related to the task e.g. noisy hospital ward. Potential patient management (e.g. demonstration of heart sound auscultation), if not a simulation learning objective. Management of potentially psychologically stressful situations.

Research has consistently shown that learning increases as a direct result of reducing the extraneous load placed on the learner through ineffective teaching and design methodologies. This effect has been observed across numerous educational contexts and is most pronounced for novice learners (Sweller, 2016). For example, removing illustrations from text has been shown to improve the reading development of children (Torcasio & Sweller, 2010). This reduction of extraneous load (the illustrations) improves the child's ability to utilise the germane load (knowledge of relationships between alphabetical symbols and sounds) to deal with the intrinsic load of decoding words (Table 1).

Emotion also contributes to the extraneous load within the educational setting. While heightened emotion may assist in retrieving learnt information (it is more "memorable"), it generally inhibits learning. Hence the design of educational material should generally limit the emotional load, a principle which has been demonstrated in medical simulation (Fraser et al., 2015).

Low-fidelity simulation

One mode of education used to improve the AMDP skills of students and clinicians is simulation. Simulation is commonly used to develop clinical judgement and skills of undergraduate nurses in a risk-free environment (Chmil, Turk, Adamson, & Larew, 2015; Ochylski, Aebersold, & Kuebric, 2017).

One variable available in simulation design is the fidelity. Levels of simulation fidelity are inconsistently defined owing to the numerous facets that influence the extent to which relevant clinical settings are replicated. Thus, distinguishing between lower and higher modes of simulation can be challenging (Tun et al., 2015). Fritz, Gray, and Flanagan (2008) describe three elements that determine the fidelity of simulation. "Equipment fidelity" is determined by the realism of hardware and/or software, and the extent to which information is fedback to the participant. For example, LFS manikins are those that represent anatomical features only, whereas HFS complements this anatomical representation with physiological and vocal feedback (Grady et al., 2008). "Environmental fidelity" refers to the simulation setting and finally, "Psychological fidelity" is the level to which the simulation is felt as an authentic experience by the learner. These elements must be carefully considered against the intended learning outcomes of a session and the level of the learner (Fritz et al., 2008).

Issues of cost and under-utilisation have driven debate around the value of higher-fidelity technologies. The cost of set-up and ongoing maintenance, time constraints on faculty, and lack of training in the use of the hardware and software interface are identified as barriers to implementation of HFS programs (Jarzemsky, McCarthy, & Ellis, 2010; Kardong-Edgren, Starkweather, & Ward, 2008; Rudd, Freeman, Swift, & Smith, 2010). The use of HFS must be justified by evidence that it is an improvement over LFS approaches for particular learner outcomes and learner level (Kardong-Edgren, Lungstrom, & Bendel, 2009; Levett-Jones et al., 2011).

The ability of LFS to deliver quality educational outcomes is often overlooked in university settings (Rudd et al., 2010). While there is some evidence of an association between higher level learning and HFS (Butler, Veltre, & Brady, 2009), a number of studies have found no significant difference in learning outcomes when comparing HFS to lower-fidelity simulation (Hayden, Smiley, Alexander, Kardong-Edgren, & Jeffries, 2014; Levett-Jones et al., 2011).

While numerous papers have looked at the use of HFS to teach undergraduate nurses AMDP (Kardong-Edgren et al., 2009; Levett-Jones et al., 2011), sparingly little has been reported on the use of low-fidelity simulation approaches. This is despite evidence that LFS has been demonstrated to be effective in teaching other groups of novices AMDP skills (Cave et al., 2007; Smith, Osgood, & Crane, 2002).

The CLT framework explains why LFS may be more effective for novice learners than HFS in some contexts. The educational setting involving simulation is multi-faceted and ever-changing due to rapid advancement in technology. In particular, HFS provides a wonderfully rich learning experience, but also comprises a high cognitive load. As the reduction of extraneous load has been demonstrated to improve learning for more novice learners (Young, Van Merrienboer, Durning, & Ten Cate, 2014), HFS is likely to be most advantageous for more experienced learners in preparation for the clinical practice setting (Josephsen, 2015). The range of simulation techniques available allow for a tailored approach to educational design with the choice of simulation type depending not only the learning task, but also taking into consideration the level of the learner. The fidelity of the simulation should increase in step with the development (learnt information) of the learner. Since HFS more accurately portrays the complex clinical environment which can be emotionally charged, the simulation experience has an extraneous emotional load which may impede learning. While learning to cope with stresses associated with situations such as deteriorating patients is an important part of undergraduate training, this should only be introduced once undergraduate nurses have developed other skills.

LFS is cost-effective, accessible and requires minimal supervision without the software or hardware requirements of HFS. These factors allow students to refine performance through *deliberate practice*, a process ideal for novice students to progress towards skill mastery through repetition (Anders Ericsson, 2008). It is important that nurses learn and practice general skills first, and then as they develop cognitive schemas, these pre-learnt skills can be incorporated and applied to new contexts and more complex scenarios.

Methods

Participants

All second-year students enrolled in an undergraduate nursing program (n = 92) were invited by email to participate in the AMDP workshop. Fourteen students attended the workshop and 13 consented to be participants in the study. Those attending the workshop had a mean age of 41.0 (SD = 11.0) years and there were 12 female and 2 male attendees. Ethics approval was received from the University of Tasmania Social Sciences Human Research Ethics Committee (Ethics #H0013951) and participation was anonymous and voluntary.

Intervention

The LFS workshop was informed by an approach used at a London medical school for undergraduate students (Cave et al., 2007) and utilised principles from the UK Acute Life-threatening Events – Recognition and Treatment (ALERT) program, a one-day course that focusses on the deteriorating patient (Smith et al., 2002). The workshop instructor, a nurse lecturer, delivered two 45-minute discussions on AMDP. Each discussion was followed by one-hour role-play simulation activities, in which students worked together in groups of three. The first discussion described the ABCDE framework for managing patient deterioration. The second discussion explored and debriefed students' experience of the first role-play simulation.

Repetition of the activities with ongoing peer feedback was encouraged, consistent with a deliberate practice approach – a simulation method recommended by Massey, Chaboyer, and Anderson (2017) for training nurses to recognise and respond to clinical deterioration. Role-play between participants was used to practice the ABCDE approach (Airway, Breathing, Circulation, Disability, Exposure). ABCDE is a commonly used systematic approach to AMDP, with role interchange an important element (Featherstone, Smith, Linnell, Easton, & Osgood, 2005).

Each group of three was provided with three, 20-minute deteriorating patient scenarios to practice. For each scenario, a student would play the role of *Clinician* and attempt to manage the clinical presentation using an ABCDE approach. One student played the role of *Assessor*, using a step-by-step scenario sheet set out in the ABCDE format to guide the simulation (see Supplementary File 1). The *Assessor* would give information based on scenario details, only when requested by the *Clinician*. For example, the *Clinician* – who did not have a scenario sheet to refer to – may ask for observations or other details of the patient presentation, or how the patient responded to an intervention. The *Assessor* would provide these details based on information on the scenario sheet.

The third student would play the role of *Patient*, who was instructed to role-play presentations such as pain or confusion. The *Patient* also had a scenario sheet to guide responses. As the student playing the *Patient* was unable to replicate the majority of physiological details for the scenario, this method of simulation remained very much on the low-fidelity end of the spectrum. At the conclusion of each scenario, the *Assessor* would give feedback to the *Clinician* and then all students would rotate roles for the next scenario. Further description of the workshop design using the simulation reporting guidelines by Cheng, Kuo, Lin, and Lee-Hsieh (2010) is provided in Supplementary File 2.

The role of CLT in the simulation design

Managing the deteriorating patient was a novel task for this cohort and hence the principles of CLT are paramount to the design and implementation of the simulation scenario. The task being learnt was deliberately limited in scope. Students could focus on the main purpose of the simulation task, the ordering of a primary assessment and initiating key interventions, while not being distracted by activities that fell outside of these objectives, such as the technique of administrating an intramuscular injection or conducting lung field percussion.

Previous to the simulation, students had developed some knowledge and skills pertinent to the simulated activity. For example, students had studied medication, fluid and oxygen administration, and had knowledge and practice in basic focused cardiovascular, neurological and respiratory assessment. Importantly these skills were not being taught or practiced at the same time as the managing the deteriorating patient scenario as a whole. Since students had already developed schemas for these skills, this prior knowledge becomes germane to the task of managing the deteriorating patient and does not add to the extraneous load of this complex task. The simulation exercise was hence made more manageable as the students have a cognitive toolkit available to them to apply to the task at hand.

Before the simulation, students were given clear instructions and a worked example in the form of an instructor demonstration. The effectiveness of worked examples is a well-known CLT effect demonstrating improvements in learning across a number of studies (Van Gog, Kester, & Paas, 2011; van Merrienboer, 2015) including in health professional education (Young et al., 2014). Additionally, students playing the role of *Assessor* and *Patient* had access to the scenario sheet while watching the worked example, reinforcing the relationship between the task and the steps described on the sheet.

In the simulation design, effort was made to minimise extraneous cognitive load, with the choice of LFS itself vital to this reduction. The three elements determining the level of fidelity were all at the low end of the fidelity spectrum, minimising distraction from the intrinsic tasks. The equipment used in the simulation had a low level of realism. A high-fidelity patient mannikin was not used and hence physiological manifestations of deterioration were not mimicked, but rather verbalised by another student. This enabled students to focus on intrinsic tasks of ordering cue collection and implementing interventions. The environment was made as simple as possible, with the immersive simulation rooms not used and the use of peripheral devices and materials minimised.

Effort was made to reduce psychological fidelity of the simulation task, reducing the emotional load on the learner. Anxiety is commonly experienced by nursing students undertaking simulation, due to the pressure of performing in front of groups, unpredictable scenarios and unfamiliar simulation environments (Najjar, Lyman, & Miehl, 2015). Rather than using an actor or a high-fidelity mannikin to play the role of patient, peers who were familiar to the students played this role, minimising stress associated with the task. Also, the decision to use a familiar teaching space, rather than immersive simulation wards, provided a low-stress environment to engage with the task.

Evaluation and statistical analysis

Data collection consisted of two identical surveys. Participants were invited to complete the first survey before commencing the simulation in the morning briefing and the second immediately following the intervention in the afternoon on the same day. The surveys consisted of seven questions that asked participants to score their confidence on a Likert type scale from *"not at all effectively"* to *"completely effectively"* (see Table 2) in relation to aspects of AMDP. The survey was modelled on a tool used in a pre-post study by Gordon and Buckley (2009), which measured the impact of an HFS intervention on nurses' confidence in AMDP. The development of the survey observed principles for the construction of domain specific self-efficacy scales (Bandura, 2006), and is similar to confidence scales that have been used to measure nurses' confidence in AMDP simulation literature (Goldsworthy, Patterson, Dobbs, Afzal, & Deboer, 2019; Lee et al., 2019; O'Leary, Nash, & Lewis, 2016). Non-parametric Wilcoxon signed rank tests were used to assess differences in pre- and post-test scores for all seven items. The non-parametric test was used since the response data are on an ordinal scale, and the small sample size does not allow for the normality assumption to be met for parametric analysis. Alpha was set at 0.05. Statistical analysis was performed using Stata 14.2 (StataCorp, 2015).

Results

Pre- and post-test scores for individual items and overall are presented in Table 2. Prior to the workshop, students' self-rated ability across all items had a mean score of 2.98 (SD = 0.19) indicating a neutral rating of ability. Following the workshop, the mean item score increased significantly across all seven categories to 4.47 (SD = 0.12) ($p < 0.001$) indicating a score close to *completely effective*. Pre-test, students' self-reported ability was lowest for *implementing interventions to support circulation* (mean = 2.62, SD = 0.65) with the highest self-reported ability to *call for help appropriately at the right time* (mean = 3.23, SD = 0.73). Post-test, the lowest self-reported ability was for *interventions to support circulation* (mean = 4.31, SD = 0.75), with the highest scores for *call for help appropriately at the right time* (mean = 4.62, SD = 0.51) and *manage airway obstruction* (mean = 4.62, SD = 0.51).

There were statistically significant improvements in self-reported ability across all survey items. The largest improvement was for *interventions to support circulation* (mean difference = 1.69, $p < 0.001$). The smallest improvement was for *perform handover to emergency response team* (mean difference = 1.31, $p < 0.001$).

Table 2: Descriptive statistics of survey responses with Wilcoxon sign rank test.

	Mean (SD)		Difference	z	p
	Pre-test	Post- test			
Q1. Assess and recognise an unstable patient	3.00 (0.71)	4.54 (0.66)	1.54	3.26	0.001
Q2. Identify priorities in managing the deteriorating patient	2.92 (0.64)	4.46 (0.66)	1.54	3.27	0.001
Q3. Call for help appropriately at the right time	3.23 (0.73)	4.62 (0.51)	1.38	3.22	0.001
Q4. Manage airway obstruction	3.00 (0.58)	4.62 (0.51)	1.62	3.25	0.001
Q5. Manage breathing difficulties	3.00 (0.58)	4.39 (0.65)	1.38	3.29	0.001
Q6. Interventions to support circulation	2.61 (0.65)	4.31 (0.75)	1.69	3.26	0.001
Q7. Perform handover to emergency response	3.08 (0.49)	4.39 (0.62)	1.31	3.31	<0.001

Discussion

The ability of nurses to identify the deteriorating patient in clinical settings has become an area of principal concern (Massey et al., 2017) and simulation has increasingly been explored as a means to address this concern (Lee et al., 2019). The LFS in this study involved basic peer role-play which was low-cost, required little input from the teacher and did not rely on technology. Undergraduate nursing students who completed this LFS workshop reported improved confidence across all aspects of AMDP. Confidence is an important factor in nurses' recognition of deterioration and timely escalation (Massey et al., 2017). The results of this study indicate that LFS may be effective for undergraduate nursing students where the intended learning outcomes are development of schemas for novel skills.

HFS is commonly used when teaching AMDP to nurses. However, the associated cost, technology and required staff input pose barriers to regular access by students which can undermine learning. The choice of fidelity must be informed by pedagogical considerations including the level of learner, type of skill, complexity of the task and intended outcomes of the learning exercise (Gore, 2017; Nimbalkar et al., 2015; Rudd et al., 2010). For nursing students, learning outcomes must reflect the novice level at which they operate, recognising the limited existence of constructed schemas in the early stage of their learning. Bloom's revised taxonomy (Anderson et al., 2001) presents a spectrum of learning categories representing depth of cognitive processing that relates to simulation fidelity. The categories of *remembering, understanding* and *applying* represent low- to mid-level learning. Higher levels of learning are associated with *analysing, evaluating* and *creating* (Krathwohl, 2002). While arguably both modes of simulation can cover a range of low- to mid-level learning outcomes, it has been suggested that LFS may be more appropriate for teaching basic or procedural tasks (Maran & Glavin, 2003), and directed at novice learners (Zendejas et al., 2013). HFS, on the other hand, is generally attributed to higher cognitive learning processes such as clinical reasoning and reflection (Butler et al., 2009; Jeffries, 2005; Levett-Jones et al., 2011). These cognitively higher-end learning activities should only occur when the necessary germane knowledge is in place to achieve the learning outcomes.

The use of low-cost LFS, therefore, may be more appropriate when teaching undergraduate nursing students AMDP skills. By allowing novices to develop cognitive schemas through LFS, they will be better equipped to manage the more complex events that can occur in clinical deterioration. Mastery of simpler categories of learning, such as *remembering* and *understanding*, is a pre-requisite to progression to more complex processes (Krathwohl, 2002). Introducing novice learners to HFS without the necessary cognitive schemata in place, may overload their working memory. The accessibility and repeatability of low-cost LFS is ideal for the elementary processes of remembering and understanding, and accommodates the construction of cognitive schemas. With LFS, students can practice scenarios outside formal teaching settings allowing repeatability to achieve clinical competence (Jeffries, 2005). This is particularly pertinent in the undergraduate context where a basic knowledge is still being developed into cognitive schemas. HFS, where higher cognitive skills are challenged, is most appropriate following the development of foundation principles and skills using LFS.

The suggestion is not that HFS should be disregarded in undergraduate nursing education. Simulation should be integrated and scaffolded throughout a curriculum (Butler et al., 2009; Campbell & Daley, 2009). However, LFS should not be considered a poor substitute for HFS, nor an *ad hoc* exercise developed in the absence of pedagogical consideration. A more coordinated approach to simulation programs should involve careful consideration of the value of various simulation modalities and how they can complement each other in order to enhance the student learning experience. The use of CLT principles in both the initial choice of fidelity of the simulation and in the educational design of the simulation, will result in improved student learning.

It should be noted that the pre-workshop self-rated ability reported by students was higher than expected given that they had had no prior training in the novel task of AMDP. While self-rated ability is widely used as an outcome measure to support the benefits of simulation programs (Blum, Borglund, & Parcells, 2010; Gordon & Buckley, 2009; Kardong-Edgren et al., 2008; Smith & Roehrs, 2009), confidence may correlate poorly with external assessments and concerns have been expressed regarding the implication of over-confidence amongst nurses in the clinical environment (Liaw, Scherpbier, Rethans, & Klainin-Yobas, 2012). Nevertheless, pre-registration clinicians need a level of confidence to engage in unfamiliar activities and a lack of confidence may limit a clinician's decision-making and ability to practice independently (Stewart et al., 2000; White, 2003). Self-confidence is linked to the ability of nurses to observe subtle changes indicating patient deterioration, increasing the likelihood of an early escalation of concerns, thus improving patient outcomes (Dalton, Harrison, Malin, & Leavey, 2018; Massey et al., 2017; Purling & King, 2012).

Limitations and further research

Self-reported ability does not necessarily translate to competent clinical practice. Clinical competence is a preferred measurable outcome and future research of this LFS workshop would benefit from other outcome measures such as knowledge and clinical performance. Also, the cognitive load was not directly measured in this study.

The single arm pre-post design was a limitation of this study. To understand the benefits of this LFS program more fully, future studies should observe and compare LFS to HFS when teaching AMDP. The lack of follow-up in this study did not allow for an analysis of retention which is an important outcome measure in simulation (Elfrink, Kirkpatrick, Nininger, & Schubert, 2010). Finally, the small sample size and self-selection bias limited the generalisability of these results. Implementation into an undergraduate curriculum, comprising of a wider and larger sample of students, would provide greater generalisability.

Conclusion

This study reports an increase in self-rated ability in assessment and management of the deteriorating patient after completion of a CLT-informed LFS workshop design. This pilot study contributes to a wider body of evidence that suggests LFS is able to improve students' ability to undertake patient assessment and management in a low-resource and accessible manner and extends this to the particular case of the deteriorating patient. The benefits of LFS are understood in terms of the CLT framework, and design principles outlined. While students may have been over-confident at both stages of data collection, and this confidence may well not transfer into effective clinical practice, the increase in confidence has educational and clinical relevance. HFS and LFS both have a place in nursing education, and careful consideration should be given to learning outcomes, the novelty of the skill and experience of the learner when deciding what mode of simulation is used. Comparative design studies using CLT-informed simulation design for AMDP which assess improvements in clinical competence are required to demonstrate the benefits of this approach compared to standard educational designs.

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