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MARIE-LAURENCE TREMBLAY

LIGHTS. CAMERA. ACTION. DEBRIEF.

Designing Immersive Simulation for Novices to Promote Learning

LIGHTS. CAMERA. ACTION. DEBRIEF.

Propositions

ML Tremblay

1. The environment in simulation is a double-edged knife; it provides a context for the clinical task but can also distract the learner if not carefully designed. (This thesis)
2. For novices, complex tasks can be challenging, but usually promote learning if effectively debriefed. (This thesis)
3. Learning through observation in simulation should not be undervalued, but rather perceived as a meaningful yet different learning opportunity. (This thesis)
4. Well-designed simulations prepare novices to face and reflect on authentic problems in the real world. (This thesis)
5. Errors can happen in simulation, so that errors can be avoided in actual practice. (Amitai Ziv)
6. Authenticity in simulation is a mean to an end, not a goal. (Peter Dieckmann)
7. It's not what you look at that matters; it's what you see. (Henry David Thoreau)
8. Designing a simulation has a lot in common with directing a play.
9. Talking about complexity in simple words is quite complex!
10. Mon pays, ce n'est pas un pays, c'est l'hiver! (Gilles Vigneault)

Lights. Camera. Action. Debrief.
Designing Immersive Simulation for Novices to Promote Learning

By
Marie-Laurence Tremblay

The research reported here was carried out at Maastricht University | Maastricht UMC+

in the School of Health Professions Education

in the context of the research school (Interuniversity Center for Educational Research)

Lights. Camera. Action. Debrief.
Designing Immersive Simulation for Novices to Promote Learning

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Lights. Camera. Action. Debrief.

Designing Immersive Simulation for Novices to Promote Learning

DISSERTATION

To obtain the degree of Doctor at Maastricht University, on the authority of the
Rector Magnificus, Prof. dr. Pamela Habibovic
in accordance with the decision of the Board of Deans,
to be defended in public on Monday, 8 May 2023, at 16:00 hours

By

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CHAPTER ONE

Introduction

INTRODUCTION

Simulation-based education (SBE) is a powerful learning method that prepares healthcare students and professionals for clinical practice (Harder, 2010). Among simulation modalities, immersive simulation allows the learner to practice tasks that are relevant to future practice, within a realistically simulated clinical environment (Chiniara, Cole, Brisbin, Huffman, Cragg, Lamacchia, Norman, et al., 2013). In immersive simulations, learners rehearse clinical skills, followed by a debriefing period during which they analyze the performance. This performance during the simulation does not need to be perfect; it must allow the learner to process the critical steps required by the situation, setting the stage for the debriefing. The purpose of this exercise is to practice clinically important tasks, safely try new approaches, receive feedback, consolidate schemas, and even create new schemas (Rivière, Jaffrelot, Jouquan, & Chiniara, 2019). The simulation and the debriefing are complementary; combining them is essential for optimal learning.

In health professions education, the use of SBE has expanded greatly since the early 2000s, with medical specialties acting as leaders in this field. Over the last two decades, faculties from various disciplines have invested in infrastructure to support integrating immersive simulations into their (under)graduate programs. Immersive simulations were first mostly used with more advanced learners with some clinical experience, enabling them to cope with the unexpected and messy clinical context of authentic situations. Given the limited clinical experience of a novice, it is likely that the messiness of an authentic clinical setting might overwhelm them and prevent them from fully reaching the intended learning goals of the simulation. Educators need to adapt the learning task and the learning environment to account for the learner's expertise level (Kalyuga, 2007; van Merriënboer & Kirschner, 2017). This thesis is built around this challenge, and is intended to help both educators and learners get optimal learning out of an immersive simulation.

COGNITIVE LOAD THEORY

Cognitive load theory provides insights to help educators design effective simulations adapted for novices. Cognitive load theory distinguishes two types of cognitive load: intrinsic and extraneous (Sweller, van Merrienboer, & Paas, 1998). The former refers to the working memory resources allocated to schema construction and automation. Extraneous cognitive load refers to any additional load that does not pertain to the learning goals. This extraneous load is generated by suboptimal instructional design, and by emotions and distractions during a learning situation (Choi, van Merriënboer, & Paas, 2014; Naismith & Cavalcanti, 2015). The original cognitive load theory model describes a third type of load, namely germane load, which refers to the working memory resources involved in processing intrinsic cognitive load (Sweller et al., 1998). In a clinical environment, whether simulated or real, germane cognitive load seems to play a limited role (Szulewski, Howes, van Merriënboer, & Sweller, 2020), and will therefore not be the focus of this research. As both intrinsic and extraneous cognitive load occupy the same limited reservoir of human cognitive capacity, to optimize learning, extraneous cognitive load must be minimized to allow the learner to allocate working memory resources to schema construction (i.e. intrinsic cognitive load).

The recent reconceptualization of cognitive load theory, originally developed by Sweller et al. (1998) considers the learning environment, and more specifically its effects on cognitive load, as a determinant of the effectiveness of instruction (Choi et al., 2014). In their revised model of this theory, Choi et al. (2014) portray a three-component model in which the synergy between the environment, the learning task and the learner explains the effect on cognitive load (see Figure 1). In this model, the learning task and the learning environment are disentangled. The *environment* refers to the whole range of physical features of a place in which teaching and learning occur. These features include physical characteristics of learning materials and tools, physical properties of the room, and the physical presence of other people. In other words, it comprises all the sensory stimuli generated by the environment that can be perceived by human senses. The *learning task* characteristics, for example the patient's medication profile or the information to be communicated to the patient, refer to the intrinsic task complexity or the type of tasks to be executed. The authors explain that what constitutes intrinsic or extraneous cognitive load will depend on the learner's expertise level and will result from the design of the learning task and the environment.

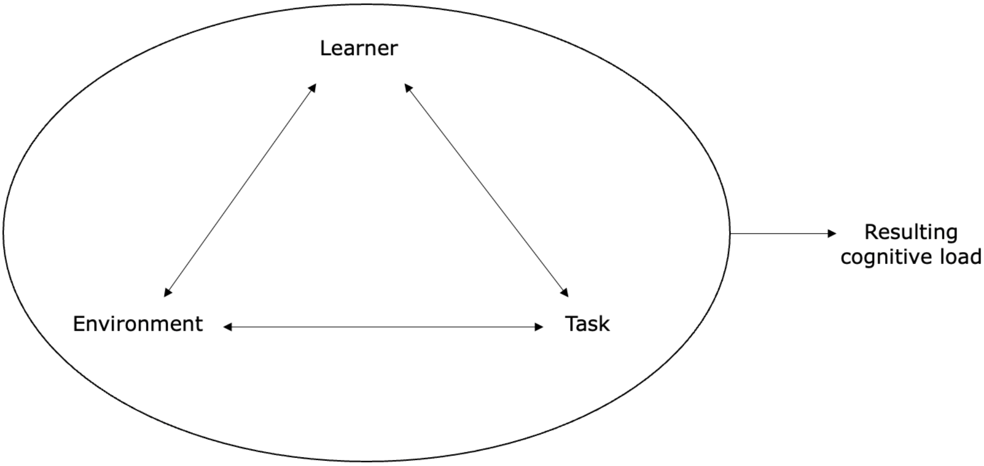

Figure 1. Causal factors of cognitive load. Adapted from Choi et al. (2014).

THE EFFECTS OF COMPLEX LEARNING ENVIRONMENTS AND TASKS

The environment is known to produce various effects on the learner from cognitive, physiological, and affective perspectives (Choi et al., 2014). For novices, frequent and unexpected interactions with elements of the environment can induce stress and extraneous cognitive load (van Merriënboer & Sweller, 2010). In simulation, experiencing stress can lead to unpredictable effects on performance (DeMaria Jr et al., 2010; Fraser et al., 2014), and affect a variety of cognitive processes such as decision-making, attention, and memory (LeBlanc, McConnell, & Monteiro, 2014). As a result, learners who experience stress during a simulation due to disturbing environmental factors can have an altered perception of the tasks to be learned (LeBlanc, 2009); they may focus on specific elements of the task, relevant or not to the intended learning, and ignore others. This phenomenon strengthens the idea that the environment acts as a distinct causal factor of cognitive load (Choi et al., 2014; Szulewski et al., 2020). This shift of focus is more likely to happen when a simulation is immersive, and the environment plays a central role in the learning process.

In immersive simulation, task complexity should be adapted to learners' expertise level and increase progressively as they become more proficient (van Merriënboer & Kirschner, 2017). However, while adapting learning tasks, educators must be careful to provide tasks that remain authentic even when simplified. For example, when learning clinical reasoning in simulation, tasks should be representative of what students will have to do in clinical practice, in order to create and/or consolidate sound scripts or prototypes in long-term memory (Pelaccia & Jaffrelot, 2019). Reducing task complexity in such instances can be done by limiting the amount of information to process (intrinsic load) and by providing clear and focused information (extraneous load)—not by creating an oversimplified story that does not reflect real life. Evidence is still very scarce as to what constitutes in practice a complex clinical task for novice students—even more so in specific disciplines such as pharmacy. By understanding how complex environments and tasks influence the learning experience of novices in simulation, we could design simulations specifically adapted for them, and promote learning.

THE LEARNER'S INTERACTIONS WITH THE TASK AND THE ENVIRONMENT

The role played by the learner in a simulation, whether passive or active, also influences their cognitive load and learning processes (Livsey & Lavender-Stott, 2015; O'Regan, Molloy, Watterson, & Nestel, 2016; Stegmann, Pilz, Siebeck, & Fischer, 2012). In simulation, learners can be actively involved in the scenario and interact with the environment, but for various reasons, they also often observe others perform a task. In their observing role, students can still benefit from the simulation, but possibly in a different manner (Stegmann et al., 2012). Although observers necessarily have less interaction with the simulation task and the environment than an active participant, they can still experience some cognitive load during the simulation and learn from it (Josephsen, 2018). We may posit that their 'back-seat' position during the simulation gives them a broader perspective on the clinical situation. However, observers are not immune to cognitive overload. Given the limited clinical experience of novices, they might struggle in discerning what is worthy of attention in a scenario with many concurrent events. How best to support novice observers in their learning process remains unclear (O'Regan et al., 2016).

RESEARCH PURPOSE AND RESEARCH QUESTIONS

Especially with the rise of competence-based education, SBE has become an educational imperative in clinical training as part of health professions education. Immersive simulations for novices represent an opportunity to develop their clinical skills in a safe environment, but the task and the environment should be adapted to account for their limited clinical experience. How to adapt these features in practice to optimise learning remains unclear. Moreover, conducting such learning activities generates costs that can be considerably high in terms of infrastructure, human resources (instructors, designers, technicians, simulated patients), technology (cameras, microphones), etc. (Zendejas, Wang, Brydges, Hamstra, & Cook, 2013). Considering these costs, it is essential that the development of simulations is well conceived, designed, and organized to ensure that students get the maximum benefit.

This research aims to inform how interactions between the learner, the environment, and the learning task in immersive simulation influence the learning experience for novice healthcare students. We developed two overarching research questions:

1. What are the effects of task and environment complexity in immersive simulation on novices' learning experience?
    a. What are the differences between immersive simulation and simulated patients in terms of cognitive load and emotions for undergraduate healthcare students? (Study 1)
    b. What are the effects of simple and complex tasks in immersive simulation for undergraduate pharmacy students, in terms of cognitive load, self-perceived learning, and performance, and how does task complexity influence students' perception of learning? (Study 2)
    c. What is the impact of modulating the complexity of the task and of the environment on novices' cognitive load and performance in immersive simulation? (Study 3)

2. How to support the learning experience of novices exposed to immersive simulation when they observe a peer perform in the simulation?
    a. What are the similarities and differences between collaboration scripts, checklists, the combination of both, and no guidance in terms of intrinsic and extraneous cognitive load, and self-perceived learning for novice observers during a simulation-based training, and how do these tools influence the observers' learning experience? (Study 4)

RESEARCH SETTING AND CONTEXT

All studies included in this dissertation took place in the Pharmacy Simulation Centre in Laval University, Quebec City, Canada. The Pharmacy Professional Practice Laboratory comprises ten pharmacy stations that are representative of community pharmacies in Quebec. The pharmacies are equipped with real medications, computer equipment and electronic patient records, telephones, compounding and drug preparation materials, reference books, and instruments to monitor clinical efficacy and drug safety (e.g., blood pressure monitor, blood glucose monitors, etc.). Each pharmacy is equipped with ceiling cameras and microphones that record the conversations between the patient and the pharmacist, or between the students as they work in teams.

The study population was made up of undergraduate pharmacy students. All participants study in a four-year competence-based program at Laval University that leads to pharmacy practice in the province of Quebec. The program is entirely taught in French. Pharmacy practice in North America is essentially patient-centred, as opposed to medication-centred in some countries. The pharmacist's role is to ensure that the patient receives the appropriate medication for his/her healthcare problem, that it is safely used (avoid/manage drug interactions, avoid undesirable effects) and effective (drug monitoring), and to facilitate treatment compliance. Pharmacy training in North America resembles medical training, aside from the development of diagnostic skills, deemed specific to medicine. Admission to the program is based on academic results and on psychometric test results; 192 students are enrolled each year. Participants were familiar with the simulation facilities, since they experience many immersive simulations throughout their program.

REFLEXIVITY

Situating my research in pharmacy education is directly related to my academic and professional background. I am a pharmacist who has practiced in a variety of clinical settings. From the moment I started my studies in pharmacy, I was fascinated by the exponential development that characterized the profession. I have always wanted to contribute to the advancement of the profession, and believed then as now that education is the key to achieve that goal. I firmly believe that by forming a new generation of motivated and innovative pharmacists, the quality of patient care can be excellent. The more I worked as a simulation instructor and designer, the more I realized that this area of pharmacy education was seriously unexplored. I have witnessed how powerful SBE is for novices, but also how stressful and challenging it is for them. I feel that simulation should be a safe space to learn, and this is probably why I see SBE first and foremost as a learning activity and not as an assessment of performance. Over the years, I have also developed the strong belief that learning in simulation is a social experience and contributes to professional identity formation. I undertook this PhD journey because I was profoundly interested in understanding what my students were experiencing in the simulation lab and ultimately, to design the most effective activities. I have used a post-positivist research paradigm, in which knowledge is conjectural and based on hypotheses that have not yet been proven wrong. This explains why my research comprises multiple measures and observations, and various methods, to expand our comprehension of the issues at play.

THESIS OVERVIEW

This dissertation presents four empirical studies that aim to inform how to adapt the learning task and the learning environment in immersive simulation for novices.

- In Chapter Two, we first investigate the effect of the learning environment on novices' cognitive load and emotions, and how it influences their learning experience.
- In Chapter Three, we examine the effect of task complexity on students' cognitive load and performance, and we attempt to understand how task complexity influences students' perception of learning.
- In Chapter Four, we investigate the interactions between task and environment complexity and their effects on novices' cognitive load, performance, and learning outcomes.

- In Chapter Five, we study the effect on cognitive load and learning outcomes for observers in immersive simulation under different forms of instructional support, and explore how these forms of guidance influence their learning experience.
- In Chapter Six, we attempt to answer our research questions, discuss the theoretical and practical implications of our work, and note the strengths and limitations inherent in our analyses.
- In Chapter Seven, we explore the valorisation implications of this research. Summaries in both English and Dutch follow.

Table 1. Empirical studies testing cognitive load theory

	Chapters			
	2	**3**	**4**	**5**
Research questions	What are the differences between immersive simulation and simulated patients in terms of cognitive load and emotions for undergraduate healthcare students?	What are the effects of simple and complex tasks in immersive simulation in terms of cognitive load, self-perceived learning, and performance for undergraduate pharmacy students, and how does task complexity influence students' perception of learning?	What is the impact of modulating the complexity of the task and of the environment on novices' learning experience in immersive simulation?	What are the similarities and differences between collaboration scripts, checklists, the combination of both, and no guidance in terms of intrinsic and extraneous cognitive load, self-perceived learning, and acquired knowledge for novice observers during a simulation-based training, and how do these tools influence the observers' learning experience?
Methodology	Mixed methods Sequential explanatory design	Mixed methods Sequential explanatory design	Quantitative	Mixed methods Sequential explanatory design
Design/Instruments	Cluster randomization Maximal variation sampling Crossover Immersive simulation vs. simulated patients Cognitive load and emotion questionnaires Focus group interviews	Cluster randomization Maximal variation sampling Simple task followed by complex task on a random clinical subject Cognitive load questionnaire Performance checklist Semi-structured interviews	Cluster randomization Two-way design Simple and complex tasks, simple and complex environments Cognitive load questionnaire Knowledge test Performance score (global rating scales)	Cluster randomization Purposeful sampling Checklists, collaboration scripts, both, and no guidance. Cognitive load questionnaire Knowledge test Focus group interviews
Context and participants	Second-year pharmacy students (N= 143) and focus group interviews (N=35) in Quebec, Canada	Second-year pharmacy students (N= 167) and semi-structured interviews (N=14) in Quebec, Canada	Second-year pharmacy students (N= 162) in Quebec, Canada	Second-year pharmacy students (N= 162) and focus group interviews (N=14) in Quebec, Canada

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CHAPTER TWO

The Simulated Clinical Environment: Cognitive and Emotional Impact among Undergraduates

Tremblay, M. L., Lafleur, A., Leppink, J., & Dolmans, D. H.

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Tremblay, M. L., Lafleur, A., Leppink, J., & Dolmans, D. H. (2017). The simulated clinical environment: cognitive and emotional impact among undergraduates. Medical Teacher, 39(2), 181-187.

ABSTRACT

Context Simulated clinical immersion (SCI) is used to expose learners to meaningful whole tasks in a safe and simulated environment. The authentic environment is intended to arouse students' interest and enhance transfer of learning. However, it might distract novices or cause anxiety, hence potentially compromising learning.

Objectives This study aims to determine whether simulated clinical immersion (with environment) imposes greater extraneous cognitive load and stress on undergraduate pharmacy students than simulated patients (SP) (without environment). It also aims to explore how features of the simulated physical environment influence students' perception of learning.

Methods In this mixed-methods study, 143 undergraduate second-year pharmacy students experienced both simulation modalities (SCI and SP) in a crossover design. After the simulations, participants rated their cognitive load and emotions experienced during the simulations. Thirty-five students met in focus groups to deepen the quantitative results and collect their perception of learning in simulation.

Results Intrinsic and extraneous cognitive load and stress scores in SCI were significantly but modestly higher compared to SP. Qualitative findings reveal that the physical environment in SCI generated more stress and affected students' focus. In SP, students concentrated on clinical reasoning. SCI stimulated a focus on data collection but impeded a more in-depth problem solving.

Conclusion This study demonstrates that the physical environment in which novice students experience the simulation will influence what and how students learn. SCI was reported as more cognitively demanding than SP. More importantly, our findings emphasize the urgent need for the development of adapted instructional design guidelines in simulation for novices.

Practice points:

- Simulated clinical immersion and simulated patients are two simulation modalities commonly used for developing clinical reasoning skills.
- The interactions with the simulated physical environment are predominant in simulated clinical immersion, making it more cognitively challenging for novice learners with limited clinical experience.
- The simulated physical environment can be a source of stress and distractions, which can generate extraneous cognitive load for juniors.
- Interactions with the physical environment affect tranquility and influence the focus of learning.
- When designing simulated clinical immersion for novices, educators should adapt both the task and the learning environment to optimize learning.

INTRODUCTION

Simulated clinical immersion (SCI), a simulation modality which reproduces real-life situations in an authentic simulated workplace environment, has now become an educational imperative of clinical training in health professions education (Teteris, Fraser, Wright, & McLaughlin, 2012). However, the assumption that learning in a highly authentic clinical environment leads to better transfer of learning is debatable (Norman, Dore, & Grierson, 2012), especially for junior students (Girzadas Jr, Clay, Caris, Rzechula, & Harwood, 2007; Issenberg, Ringsted, Østergaard, & Dieckmann, 2011). For novices, who have limited clinical experience, unfamiliar learning environments can potentially be distracting rather than add meaning to a learning task (van Merriënboer & Sweller, 2010). Current instructional design models hardly inform us on how to adapt the physical environment in simulation for undergraduate healthcare students in part because its cognitive and emotional impact remain misunderstood.

Simulation-based education provides meaningful learning opportunities for students to practice, to err, and to learn in a safe simulated environment (Cook et al., 2013; Cook et al., 2011; Weller, 2004; Ziv, Wolpe, Small, & Glick, 2003). Different simulation modalities enable the alignment of task demands with the learning objectives (Chiniara et al., 2013; Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014). By design, SCI offers significant learning tasks closely connected and constantly interacting with the clinical environment, therefore reaching higher levels of the Miller's pyramid of clinical competency (Miller, 1990). These learning activities are undoubtedly cognitively stimulating for novices. The type of cases presented in SCI may comprise many new elements that still have to be integrated in students' cognitive schemas, which will contribute to intrinsic cognitive load, a type of cognitive load arising from processing the content to be learned (Leppink & van den Heuvel, 2015).

The physical environment in SCI is a double-edged knife because environmental factors might reinforce learning with the potential risk of causing stress and disturbance in less experienced participants (DeMaria & Levine, 2013). This risk may contribute substantially to extraneous cognitive load (Leppink & van den Heuvel, 2015), which is cognitive load that does not pertain to learning processes and consequently hinders rather than facilitates learning (Leppink, van Gog, Paas, & Sweller, 2015). Since the combination of intrinsic and extraneous cognitive load has to respect the rather narrow limits of working memory capacity, education should be designed such that extraneous cognitive load is minimized and students are stimulated to optimally allocate their available resources to deal with the intrinsic cognitive load (Leppink et al., 2015). A recent mixed-methods study provided evidence for how it can be achieved in the context of the design of objective structured clinical examinations (OSCEs) by changing task demands (Lafleur, Côté, & Leppink, 2015). Given the amount of human and material resources invested in the use of SCI, it is pressing to explore how novices experience this simulation modality and how it affects their learning processes (Issenberg et al., 2011).

Recent evidence suggests that emotions experienced by learners during a simulation is directly linked with the cognitive load imposed on them (Fraser et al., 2014; Fraser et al., 2012). A growing amount of data demonstrates that excessive stress and anxiety produce a negative impact on learning, whereas positive emotions – particularly emotions associated with a pleasant state of mind – can either enhance or hinder learning (Darke, 1988; Fraser et al., 2014; Isen & Reeve, 2005; Sorg & Whitney, 1992). Stress in simulation has been associated with a positive performance, up to a certain level after which detrimental effects on performance and learning can be observed (DeMaria & Levine, 2013; Fraser et al., 2014). Fraser et al. (Fraser et al., 2012) have demonstrated that increased *invigoration* and decreased *tranquility* during SCI training impose a greater cognitive load on medical students, which resulted in a poorer task performance. It is still unknown whether different simulation modalities have a different impact on emotions.

Among the different modalities, simulated patients (SP) are typically used to replicate encounters with real patients and are useful to learn history taking, physical examination, and clinical reasoning (Barrows, 1993; Cleland, Abe, & Rethans, 2009). SPs are persons who have been trained to portray a patient with a specific condition in a realistic manner (Barrows, 1993). As opposed to SCI, the environment in which SP simulation takes place can either be in clinical or nonclinical settings, since it is not intended to interact directly with the learning tasks (Chiniara et al., 2013). Considering the additional environmental factors inherent to SCI, we can hypothesize that this modality mobilizes more cognitive resources than SP (Maran & Glavin, 2003). More specifically, cognitive load theory predicts that the increase in manoeuvres and other actions elevate intrinsic cognitive load, while an increased demand on problem-solving search contributes to a higher extraneous cognitive load (Leppink et al., 2015). The purpose of this study is to determine how SCI affects cognitive load and emotions compared to less resource-intensive SP simulation.

We designed this experiment to address the following research questions: *What is the difference between SCI and SP in terms of intrinsic and extraneous cognitive load, self-perceived learning, emotions, and overall appreciation of their experience for undergraduate pharmacy students?* To understand what constituted intrinsic and extraneous cognitive load for our students and explore students' perception of learning during simulation, we studied qualitatively *how do features of the simulated physical environment influence students' perception of learning?* We hypothesize that, compared to SP, SCI increases intrinsic cognitive load (**H1**), does not increase self-perceived learning (**H2**) but rather elevates extraneous cognitive load (**H3**) and negative emotions (**H4**). Therefore, altogether, we have no reason to expect that students appreciate SCI more or less than SP (**H5**).

METHODS

SETTING

This study was conducted from November 2014 to January 2015 at Laval University Faculty of Pharmacy (Quebec, Canada) in the Pharmacy Simulation Laboratory, which replicates a pharmacy workplace fully equipped with authentic material commonly found in community pharmacies. For instance, real medications, electronic pharmacy records, telephones, and electronic references and books are made available if required for a learning task.

PARTICIPANTS

Participants study in a four-year competency-based pharmacy program (PharmD), entirely administered in French. Admission in the program is based on academic results and on psychometric test results. Participants were enrolled on a voluntary basis and had experienced four SCI and six SP activities prior to the experiment in the Pharmacy Simulation Laboratory. They were familiar with the different roles they played during the simulation. Sampling was made using cluster randomization for the experiment. All students had prior knowledge on the targeted clinical contents of the cases.

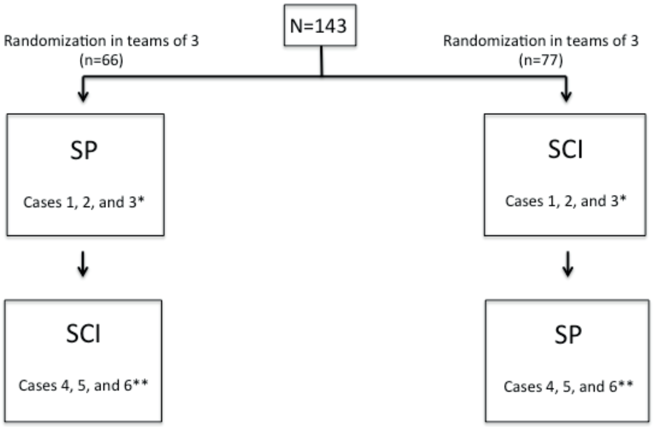
INTERVENTION

Participants experienced both SP and SCI in a crossover sequence (Figure 1). Based on quality features for designing simulation activities (Issenberg, McGaghie, Petrusa, Lee Gordon, & Scalese, 2005; Motola, Devine, Chung, Sullivan, & Issenberg, 2013), both SP and SCI had the same course of events. Each simulation session started with a short briefing, followed by a case and a debriefing period. Three cases were experienced per simulation session separated by their related debriefings.

Participants played three different roles in rotation during these simulation sessions: the pharmacist, the patient (simulated patient), and the observer. When students played the patient, a role description was provided as well as a 10-minute training prior the simulation. One trained pharmacy simulation instructor conducted the simulations and the debriefing periods for both SCI and SP for all groups.

The main difference between SP and SCI in this study is the interactions with the physical environment. In SP, students had access to paper patients' file only, and telephones and medications were not available. Students therefore did not have to deliver the medication, to enter information in patients' file, and to use the real telephone to communicate with a simulated third party (physician for example). Interactions with the physical environment were very limited in SP.

In SCI, participants had to be able to select and deliver accordingly with the legislation the appropriate drugs based on the medication in stock in their pharmacy, use the electronic pharmacy records to retrieve and enter the necessary information, and use telephones to communicate with a simulated third party if required. Interactions with the physical environment were abundant in SCI.



SP = Simulated patients
SCI = Simulated clinical immersion
**Case 1: Selecting a safe alternative and avoid penicillin cross-reactivity in cellulitis therapy, Case 2: Statins' monitoring (recognizing and managing myopathy), Case 3: Evaluating herpes simplex symptoms and suggesting appropriate over-the-counter therapy*
***Case 4: Evaluating renal function and adjusting antibiotics in moderate renal failure, Case 5: Managing patient's compliance problem with antibiotic, Case 6: Questioning, recognizing and managing a potentially abusive patient using over-the-counter medication*

Figure 1. Randomization and Experimental design

QUANTITATIVE DATA COLLECTION

Immediately after each debriefing period, participants completed a three-section questionnaire, starting with a translated version (French) of the cognitive load questionnaire developed by Leppink, Paas, van Gog, van der Vleuten, and van Merrienboer (2014) used to measure intrinsic and extraneous cognitive load, and self-perceived learning with eleven-point (0-10) rating scales (See questionnaires in Appendix 1).

The second section of the questionnaire involved rating emotions associated with the simulation using an eight-item scale containing bipolar oppositional descriptors of emotion suggested by Feldman Barrett and Russell (1998). The oppositional descriptors were tense/calm, nervous/relaxed, stressed/serene, upset/contented, sad/happy, depressed/elated, lethargic/excited, and bored/alert. Participants were asked to rate each bipolar emotion descriptor from -2 to +2, where positive values represent a more pleasant state of mind and negative values are associated with an undesirable mood. This instrument has been tested on medical students during simulation sessions (Fraser et al., 2014; Fraser et al., 2012). In these studies, a factor analysis revealed two principal components. The descriptors tense/calm, nervous/relaxed, and stressed/serene were characterized as *tranquility*, whereas the remaining five represented *invigoration* (upset/contented, sad/happy, depressed/elated, lethargic/excited, and bored/alert).

In total, each participant filled out six times the questionnaires (cognitive load and emotions) - three times per session – each time immediately after the debriefing period.

Finally, once per session, participants had to rate their appreciation of both SCI and SP using 0-10 rating scales. We considered that scores of 8 and above would be excellent, 7 would be satisfactory, and 6 or below would be insufficient, meaning that simulation modality would not be of sufficient quality and would require improvement.

QUANTITATIVE ANALYSIS

Quantitative analysis was performed with IBM SPSS version 23.0. To test our five hypotheses **H1-H5** while accounting for the characteristics of the crossover design and the few missing responses in the outcome variables of interest, we performed mixed-effects (multilevel) models (Leppink, 2015; Leppink & van Merriënboer, 2015). We specified simulation type (SCI vs. SP) and role (pharmacist, patient, observer) as fixed effects and student-level random intercepts as random effects.

Internal consistency for each scale was sufficient for the cognitive load and the emotion-rating questionnaires, and quality-assurance items. All Cronbach's alpha coefficients were above 0.7, except for extraneous cognitive load in SP for the three roles ($\alpha = 0.577$, 0.662 and 0.697).

QUALITATIVE DATA COLLECTION AND ANALYSES

As part of an explanatory sequential design, two months after the simulation sessions, participants were convened to participate in focus groups, which were conducted by one author (MLT). The purpose of collecting qualitative data was to understand what contributed to intrinsic and extraneous cognitive load for our students and explore their perception of learning during simulation. Thirty-five volunteers who had experienced the simulations were divided into six different groups using maximal variation sampling based on the correlation between differences in extraneous cognitive load and *tranquility*. Open questions were asked on students' perception of learning during SP and SCI and elements that enhance or hinder learning in simulation (See focus group questions in Appendix 2).

Focus groups were audio-recorded and transcribed integrally. The interviewer listened to the interviews and coded the content of the discussions. A second author (AL) listened to 50% of the interviews and validated the coding (topics, themes). In case of disagreement, discussions between the authors occurred until an agreement was reached, although no major issues arose during the analysis.

ETHICAL CONSIDERATIONS

This study received approval from the Research Ethics Committee of Laval University. Written informed consents were obtained prior to randomization. Participants were asked to reiterate their consent to participate to the focus groups. They were made aware that the research material would remain confidential and that performance during the simulations would not be used for assessment purposes. Investigators were not directly involved with students' training at the moment of conducting the research.

RESULTS

QUANTITATIVE RESULTS

174 second-year undergraduate pharmacy students were invited to participate to this study. 143 students (average age of 21.75 with a standard deviation of 2.46; 71% female) responded positively and were representative of the studied population (response rate of 82.2%).

Table 1 presents means and standard deviations for each of the outcome variables for each combination of simulation type and role.

Table 2 presents the outcomes of mixed-effects analysis for each of the response variables.

Table 1. Means (*M*) and standard deviations (*SD*) [and sample size *n*] for each of the outcome variables for each combination of simulation type and role

Condition	**SP**	**SCI**
Intrinsic cognitive load (0-10)		
Pharmacist	4.30 (2.06) [*n* = 143]	4.72 (2.03) [*n* = 143]
Observer	4.08 (1.71) [*n* = 142]	4.28 (1.85) [*n* = 140]
Patient	4.04 (1.77) [*n* = 142]	4.34 (1.79) [*n* = 143]
Extraneous cognitive load (0-10)		
Pharmacist	1.60 (1.59) [*n* = 141]	2.95 (2.14) [*n* = 143]
Observer	1.12 (1.26) [*n* = 141]	1.86 (1.71) [*n* = 142]
Patient	1.14 (1.16) [*n* = 140]	1.69 (1.74) [*n* = 138]
Self-perceived learning (0-10)		
Pharmacist	7.02 (1.76) [*n* = 143]	7.43 (1.40) [*n* = 143]
Observer	6.83 (1.67) [*n* = 140]	7.29 (1.50) [*n* = 142]
Patient	6.84 (1.65) [*n* = 142]	7.02 (1.55) [*n* = 140]
Tranquility 1 (-2 - +2)		
Pharmacist	0.66 (1.09) [*n* = 143]	0.35 (1.15) [*n* = 142]
Observer	1.41 (0.85) [*n* = 142]	1.32 (0.87) [*n* = 143]
Patient	1.36 (0.81) [*n* = 143]	1.30 (0.88) [*n* = 142]
Invigoration 2 (-2 - +2)		
Pharmacist	0.97 (0.76) [*n* = 143]	0.96 (0.78) [*n* = 143]
Observer	1.13 (0.75) [*n* = 142]	1.16 (0.80) [*n* = 140]
Patient	1.17 (0.76) [*n* = 143]	1.14 (0.75) [*n* = 142]
Students' appreciation (0-10)		
No distinction between roles	8.77 (1.14) [*n* = 142]	8.83 (1.06) [*n* = 142]

[1] Tranquility = Tense/calm, nervous/relaxed, stressed/serene (items 1 to 3 of the emotion-rating questionnaire)

[2] Invigoration = Upset/contented, sad/happy, depressed/elated, lethargic/excited, bored/alert (items 4 to 8 of the emotion-rating questionnaire)

Table 2. Outcomes of mixed-effects analysis for each of the response variables

Effect	**df1, df2**	**F-value**	**p-value**
Intrinsic cognitive load			
Role [1]	2, 565.851	4.067	0.018
Simulation [1]	1, 142.817	5.960	0.016
Simulation *by* role [2]	2, 566.150	0.361	0.697
Extraneous cognitive load			
Role [1]	2, 554.896	44.260	< 0.001
Simulation [1]	1, 140.349	48.616	< 0.001
Simulation *by* role [2]	2, 555.128	8.519	< 0.001
Self-perceived learning			
Role [1]	2, 560.984	4.769	0.009
Simulation [1]	1, 141.493	11.233	0.001
Simulation *by* role [2]	2, 560.775	0.850	0.428
Tranquility			
Role [1]	2, 565.621	122.761	< 0.001
Simulation [1]	1, 141.761	6.115	0.015
Simulation *by* role [2]	2, 565.624	2.480	0.085
Invigoration			
Role [1]	2, 563.933	14.017	< 0.001
Simulation [1]	1, 142.111	0.012	0.913
Simulation *by* role [2]	2, 563.928	0.293	0.746
Students' appreciation			
Simulation [1]	1, 708.986	2.780	0.096

[1] Main effect

[2] Interaction effect

In line with **H1** (intrinsic cognitive load) and **H3** (extraneous cognitive load), the presented findings indicate that intrinsic and extraneous cognitive load were on average significantly higher in SCI than in SP, and in line with **H4**, *tranquility* was on average somewhat lower in SCI as well. Further, we did not find convincing evidence against **H5** that SCI and SP are appreciated about the same. However, not in line with **H2**, the findings with regard to self-perceived learning do appear to indicate a slight preference towards SCI.

QUALITATIVE RESULTS

The focus groups added enlightenment to the quantitative analysis by helping to understand which elements of the simulation (environment and learning task) mobilized their mental efforts and how the simulated physical environment influences students' perception of learning. Data saturation was reached after three of the six focus groups.

STUDENTS LEARN CLINICAL REASONING IN SP

Although all cases were designed to develop clinical reasoning, students confirm their deeper engagement in clinical reasoning during SP because they felt that they had more time to focus on the clinical cases rather than on technical aspects of the environment. They also felt that they could interact more with their simulated patient during SP.

> “ In SP, we develop more our clinical judgment. I felt we had more time to think and practice our counselling.” (P431)

STUDENTS PRACTICE DATA COLLECTION IN SCI

Students admitted not to engage as deeply in problem solving in SCI, because they essentially focus on data collection. They invested considerably more mental effort in locating and collecting information from the patient’s authentic computer file, which distracted them from actually solving the problem once recognized. In the end, SCI helps novices develop autonomy with technical skills rather than engaging in deep problem solving.

> “ In SCI, we develop strategies to collect information and analyse the patient’s file.” (P213)

THE PHYSICAL ENVIRONMENT OF SCI WAS CONSIDERED AS STRESSFUL AND PROBABLY HINDERS LEARNING

Most students reported the physical environment, but not all aspects of it, as stressful. They mention that the environment mobilizes mental effort in SCI. For example, accessing and consulting the patient’s electronic pharmacy records was more demanding for most students compared to paper files. Consequently, students have less time for experiencing the rest of the case, if they even finish it, which adds to performance anxiety. Even though they are familiar with software and common pharmaceutical websites, all students do not refer to them effortlessly. Having access to telephones and medications was less stressful and did not seem to influence students’ perception of learning.

> “I learned more in SP, because in SCI, there were too many things to consider at the same time, it was just too much.” (P601)

> “I am more stressed in SCI. I try to think, but when I am stressed, I just don’t compute!” (P151)

PERFORMANCE ANXIETY IS INHERENT, EVEN IN THE ABSENCE OF FORMAL ASSESSMENT

Students reported that being observed by peers and teachers while playing the pharmacist contributes to the stress of performance. Other roles in the simulation, such as the patient and the observer, are not associated with performance anxiety. Performance anxiety was present in both SP and SCI even though the simulations were presented as learning activities and did not comprise any formal assessment of performance.

> “The fact that we are being observed or filmed is stressing [in both SP and SCI]. I don’t perform well when I am feeling evaluated. But I don’t know if the fact that I did not perform well hinders my learning, maybe…” (P111)

DISCUSSION

This study helps to understand how the simulated physical environment influences students’ perception of learning in simulation. Students reported on average higher intrinsic and extraneous cognitive load scores and slightly more negative emotions in SCI compared to SP, as well as a somewhat higher self-perceived learning score. These results confirm our hypothesis that SCI is more cognitively challenging for novices, because it requires them to be able to deal with more information at the same time. In terms of task complexity, which is mainly determined by the degree to which elements within the task interact and by the number of interactions with the environment (Choi, van Merriënboer, & Paas, 2014; van Merriënboer & Sweller, 2010), SCI is unsurprisingly perceived as slightly more complex since students had to perform additional technical steps (e.g. preparing the medication, entering information in the patient’s file, use the real telephones to communicate with the physician if needed, etc.) that resulted from interactions between the task and the environment. Nevertheless, the principal learning objectives both in SP and SCI aimed at developing clinical reasoning and problem-solving skills in various clinical situations (see figure 1), although in SCI, students incidentally developed technical and administrative sub-skills associated with the primary tasks. Our qualitative findings indicate that the interactions with the physical environment can influence that very nature of what students learn (data collection only in SCI and problem-solving in SP), even though we did not intend it. To our knowledge, this is the first study that highlights the impact of the physical environment in simulation on students’ perception of learning. Immersing junior pharmacy students in a highly authentic clinical environment can potentially lead to a shift of focus and prevent them from learning what they should have learned. Other studies are needed to confirm whether this effect is also observed in other healthcare disciplines. Both SP and SCI are powerful educational tools for skills training, but extraneous cognitive load arising from the physical environment should not be underestimated when selecting a simulation modality to match with the learning objectives (Choi et al., 2014; Hamstra et al., 2014).

Our quantitative and qualitative results show that students experience stress and performance anxiety in SCI, but also in SP. In our study, simulations were designed to minimize sources of stress by avoiding performance assessment and unfamiliar environments. Although students described being observed by peers and videotaped as stressful, these aspects are very common features of simulation activities used to facilitate feedback and debriefing (Fanning & Gaba, 2007) and to encourage deliberate practice (Issenberg et al., 2005). By nature, simulation engenders stress and extraneous cognitive load, even with our best effort to put our students in a comfortable and safe learning environment (LeBlanc, McConnell, & Monteiro, 2014). Emotions experienced during simulations are proven to affect a variety of cognitive processes in short or long-term, such as decision-making, attention, and memory (LeBlanc, 2009; LeBlanc et al., 2014). For example, recent evidence suggests that exposing medical students to deteriorating cases in simulation engenders more stress and leads to negative short-term learning outcomes (Fraser et al., 2014). Our study focussed only on the immediate effect of simulation, which showed that small environmental changes affect *tranquility* and influence the focus of learning (problem solving vs. data collection). We are however lacking evidence with regard to long-term retention of information learned in stressful simulations in health professions education.

In our study, differences between SCI and SP in average intrinsic and extraneous cognitive load were on the proximal end of the scale. Although this may indicate that – for learners comparable to the participants in the current study – SP and SCI are not that different in terms of cognitive load, it might also reflect to some extent that cognitive load research thus far has not really considered the effect of the physical environment on the learner's perception of the learning task (Choi et al., 2014). A recent systematic review on the validity of cognitive load measures in simulation-based education demonstrated that, although cognitive load theory is an interesting framework for instructional design in healthcare simulation training, current tools to measure cognitive load seem to engender inconsistent correlations between cognitive load and learning outcomes in the context of simulation (Naismith & Cavalcanti, 2015). These findings can partially explain why our quantitative findings indicate a rather modest difference between the modalities and why our qualitative findings are more polarized. We believe that current cognitive load questionnaires do not fully grasp the sources of extraneous cognitive load in simulation, revealing the need for the development of adapted tools to adequately measure the components of cognitive load in simulation (Haji, Rojas, Childs, Ribaupierre, & Dubrowski, 2015; Naismith, Cheung, Ringsted, & Cavalcanti, 2015).

CONCLUSION

Simulation-based education offers meaningful learning opportunities for undergraduate healthcare students without compromising patients' safety, but emotions experienced during the simulation and the environment in which it takes place will impact what and how students learn. Regulating the simulated physical environment changes how students attend to learning objectives, emphasizing educators' role in designing simulation tasks and environments adapted to the learners' needs (Sandars, Patel, Goh, Kokatailo, & Lafferty, 2015).

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CHAPTER THREE

Simulation-based Education for Novices: Complex Learning Tasks Promote Reflective Practice

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ABSTRACT

Context Simulated clinical immersion (SCI), which simulates clinical situations in a realistic environment, safely and gradually exposes novices to complex problems. Given their limited experience, undergraduate students can potentially be quite overwhelmed by SCI learning tasks, which may result in deceiving learning outcomes. Although task complexity should be adapted to the learners' expertise level, many factors, both intrinsic and extraneous to the learning task, can influence the perceived task complexity and its impact on cognitive processes.

Objectives The purpose of this mixed-method study was to understand the effect of task complexity on undergraduate pharmacy students' cognitive load, task performance, and perception of learning in SCI.

Methods One hundred sixty-seven second-year pharmacy students experienced consecutively one simple and one complex learning task in SCI assigned randomly. Participants' cognitive load was measured after each task and debriefing. Task performance and time-on-task were also assessed. As part of a sequential explanatory design, semi-structured interviews were conducted with students showing maximal variations in intrinsic cognitive load to understand their perception of learning when dealing with complexity.

Results Although the complex task generated significantly higher cognitive load and time-on-task than the simpler task, performance was high for both tasks. Qualitative results revealed that a lack of clinical experience, an unfamiliar resource in the environment, and the constraints inherent to SCI, such as time limitations, hindered the clinical reasoning process and led to poorer self-evaluation of performance. Simpler tasks helped students gain more self-confidence, whereas complex tasks further encouraged reflective practice during debriefings.

Conclusions Although complex tasks in SCI were more cognitively demanding and took longer to execute, students indicated that they learned more from them as opposed to the simpler tasks. Complex tasks constitute an additional challenge in terms of clinical reasoning, thus providing a more valuable learning experience from students' perspective.

INTRODUCTION

Simulated clinical immersion (SCI) is a simulation modality that reproduces real-life situations in a realistic simulated clinical setting (Chiniara, Cole, Brisbin, Huffman, Cragg, Lamacchia, & Norman, 2013). For undergraduate healthcare students, SCI represents a unique opportunity for an early exposure to authentic clinical problems while safely developing various procedural and cognitive skills. Given their limited experience, novices can potentially be quite overwhelmed by SCI learning tasks, which may result in deceiving learning outcomes (La Rochelle et al., 2011; LaRochelle et al., 2012; van Merriënboer & Sweller, 2010). To maximise learning, task complexity should be adapted to the learners' expertise level, and increase progressively as they become more proficient (van Merriënboer, Kester, & Paas, 2006). However, even if the learning task itself remains relatively simple and comprises only a limited number of information elements to process, many factors, both intrinsic and extraneous to the learning task, will determine the complexity of the learning experience (Naismith, Cheung, Ringsted, & Cavalcanti, 2015; Tremblay, Lafleur, Leppink, & Dolmans, 2017). This might explain why multiple studies have failed to consistently demonstrate enhanced learning among novices in complex skills learning in the context of simulation (La Rochelle et al., 2011; LaRochelle et al., 2012). This study focuses on the relationship between task complexity and learning of novices in SCI.

The complexity of a task, as defined by cognitive load theory, is mainly determined by its degree of elements interactivity (van Merriënboer & Sweller, 2010). Regulating task complexity for a given learner therefore means controlling the number of information elements and their interactions to be processed to account for the limited capacity of the working memory (Leppink & Duvivier, 2016). The sources of cognitive load imposed on a learner can be both intrinsic and extraneous to the learning task. Intrinsic cognitive load refers to the processing of new information to be learned and schema construction (Leppink & van den Heuvel, 2015). Conversely, extraneous cognitive load pertains to the working memory resources spent on information unrelated to the goals of instructions, such as an unfamiliar, malfunctioning or unsuited learning environment, and emotions felt during a simulation that distract from the task at hand (Naismith et al., 2015; Tremblay et al., 2017). To optimize the learning process, extraneous cognitive load must be minimized to allow learners to allocate their working memory resources to dealing with intrinsic cognitive load (Leppink, van Gog, Paas, & Sweller, 2015).

While studying the relationship between cognitive load measures and students' perception of cognitive load in simulation-based training, Naismith et al. (Naismith et al., 2015) have demonstrated that task complexity is accurately detected through self-reported intrinsic cognitive load measures. The authors also reveal that a lack of prior experience and having to integrate multiple skills in one scenario contribute to increasing the perception of task complexity. Recent evidence suggests that reduced task complexity in procedural skills training for novice learners is associated with superior task performance and lower cognitive load during the learning phase, but with mixed results on transfer of learning (Haji, Cheung, Woods, Regehr, Ribaupierre, et al., 2016). These results indicate that task complexity, regulated through patient characteristics and environment features, plays an important role in simulation-based learning outcomes. However, these conclusions can hardly be generalized to non-procedural skills training because the process of skill acquisition may differ.

Evidence in simulation-based training among novices remains equivocal as to its learning benefits (La Rochelle et al., 2011; LaRochelle et al., 2012; Norman, Dore, & Grierson, 2012). This divergence between the intended learning goals and observed learning outcomes might partly be explained by the fact that students' learning processes in simulation are still misunderstood, which could be clarified by qualitative data indicating what students really learn. Moreover, other factors known to have an impact on learning processes, such as intrinsic motivation and sources of extraneous cognitive load in simulation, still need to be investigated (Naismith et al., 2015). Given that simulation-based education is very resource-intensive, it is imperative that we understand how task complexity influences undergraduate healthcare students' cognitive load, performance and perception of learning to improve our capacity to design SCI trainings that promote learning.

RESEARCH QUESTIONS

We designed this mixed-method study to determine the effect of simple and complex tasks in SCI in terms of cognitive load, self-perceived learning and performance for undergraduate pharmacy students (**RQ1**). We hypothesized that students would experience higher intrinsic cognitive load (**H1**), higher extraneous cognitive load (**H2**) and higher self-perceived learning (**H3**) when facing a complex task in SCI as opposed to a simpler task. Moreover, we postulated that complex tasks would lead to a poorer performance (**H4**). As part of a sequential explanatory design, we also aimed to understand how task complexity influenced students' perception of learning (**RQ2**).

METHODS

SETTING

We conducted this study at Laval University Faculty of Pharmacy (Quebec, Canada) in the Pharmacy Simulation Laboratory, which replicates ten pharmacy offices fully equipped with authentic material commonly found in community pharmacies (e.g. medications, electronic pharmacy records, e-resources, and books). All workstations were equipped with ceiling cameras that recorded the simulations.

PARTICIPANTS

One hundred seventy-two second-year undergraduate pharmacy students, in a four-year competency-based pharmacy program (Pharm.D.) dispensed in French, were eligible to participate on a voluntary basis. Given their limited clinical experience (i.e. three weeks of clinical clerkship) and completion of only one fourth of the program prior to the experiment, the participants were considered novices in this study context. They had experienced four simulation activities similar to the study in the Pharmacy Simulation Laboratory prior to recruitment and had theoretical prior knowledge on the learning tasks' clinical content.

INTERVENTION

Participants were randomly assigned to groups of three to four students (see Figure 1 for information on study design). Each participant took turns at acting as the pharmacist for two consecutive SCI learning tasks, one simple and one more complex (see Table 1). Students' turn to perform was determined randomly among the smaller groups. Students' turn dictated the clinical topic for the series of simple and complex tasks (e.g. the first student to perform in one group would do both tasks on dyslipidemia, starting with the simple one and following with the complex one. The second student would then do both simple and complex task on content B, namely cellulitis, etc.). Tasks were always ordered from simple to complex, which typically represents how learning tasks are sequenced in simulation activities (van Merriënboer & Kirschner, 2012). When not playing the pharmacist, the participants observed other students' simulations and listed actions executed by the pharmacist using a checklist developed for each task (see Appendix A for an example of a checklist). To ensure that all participants had the same learning experience and were not biased while observing their peers, each series of tasks (i.e. A, B, C and D) addressed completely different topics, which should not influence how to solve future tasks.

Table 1. Learning task characteristics

Learning tasks	Simple	Complex
A. Dyslipidemia	Initiation of therapy (statin) – Patient Counselling No drug related problem Friendly patient	Statin myopathy (side effect management) Prescribing lab tests, writing drug prescription Communicating with the physician to inform of the management plan (verbally or by writing) OR elaborate plan collaboratively Friendly but anxious patient
B. Cellulitis	Drug monitoring (mid-treatment) No drug related problem Friendly patient, phone conversation	Initiation of therapy (penicillin-allergic patient) Risk of cross-reactivity Elaborating a new treatment plan and preparing the medication Communicating with the physician verbally and by writing to elaborate plan collaboratively Friendly patient but anxious about risks
C. Dose adjustment in renal failure	Initiation of therapy (moderate renal failure) No adjustment needed GFR (kidney function) already calculated and present in patient's file Friendly patient, aware of his condition	Initiation of therapy (severe renal failure) Adjustment required Creatinin levels available, but GFR not calculated Communication with physician (or not required if pharmacist adjust dosage independently) Writing verbal drug prescription Friendly but cannot provide a lot of information Communicating with the physician verbally and by writing to elaborate plan collaboratively (or not required if pharmacist adjust dosage independently)
D. Vaginitis	Initiation of therapy (pregnant patient) No adjustment needed – prescribed by physician Friendly patient	Initiation of therapy (breastfeeding patient) Prescription by pharmacist after investigation Writing verbal drug prescription

Experienced actors played the standardized patients (SP). They received a two-hour training during which the goals of each task and acting tips were clearly explained. The Maastricht Assessment of Simulated Patients (MaSP) tool (Wind, van Dalen, Muijtjens, & Rethans, 2004) was used to rate each actor's authenticity using the recordings of the simulations. Quality of feedback was not assessed, as SPs did not provide it. One author (MLT) assessed twice each actor while playing various roles using video recordings. Overall acting performance was of good quality based on the MaSP tool.

In terms of logistics, the simulation sessions started with a short briefing exposing the overall learning objectives. Students then experienced the two learning tasks (approximately 10 to 15 minutes per case) immediately followed by their respective debriefing periods (approximately 15 to 25 minutes).

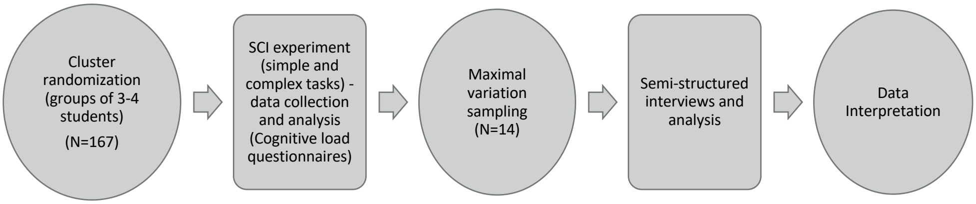

Figure 1. Study design. After each simulation tasks (both simple and complex), students rated their cognitive load using an adapted and validated questionnaire. Students' time-on-task and performance were assessed using a checklist of predictable actions. Fourteen semi-structured interviews were then conducted during which students' perception of task complexity in SCI was questioned.

LEARNING TASKS

All learning tasks were real-life whole tasks, meaning that the clinical situations were authentic, reliable and complete (van Merriënboer & Kester, 2008). An expert panel consisting of two clinical pharmacists familiar with simulation-based education and one educationalist designed the tasks and agreed on the complexity level (simple or complex, yet still appropriate for novice pharmacy students). Task complexity was modulated through patient characteristics, clinical context and necessity to interact with the physical environment. Simple tasks generally contained friendly encounters, patients presenting less comorbidity or potential drug interactions, and fewer interactions with the environment as opposed to complex tasks (see Table 1). Learning tasks were piloted prior to the experiment to confirm the complexity level and to ensure that they were suited for our facilities.

DATA COLLECTION

MEASUREMENTS AND INSTRUMENTS

COGNITIVE LOAD (RQ1)

Intrinsic and extraneous cognitive load and self-perceived learning were measured four times for each participant using a translated and adapted version of a cognitive load questionnaire developed by Leppink et al. (2014) (see Appendix C). After playing the pharmacist, participants rated their cognitive load immediately after each learning task (simple and complex) and after the related debriefing.

PERFORMANCE (RQ1)

Observing students used a checklist to report actions performed by the pharmacist during the simulation. After the simulations, a blinded author (MLT) associated each reported action taken by the student with a corresponding score (i.e. appropriate, inappropriate but not damaging, or damaging for the patient) (see Appendix B). A global performance score was then allocated for both simple and complex tasks, depending on the prevalence of damaging actions taken by the student. The association between possible actions and their appropriateness was predetermined by the expert panel prior to the simulations while developing the checklists. Finally, time-on-task was also collected for both simple and complex tasks.

SEMI-STRUCTURED INTERVIEWS (RQ2)

As part of an explanatory sequential design, semi-structured interviews were conducted a few weeks after the simulations to understand how task complexity affected their perception of learning (see Appendix D for interview guide). Maximal variation sampling was used to select the participants for the interviews (smallest and biggest differences of intrinsic cognitive load for the simple and the complex tasks, both positive and negative differences) to ensure a wide representation of perspectives. Data were collected until a saturation of themes was reached as consented by the authors.

DATA ANALYSIS

QUANTITATIVE ANALYSIS

Statistical analyses were conducted using JAMOVI version 0.9.1.7 (i.e., confirmatory factor analysis and mixed-effects analysis) and JASP 0.9.0.1 (Love et al., 2017) (i.e., correlations and paired *t*-tests for differences between simple and complex case). Intra-class correlation due to students working in groups frequently requires multilevel analysis (i.e., lower level: students; upper level: groups) (Leppink, 2015). However, in the current study, the intra-class correlation was close to zero (see Appendix E figure 2), and therefore paired *t*-tests were performed (i.e., difference between simple and complex case).

Confirmatory factor analysis (CFA) yielded support for which items in the cognitive load questionnaire could be grouped together for creating scale scores (i.e., intrinsic and extraneous cognitive load, and self-perceived learning) (see Appendix C table 4 for more information on the questionnaire and item grouping based on CFA). Cohen's d values were computed to assess the effect sizes of our results. Values of 0.2, 0.5 and 0.8 respectively reflect small, medium, and large effects (Cohen, 1988).

QUALITATIVE ANALYSIS

All interviews were audio-recorded and transcribed integrally. A thematic analysis was performed using both deductive and inductive approaches to code and analyse the verbatim. Using sensitizing concepts from the literature on causes of intrinsic and extraneous cognitive load in SCI, we sought to identify specific themes to understand students' perception of task complexity (LeBlanc, 2009; Naismith et al., 2015; Tremblay et al., 2017), while remaining open to new emerging themes. Two authors analyzed the verbatim (MLT and GL). An iterative approach and constant comparative analysis was used to understand the effect of task complexity in SCI. In case of disagreement, discussions between the authors occurred until an agreement was reached.

ETHICS

This study was approved by the Research Ethics Committee of Laval University (# 2016-254 / 23-09-2016). Written informed consents were obtained prior to randomization. Participants were made aware that the research material would remain confidential and that performance during the simulations would not be used for assessment purposes in their program. The investigators were not directly involved with students' training at the moment of the study. There were no negative consequences for students if they preferred not to participate.

RESULTS

QUANTITATIVE RESULTS

In total, 167 students agreed to participate in this study (response rate of 97.1 %). They were mostly female (71.6%) of *M* = 21.6 years old (*SD* = 2.05) with a college degree (84.1%) prior to entering the PharmD program. Table 2 presents means (*M*), standard deviations (*SD*), and effect size (Cohen's d) for intrinsic and extraneous cognitive load, self-perceived learning, and time on task for simple and complex tasks.

Table 2. Means (*M*), standard deviations (*SD*), and Cohen's d (effect size) with 95% confidence interval (CI) for intrinsic and extraneous cognitive load, self-perceived learning, and time. Software: JASP version 0.9.0.1.

Variable	**Simple** *M (SD)*	**Complex** *M (SD)*	**Cohen's *d***	**Cohen's *d* 95% CI Lower-Upper**
ICL (0-10)				
Case	2.82 (1.49)	4.81 (1.88)	1.23	1.02-1.43
Debriefing	1.82 (1.15)	3.25 (1.85)	0.90	0.71-1.09
ECL (0-10)				
Case	1.69 (1.58)	2.98 (2.16)	0.61	0.44-0.78
Debriefing	0.63 (0.74)	0.91 (1.00)	0.39	0.23-0.56
SPL (0-10)				
Case	5.05 (2.08)	5.96 (1.90)	0.43	0.27-0.60
Debriefing	6.05 (2.22)	7.30 (1.85)	0.64	0.47-0.82
Time (seconds)	448.90 (98.94)	769.28 (158.38)	2.13	1.85-2.41

Table 3. Distribution of performance (n) for simple and complex tasks

Performance score	Simple	Complex
2 = Only appropriate actions	159 (95.8%)	142 (85.5%)
1 = A mix of appropriate and inappropriate actions, but not damaging	6 (3.6%)	7 (4.2 %)
0 = At least one damaging action	1 (0.6 %)	17 (10.3%)

***Note= The restriction of range in students' performance, especially for the simple case, did not allow to subject the difference in performance between simple and complex task to statistical testing.

Most of the participants (92.1%) had previous working experience as pharmacy technician prior to the study (*M* = 16.5, *SD* = 17.8 months). Of note, our results indicated a small correlation between previous working experience and intrinsic cognitive load for both the complex (Spearman's rho = -0.048, 95% CI: -0.207, 0.113) and the simple tasks (Spearman's rho = -0.128, 95% CI: -0.282, 0.032).

In line with **H1**, **H2** and **H3**, our findings indicate a significant difference in terms of intrinsic (*M* = 1.97, 95% CI: 1.72, 2.23) and extraneous cognitive load (*M* = 1.29, 95% CI: 0.95, 1.62) and self-perceived learning (*M* = 0.86, 95% CI: 0.54, 1.17) between the complex and the simple tasks. We also found a statistically significant difference between the debriefings of complex and simple tasks in terms of intrinsic cognitive load (*M* = 1.50, 95% CI: 1.23, 1.77), extraneous cognitive load (*M* = 0.30, 95% CI: 0.18, 0.42), and self-perceived learning (*M* = 1.29, 95% CI: 0.96, 1.66).

In terms of performance, our findings showed that 95.8 % (*N* = 159) of the participants performed only appropriate actions when facing the simple task as opposed to 85.5 % (*N* = 142) for the complex one, (see Table 3). For the simple task, only one participant performed a damaging action and six participants executed a mix of appropriate and inappropriate actions that were not damaging for the patient. For the complex task, 17 participants performed actions that damaged the patient, whereas seven performed a mix of appropriate and inappropriate but not damaging actions. Given the restriction of range in students' performance, especially for the simple case, we could not subject the difference in performance between simple and complex task to statistical testing, thus leaving **H4** unanswered. Even when merging damaging and non-damaging actions to perform a *McNemar* test on the difference of inappropriate and appropriate actions between the simple and complex tasks, results remain difficult to interpret due to this restriction of range (95.8% of appropriate actions for the simple task). However, we found a statistically significant difference for time-on-task between the complex and the simple tasks, and a small positive correlation between difference of time-on-task and difference of intrinsic cognitive load between the simple and complex task (Spearman's rho = 0.188, 95% CI: 0.029, 0.339).

QUALITATIVE RESULTS

Fourteen semi-structured interviews were conducted to understand students' perception of learning when dealing with complexity. Saturation of themes was reached after twelve interviews.

A LACK OF CLINICAL EXPERIENCE LEADS TO A POORER PROBLEM REPRESENTATION AND AN ARBITRARY DECISION-MAKING PROCESS.

From the learner's perspective, a lack of clinical experience was a predominant factor that contributed to task complexity. Even if the theory on clinical contents had been extensively covered prior to the simulations, the absence of previous similar experience made them feel uncertain and prevented them from fully picturing the clinical problems, which altered their decision-making process. Too much uncertainty was associated with a decreased intrinsic motivation, which resulted in a lower perception of learning.

> "I had never done something like that at my job, but I did know which resources to consult. So I did, but I couldn't find what I was looking for. [The references] say we can give between 150 to 450 mg of Clindamycin for that indication, so how do I choose which dosage, or duration, or frequency? I really did not know and I felt uncomfortable… it was difficult." (P572)

UNFAMILIARITY WITH RESOURCES IN THE ENVIRONMENT INCREASES TIME-ON-TASK AND AFFECTS STUDENTS' PRIORITIZATION OF PROBLEMS.

An unfamiliar resource, such as unknown computer functions, e-resources and reference books, all contributed to increase time-on-task. Although all of the interviewed participants had worked in community pharmacies prior to the study, when confronted to new resources that could be useful for the task, students were easily distracted and often could not find the information they were looking for to solve the problem. They felt that they spent too much time on trying to understand the resource rather than focussing on the clinical problems. Time spent on this resource prevented them from organising a complete and appropriate solution.

> "When I realized that the patient had renal failure, I knew I had to make some research because I did not know what to do. Then, I took the [reference book], but I had never used it before, it took my like… two or three minutes just to try to find something. And then, I started panicking. […] So I decided to call the doctor, but instead of suggesting a dosage adjustment [which I should have done], I just suggested another antibiotic [which just seemed easier]." (P263)

THE EDUCATIONAL CONSTRAINTS INHERENT TO SCI (E.G. TIME LIMITATION, BEING OBSERVED, PRIDE, AND PERFORMANCE ANXIETY) SOMETIMES ENCOURAGE SHORTCUTS IN THE CLINICAL REASONING PROCESS.

When the problem-solving process involved many sub-tasks, students immediately felt the need to reorganize and prioritize the tasks that had to be done within the limited time they had. This time restriction was perceived as a realistic yet stressful parameter with which to cope. Some students reported however that instead of reassessing priorities when facing many sub-tasks, they skipped steps in the process, deliberately or not, which may have resulted in a suboptimal treatment plan.

> "I knew I had many things to do so I was nervous. I knew I wanted to call the doctor and I said 'Oh my God' I won't have enough time, so I tried to prioritise in my head, what should I do first, so that I could finish in time and do everything." (P572)

SIMPLE TASKS HELPED STUDENTS GAIN MORE SELF-CONFIDENCE, WHEREAS COMPLEX TASKS FURTHER ENCOURAGED REFLECTIVE PRACTICE DURING DEBRIEFINGS.

Simple tasks are useful to rehearse skills and concepts that are already mastered, hence increasing students' self-confidence. However, the debriefings of simpler tasks seem less stimulating as students are less interested in analysing why their performance was adequate. Complex tasks are more prone to making mistakes because some aspects of the tasks are not yet fully integrated. Debriefings of complex tasks are reported as more valuable as they help students decontextualize the learning experience and reflect on better options.

> "In a complex case, well… it's not really possible to do everything perfectly, but it's just normal, and that's what you will learn from it. You ask yourself why you did this and that, and why you did not think of that, and you'll learn. For simple cases that you can meet on a day-to-day basis, well at least, you will learn to gain more confidence in yourself, which is also very important." (P272)

DISCUSSION

Among the many studies in simulation-based education interested in cognitive load and task complexity, none had ever examined how undergraduate students experience non-procedural learning tasks of various complexities in a highly authentic simulated environment. Our study demonstrates that the factors contributing to increase task complexity are likely to impose a higher cognitive load while affecting the problem-solving process. These findings build on current evidence regarding the various factors that contribute to increase either intrinsic or extraneous cognitive load for medical students in simulation such as lack of knowledge, unfamiliar resources and time limitation (Naismith et al., 2015). The richness of our mixed-methods design helped clarify how these factors can either impede or improve their performance in the training phase. The impacts of task complexity on transfer of learning in the context of non-procedural simulations still remain to be studied. Nonetheless, students perceived that they learned more from the complex tasks even though they constitute an additional challenge in terms of clinical reasoning and generate more mistakes. From their perspective, complex tasks represent a more valuable learning experience because their debriefings stimulated a deeper reflection.

Although the learning environment in SCI has typically been associated with extraneous cognitive load (Choi et al., 2014; Naismith et al., 2015), it rather seems to contribute to both to intrinsic and extraneous cognitive load. In immersive simulation, the physical environment is inherently related to the learning task and can hardly be disentangled from it. Computers, medications, or examination instruments can certainly mobilise learners' cognitive resources if they are unfamiliar with them. However, if the learning goal of the simulation is actually to learn how to use and integrate them in the problem-solving process, any load related to this activity is intrinsic to the learning goal(s) and hence a source of intrinsic cognitive load. Conversely, if the learners are expected to master these resources beforehand, being distracted by them then pertains to extraneous cognitive load. The fact that a given element of the learning environment can contribute to increase either intrinsic or extraneous cognitive load shows that sources of extraneous load in simulation are not fixed. Other environmental features in simulation unrelated to the instructions have indisputably been associated with extraneous cognitive load such as the room temperature and noises (Choi et al., 2014). Therefore, sources of intrinsic and extraneous cognitive load in simulation essentially depend on the learning goals. This observation has also been recognized in learning contexts other than simulation (Kalyuga & Singh, 2016; Leppink, 2017).

Although the vast majority of students found the complex tasks more complex as reflected through a higher intrinsic cognitive load, what made these tasks complex sometimes differed from our expectations, which can explain why some participants designated the simpler tasks as more complex for them. Although we designed the complex tasks to include more challenging patient encounters, students surprisingly did not report this aspect as complex for them. This finding reinforces the idea that task complexity is a dynamic concept that is the result of the interactions between a given learning situation and a learner (Bleakley & Cleland, 2015; Davis & Sumara, 2006).

LIMITATIONS

Despite our relatively large sample size, we could not subject differences in performance between simple and complex tasks to statistical testing, as a vast majority of students performed only appropriate actions for both tasks. The instrument used to grade performance did not focus on the quality of each action, but rather on their acceptability. Therefore, some actions might be acceptable and not damaging in today's practice but might not be ideal either. We chose this type of instrument mainly because we did not want to assess the quality of student's actions on tasks they had never performed before. Making mistakes and debriefing them is inherent to the learning experience in SCI. The ceiling effect we observed in our performance results did not allow us to test our hypothesis regarding the effect of complexity on performance. Nonetheless, we have reasons to expect differences in terms of the quality of performance between simple and complex tasks. Moreover, we only collected data regarding cognitive load and perception of learning and did not measure learning outcomes, as this was not the focus of this study. Whether complex SCI learning tasks lead to better learning outcomes or increased transfer of learning remain to be studied.

CONCLUSION

Providing a wide range of task complexity has been associated with better learner engagement and positive learning outcomes in simulation-based education (Cook et al., 2013). Although complex tasks in SCI were more cognitively demanding and took longer to execute, students indicated that they learned more from them because they stimulated reflection on practice. Complex tasks constitute an additional challenge in terms of clinical reasoning, thus providing a more valuable learning experience from students' perspective.

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CHAPTER FOUR

Task Complexity and Cognitive Load in Simulation-based Education: A Randomized Trial

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ABSTRACT

Context When designing simulation for novices, educators aim to design tasks and environments that are complex enough to promote learning, but not too complex to compromise task performance and cause cognitive overload.

Objectives To determine the impact of modulating task and environment complexity on novices' performance and cognitive load during simulation.

Methods Second-year pharmacy students (*N*=162) were randomly assigned to one of four conditions (2x2 factorial design) in simulation: simple task in simple environment, complex task in simple environment, simple task in complex environment, and complex task in complex environment. Using video recordings, two raters assessed students' performance during the simulation. We measured intrinsic (ICL) and extraneous cognitive load (ECL) with questionnaires after the task, and tested knowledge after task and debriefing.

Results Mean performance scores in simple environment were 28.2/32 (*SD*=3.8) for simple task and 25.8/32 (*SD*=4.2) for complex task. In complex environment, mean performance scores were 24.6/32 (*SD*=5.2) for simple task and 25.6/32 (*SD*=5.3) for complex task. We found significant interaction effects between task and environment complexity for performance. In simple environment, mean ICL scores were 4.2/10 (*SD*=2.2) for simple task and 5.7/10 (*SD*=1.5) for complex task. In complex environment, mean ICL scores were 4.9/10 (*SD*=1.8) for simple task and 5.1/10 (*SD*=1.9) for complex task. There was a main effect of task complexity on ICL. For ECL, we found neither an interaction effect nor main effects of task and environment complexity. There was a main effect of task complexity on knowledge test after task and main effects of both task and environment complexity on knowledge after debriefing.

Conclusion Performance was good and cognitive load remained reasonable in all conditions, which suggests that, despite increased complexity, students seemed to strategically manage their own cognitive load and learn from the simulations. Our findings also indicate that environmental complexity contributes to ICL.

INTRODUCTION

For novices, experiencing authentic clinical tasks in a controlled environment with simulated patients allows them to safely integrate knowledge, skills and attitudes required in the workplace. The learning tasks in simulation can be challenging for novices, since they have limited clinical experience and are still consolidating newly acquired cognitive schemas (Tremblay, Leppink, Leclerc, Rethans, & Dolmans, 2018). The dynamic learning environment is also highly engaging both cognitively and emotionally, and can directly influence what students learn (Fraser et al., 2012; Tremblay, Lafleur, Leppink, & Dolmans, 2017). When mixing such complex learning tasks with a complex learning environment, inexperienced learners may potentially experience cognitive overload and be at risk of negative impact on learning. Although modulating task and environment complexity is part of every simulation design, the combined effect of these two components on novices' learning process remains unclear.

COGNITIVE LOAD THEORY

Cognitive load experienced during a simulation highly depends on the interactions between the learner, the simulation task and the learning environment (Choi et al., 2014; Sweller, 1988). The greater the interactions, the higher the cognitive load for that learner. Cognitive load theory distinguishes two types of cognitive load, namely intrinsic and extraneous cognitive load. The intrinsic load relates to the complexity of information and the degree of interacting elements. Extraneous cognitive load refers to any additional load that does not pertain to the learning goals. The original cognitive load theory model describes a third type of load, namely germane load, which refers to the working memory resources involved in processing intrinsic cognitive load (Sweller et al., 1998). In a clinical environment, whether simulated or real, germane cognitive load seems to play a limited role, and will therefore not be the focus of this research(Szulewski et al., 2020). In simulation, both the task and the environment contribute to intrinsic load because these two features comprise relevant information that needs to be processed by the learner to perform the task (Szulewski et al., 2020). To optimise learning, extraneous cognitive load must be minimised to allow learners to focus their working memory resources on dealing with essential element (van Merriënboer & Sweller, 2010).

A reconceptualization of cognitive load theory proposed by Choi et al. (2014) considers the learning environment as a determinant of the effectiveness of instruction. In their revised model of this theory, the learning task and the environment are disentangled. The *environment* refers to the whole range of physical features of a place in which teaching and learning occur. These features include physical characteristics of learning materials and tools (i.e., the media through which the information is presented to the learner), physical properties of the room, and the physical presence of other people. In other words, it comprises all the sensory stimuli generated by the environment that can be perceived by the human senses. The *learning task* characteristics, for example the patient's medication profile or the information to be communicated to the patient, refer to the intrinsic task complexity or the type of tasks to be executed. The authors explain that what will constitute intrinsic or extraneous cognitive load will depend on the learner's expertise level and will result from the design of both the task and the environment.

ADAPTING TASKS AND ENVIRONMENTS FOR NOVICES

In simulation-based education, complexity should be adapted to the learners' expertise level and increase progressively as they become more proficient (van Merriënboer & Kirschner, 2017). Task complexity is mainly determined by the *number* of information elements to process and the *degree of interaction* between them (van Merriënboer & Sweller, 2010). From the novices' perspective, complex tasks are highly valuable as they provide opportunities during debriefings to learn from ones' mistakes (Tremblay et al., 2018). In simulation, the learning tasks are situated in a simulated clinical environment which adds context to this task and allows students to incorporate environmental features in their decision-making process (Chiniara, Cole, Brisbin, Huffman, Cragg, Lamacchia, Norman, et al., 2013; Szulewski et al., 2020; Weller, 2004). This learning environment can seem complex for an inexperienced learner (Tremblay et al., 2017). Unlike a real clinical environment, a simulated environment can be controlled by decreasing the *element interactivity* in the learner's working memory without compromising its authenticity. When designing simulation for novices, it is advisable to first remove elements that can typically be found in a real "messy" clinical environment that do not pertain to the learning goal and may contribute to extraneous cognitive load (e.g., ambient noise in the pharmacy). Environmental complexity can also be modulated by presenting the information to the learner in an either simple or complex way. For example, a disorganized electronic patient record (EPR) reflects a complex environmental feature with high element interactivity as opposed to a well-organized EPR that comprises the *same information* than a complex one, but that facilitates the retrieval of relevant information to accomplish the learning task. Therefore, learners do not need to invest too much mental effort in processing the functioning of the EPR and can devote their cognitive resources in solving the clinical problem.

THE COMBINED EFFECT OF COMPLEX TASKS AND ENVIRONMENTS

Although both the learning task and the environment can be adapted to take into account the learner's ability, increasing evidence indicates that modulations made in the learning environment to accommodate learners' skill level might influence their capacity to attend to specific learning goals (Brooks, 2011, 2012; Whiteside, Brooks, & Walker, 2010). In simulated environments, multiple studies have shown enhanced learning among novices for simple skills training (Scerbo, Bliss, Schmidt, & Thompson, 2006; Scerbo, Schmidt, & Bliss, 2006), but equivocal results in terms of complex skills acquisition such as clinical reasoning (Chen, Grierson, & Norman, 2015; LaRochelle et al., 2012; Norman et al., 2012). LaRochelle et al. (2012) found that clinical reasoning skills of undergraduate medical students improved as authenticity increased for top students and for the bottom tertile of the cohort. Contrastingly, performance decreased as authenticity increased for students in the middle tertile, thus failing to demonstrate the consistent superiority of increased authenticy on novices' performance. The authors postulate that increased authenticity might provoke extraneous cognitive load which can explain why some students do not benefit from this instructional change. However, they could not entirely explain why only middle students would be subjected to this increase in extraneous cognitive load. Learning complex skills in a complex environment is likely to be overwhelming for a novice learner, partly because of their lack of experience with both the task and the environment. Haji, Cheung, Woods, Regehr, de Ribaupierre, et al. (2016) have demonstrated that novices perform better and experience lower cognitive load when learning a simple task in a complex environment than when learning a complex task in a complex environment. It is still unclear whether modulating environment complexity would lead to better skills acquisition for complex tasks. Since simulation requires considerable resources, it is imperative that scenarios be optimally designed so that learners can reach learning goals efficiently.

OBJECTIVE OF THE CURRENT STUDY

This study aimed to determine the impact of modulating task and environmental complexity on novices' performance, cognitive load and knowledge in simulation.

METHODS

SETTING

We conducted this study at Laval University Faculty of Pharmacy (Canada) in the Pharmacy Simulation Laboratory, which replicates ten pharmacy offices fully equipped with authentic material commonly found in community pharmacies (e.g., medications, EPR, e-resources, and books). Every workstation is equipped with a ceiling camera.

PARTICIPANTS

All second-year undergraduate pharmacy students (one hundred sixty-seven), in a four-year competency-based pharmacy program (Pharm.D.) that is taught in French, were eligible to participate on a voluntary basis. Given their limited clinical experience (i.e. three to four weeks of clinical internship) prior to the experiment, the participants were considered novices. They had experienced four simulation training in the Pharmacy Simulation Laboratory similar to the ones in this experiment prior to recruitment on other subjects.

In the program, the large cohort of students is originally divided into six groups of approximately 30 students for various educational activities. For this study, stratified random assignment (i.e., random assignment within the predetermined groups of 30) was used to subdivide students into teams of three using a random number generator. An unblinded technician from the Simulation Centre assigned each team to a workstation for a full session. Each session comprised three different learning tasks that require the participation of one student playing the pharmacist's role. Each student played the pharmacist once and observed their peers twice during one simulation session. The order in which they played the pharmacist or the observer was assigned by the unblinded technician using the random numbers generated previously (i.e., of the three students assigned to a station, participants performed the pharmacist in ascending order). The research team involved in analysing the data remained blinded throughout the process.

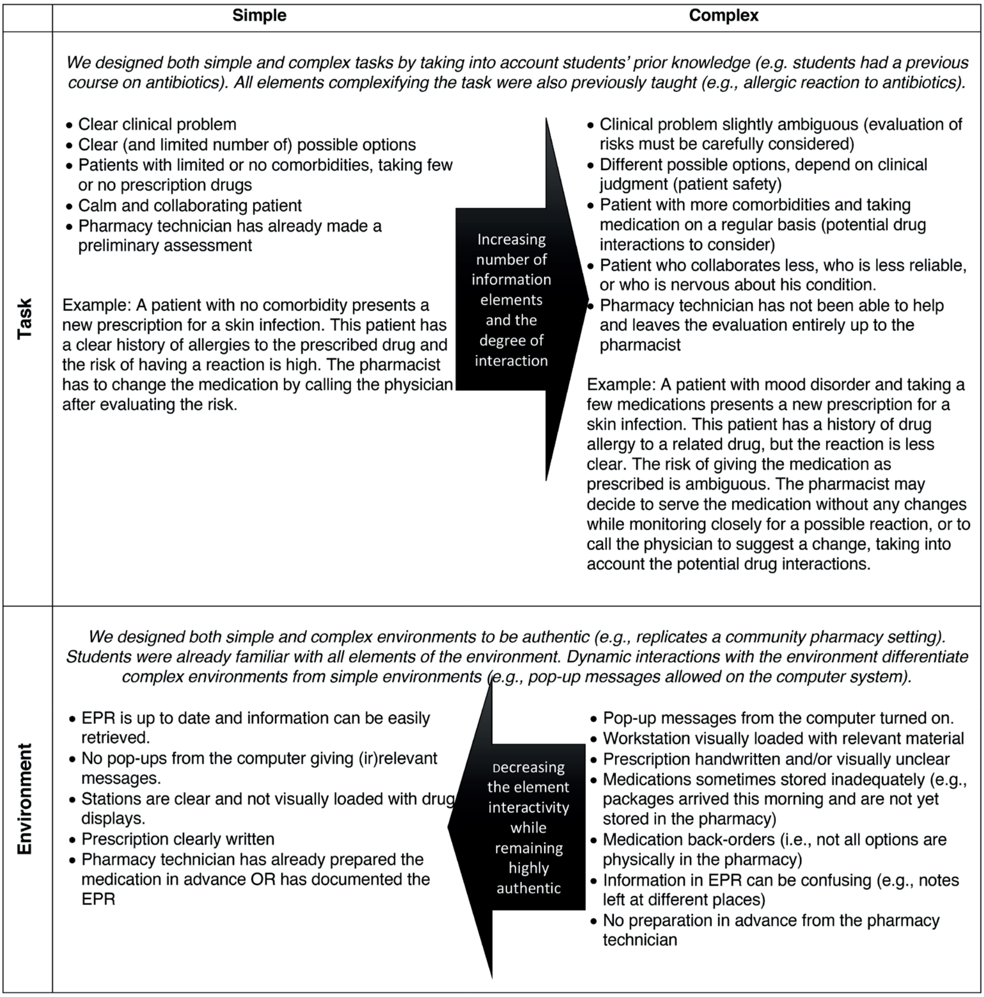
DESIGN

EXPERIMENTAL CONDITIONS

While acting as the pharmacist, students randomly experienced one of the four experimental conditions in a 2x2 factorial design: simple task in simple environment, complex task in simple environment, simple task in complex environment, and complex task in complex environment. Each simulation session displayed one experimental condition at a time to facilitate the debriefing. Two simulation experts and pharmacy clinicians designed the tasks and environments. All conditions were pilot-tested prior to the study with a small group of third-year students. Clinical aspects of each case were previously taught in the program, but never in simulation.

Based on the literature, we created a blueprint, presented in Figure 1, to modulate task and environment complexity. Simple and complex learning tasks differed by the increasing number of information elements and the degree of interaction between them. For example, simple tasks involved patients with limited or no comorbidities, taking few or no prescription drugs, as opposed to complex tasks comprised patients with more comorbidities and taking medication on a regular basis with therefore potential drug interactions. Both simple and complex learning environments were highly authentic, and included medication, EPR, telephones, and other equipment commonly found in real-life practice. Simple and complex environments differed in terms of element interactivity. For instance, simple environments involved stations that were in order and not visually loaded with drug displays, and clearly written prescriptions. Complex environments displayed visually loaded stations with relevant material, messy handwritten prescriptions and/or visually unclear. In total, twelve different learning tasks were developed (i.e., 3 different clinical topics, varying in task/environment complexity for the 4 conditions).

A general briefing at the beginning of the simulation session presented the environmental features and logistical details to consider. During the simulation, 17 different experienced actors played the simulated patients. All students, whether having acted as pharmacists or observers, participated in the debriefing. After this debriefing, a new learner experimented a new learning task followed by its debriefing.



	Simple		Complex
Task	*We designed both simple and complex tasks by taking into account students' prior knowledge (e.g. students had a previous course on antibiotics). All elements complexifying the task were also previously taught (e.g., allergic reaction to antibiotics).*		
	• Clear clinical problem • Clear (and limited number of) possible options • Patients with limited or no comorbidities, taking few or no prescription drugs • Calm and collaborating patient • Pharmacy technician has already made a preliminary assessment Example: A patient with no comorbidity presents a new prescription for a skin infection. This patient has a clear history of allergies to the prescribed drug and the risk of having a reaction is high. The pharmacist has to change the medication by calling the physician after evaluating the risk.	Increasing number of information elements and the degree of interaction	• Clinical problem slightly ambiguous (evaluation of risks must be carefully considered) • Different possible options, depend on clinical judgment (patient safety) • Patient with more comorbidities and taking medication on a regular basis (potential drug interactions to consider) • Patient who collaborates less, who is less reliable, or who is nervous about his condition. • Pharmacy technician has not been able to help and leaves the evaluation entirely up to the pharmacist Example: A patient with mood disorder and taking a few medications presents a new prescription for a skin infection. This patient has a history of drug allergy to a related drug, but the reaction is less clear. The risk of giving the medication as prescribed is ambiguous. The pharmacist may decide to serve the medication without any changes while monitoring closely for a possible reaction, or to call the physician to suggest a change, taking into account the potential drug interactions.
Environment	*We designed both simple and complex environments to be authentic (e.g., replicates a community pharmacy setting). Students were already familiar with all elements of the environment. Dynamic interactions with the environment differentiate complex environments from simple environments (e.g., pop-up messages allowed on the computer system).*		
	• EPR is up to date and information can be easily retrieved. • No pop-ups from the computer giving (ir)relevant messages. • Stations are clear and not visually loaded with drug displays. • Prescription clearly written • Pharmacy technician has already prepared the medication in advance OR has documented the EPR	Decreasing the element interactivity while remaining highly authentic	• Pop-up messages from the computer turned on. • Workstation visually loaded with relevant material • Prescription handwritten and/or visually unclear • Medications sometimes stored inadequately (e.g., packages arrived this morning and are not yet stored in the pharmacy) • Medication back-orders (i.e., not all options are physically in the pharmacy) • Information in EPR can be confusing (e.g., notes left at different places) • No preparation in advance from the pharmacy technician

Figure 1. Blueprint to Modulate Task and Environment Complexity in the Design of Simulation for Novices

INSTRUMENTS

TASK PERFORMANCE

We used video recordings to assess the performance of each student playing the pharmacist. We developed a global rating scale to assess the quality of the performance (see Appendix 1) based on the Anaesthetist's Non-technical Skills Global Rating Scales (ANTS) rubric, originally designed and validated to assess teams during anesthesiology trainings (Fletcher et al., 2003). The ANTS system was developed using psychological research techniques to identify and structure non-technical skills. The evaluation process, which involved 50 trained anaesthetists using the instrument while watching eight videos of simulated anaesthetic scenarios, resulted in a satisfactory level of validity, reliability and usability. The original items of the rubric were modified to account for the study context. Eight items were selected because they assessed task or environment management. The eight items were rated from 1 to 4 with a global score minimum 8 to maximum 32 (1=Poor, i.e., performance endangered or potentially endangered patient safety, 2=Marginal, i.e., performance indicated cause of concern, considerable improvement is needed, 3= Acceptable, i.e., performance was of a satisfactory standard, but it could be improved, 4=Good, i.e., performance was of a consistently high standard, it could be used as a positive example for others). The rubric had been piloted prior to the study with the same population during a previous simulation session. The Cronbach's alpha for this adapted tool was 0.80, which provides validity evidence for internal structure. Videos were assigned randomly to two blinded independent raters (MLT and GL), both pharmacists and educators. MLT rated all participants. GL rated 20% of the participants. Interrater reliability on performance scores was 0.64 (substantial), 95 % CI [0.55 – 0.72].

COGNITIVE LOAD

We measured intrinsic and extraneous cognitive load after the simulations using a translated (French) and adapted version of a cognitive load questionnaire (see Appendix 2) developed by Leppink et al. (2014). The original questionnaire was developed in the context of lectures in statistics and was tested to provide evidence for the validity and reliability of a three-factor solution (i.e., three types of cognitive load) (Leppink, Paas, van der Vleuten, van Gog, & van Merriënboer, 2013). The translation of each item had first been done from English to French by one researcher. Another member of the team then translated back the items from French to English to ensure their appropriateness. Our questionnaire consisted in 5 items targeting intrinsic cognitive load and 5 items relating to extraneous cognitive load. Participants rated each item on a scale of 0 to 10 (0 = not at all, 10 = completely the case). The tool used in this study had previously been used in the context of simulation for undergraduate pharmacy students (Tremblay et al., 2017; Tremblay et al., 2018). This version was pilot-tested prior to the intervention with the same students during a simulation session to familiarise participants with the terms and clarify any imprecision. The Cronbach's alpha for intrinsic cognitive load in this study was 0.9 and 0.77 for extraneous cognitive load.

KNOWLEDGE TESTS

We measured knowledge through 10 true or false items related to the task participants had just performed. The test was administered after the simulation and once again after debriefing. The tests were designed by the same team who developed the learning tasks to ensure that the content of the test reflected the intended learning goals. The tests were pilot-tested with third-year students at the same time as the four conditions.

DATA ANALYSIS

We conducted statistical analyses with SPSS Statistics 28 (IBM Corp, Armonk, NY). We performed two-way ANOVAs to determine the main effects and interactions of task complexity and environment complexity on task performance, cognitive load, and knowledge test scores. For significant interactions, we conducted follow-up analysis with simple effects to help interpreting the results. Due to the number of planned comparisons, Bonferroni corrections were applied, resulting in a *p*-value of significance of 0.01. A post-hoc power analysis revealed a power of 0.52.

ETHICS

This study was approved by the Research Ethics Committee of Laval University (2019-230/03-09-2019).

RESULTS

A total of 162 students agreed to participate in this study (response rate of 97%). They were mostly female (72%) with a mean of 22.0 years old (*SD*=2.5) with a college degree (78%) prior to entering the PharmD program. Just over 27% (n=43) participants had experienced a case similar to the one they had experienced during the simulation in real-life practice (Figure 2).

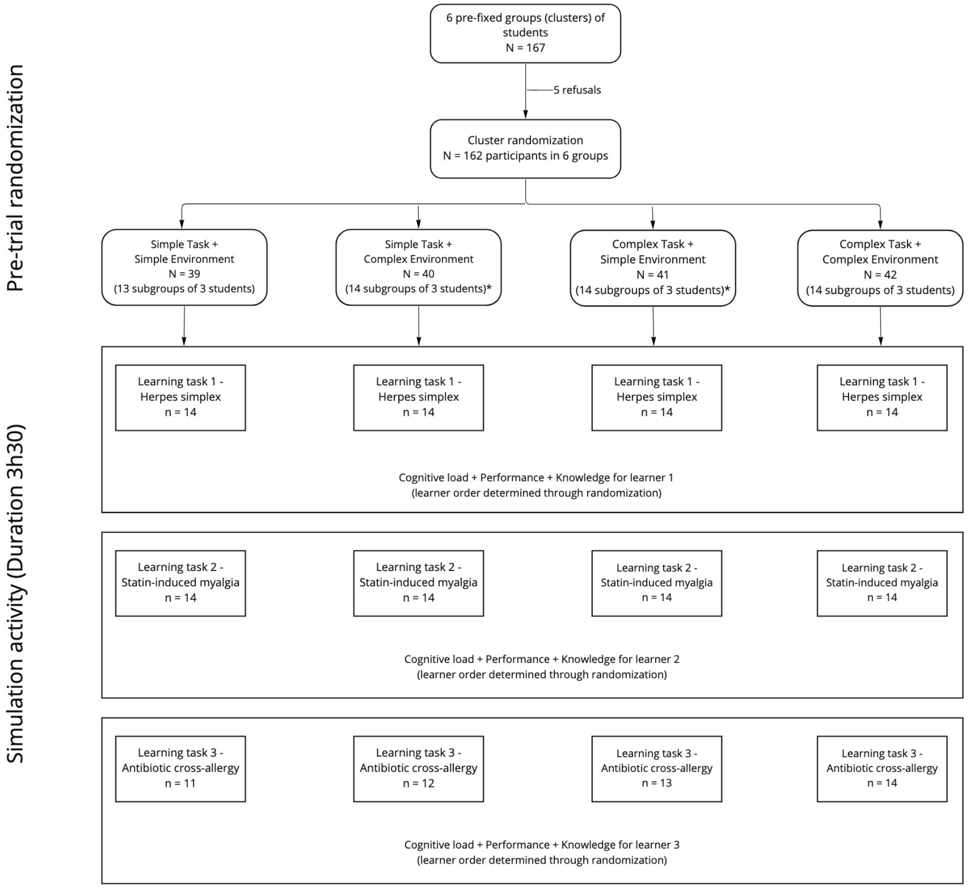


Figure 2. Flow diagram of study randomization process and intervention.

As shown in Figure 3, students' mean performance scores in simple environment were 28.2/32 (*SD*=3.8) for simple task and 25.8/32 (*SD*=4.2) for complex task. In complex environment, mean performance scores were 24.6/32 (*SD*=5.2) for simple task and 25.6/32 (*SD*=5.3) for complex task. We found a significant interaction effect between task and environment complexity in terms of performance, *F*(1-158)=5.61, *p*=0.01, which indicates that the effect of task complexity on performance depends on the level of environment complexity. As this interaction effect was statistically significant, main effects cannot be sensibly interpreted. Simple effect analysis revealed that performance of simple tasks significantly decreased between simple and complex environments (*p*<0.001). For complex task, performance remained unchanged (*p*=0.89) between simple and complex environments. There was no significant difference in performance between simple and complex tasks in both simple (*p*=0.02) and complex environment (*p*=0.33).

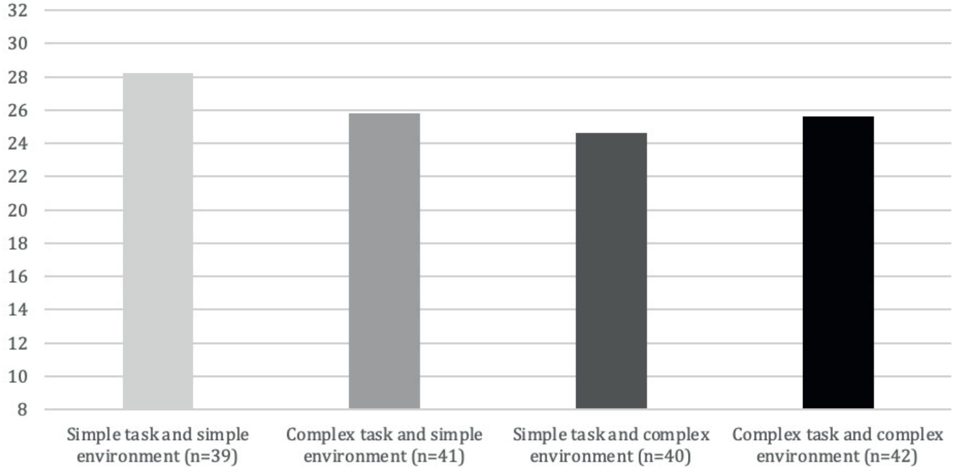


Figure 3. Impact of Modulating Task and Environment Complexity on Students' Task Performance (scored from 8 to 32). Mean performance scores in simple environment: 28.2/32 (*SD*=3.8) for simple task vs. 25.8/32 (*SD*=4.2) for complex task. In complex environment, mean performance scores: 24.6/32 (*SD*=5.2) for simple task vs. 25.6/32 (*SD*=5.3) for complex task. Significant interaction effect between task complexity and environment complexity (*p*=0.01). Simple effect analysis revealed that performance of simple tasks significantly differed between simple and complex environments (*p*<0.001). For complex task, performance remained unchanged (*p* = 0.89) between simple and complex environments. There was no significant difference in performance between simple and complex tasks in both simple (*p*=0.02) and complex environment (*p*=0.33).

In simple environment, mean intrinsic load scores were 4.2/10 (*SD*=2.2) for simple task and 5.7/10 (*SD*=1.5) for complex task (see Figure 4). In complex environment students reported a mean intrinsic cognitive load of 4.9/10 (*SD*=1.8) for simple task and 5.1/10 (*SD*=1.9) for complex task. There was no significant interaction effect between task and environment complexity in terms of intrinsic cognitive load, *F*(1-152)=4.43, *p*=0.04. There was a main effect of task complexity (*p*=0.004), but no main effect of environment complexity (*p*=0.77) on intrinsic cognitive load. We found no significant interaction effect between task and environment complexity for extraneous cognitive load, *F*(1-150)=2.84, *p*=0.09. There was no main effect of either task complexity (*p*=0.56) or environment complexity (*p*=0.19) on extraneous cognitive load.

We found no significant interaction effect between task and environment complexity on mean results of knowledge tests, both after task, *F*(1-152)=0.90, *p*=0.34, and after debriefing *F*(1-153)=1.29, *p*=0.26 (see Figure 5). There was a main effect of task complexity (*p*=0.01) and a non-significant main effect of environment complexity (*p*=0.79) on knowledge test after task. There was a main effect of environment complexity (*p*=0.003) but a non-significant effect of task complexity (*p*=0.02) on knowledge test scores after debriefing.

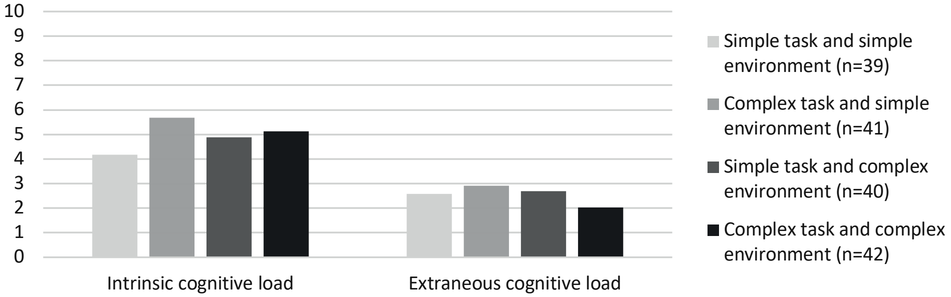


Figure 4. Impact of Modulating Task and Environment Complexity on Students' Mean Scores of Intrinsic Cognitive Load and Extraneous Cognitive Load (agreement scale from 0 to 10). In simple environment, mean intrinsic load scores were 4.2 (*SD*=2.2) for simple task and 5.7 (*SD*=1.5) for complex task. In complex environment students reported a mean intrinsic cognitive load of 4.9/10 (*SD*=1.8) for simple task and 5.1/10 (*SD*=1.9) for complex task. No significant interaction effect between task and environment complexity in terms of intrinsic cognitive load, *p*=0.04. There was a main effect of task complexity (*p*=0.004), but no main effect of environment complexity (*p*=0.77) on intrinsic cognitive load. In simple environment, mean extraneous load scores were 2.6 (*SD*=1.8) for simple task and 2.9 (*SD*=2.1) for complex task. In complex environment, mean extraneous load scores were 2.7 (*SD*=1.9) for simple task and 2.1 (*SD*=1.5) for complex task. No significant interaction effect between task complexity and environment complexity (*p*=0.09). No main effect of either task complexity (*p*=0.56) or environment complexity (*p*=0.19).

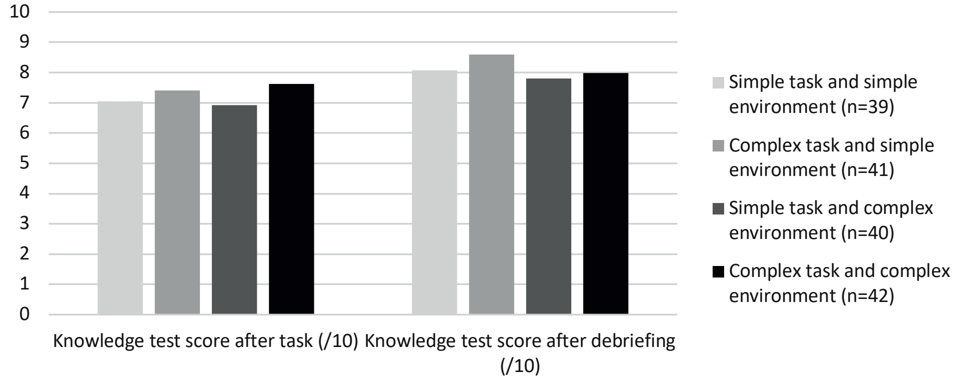


Figure 5. Impact of Modulating Task and Environment Complexity on Students' Mean Results in Knowledge Tests (10 true or false questions) After Simulation Tasks and Debriefing. Mean score in simple environment were 7.1/10 (*SD*=1.0) after simple task and 7.4/10 (*SD*=1.5) after complex task. In complex environment, mean score were 6.9/10 (*SD*=1.2) after simple task and 7.6/10 (*SD*=1.1) after complex task. No significant interaction effect between task complexity and environment complexity (*p*=0.34). There was a main effect of task complexity (*p*=0.01) and a non-significant main effect of environment complexity (*p*=0.79) on knowledge test after task. Mean score in simple environment were 8.1/10 (*SD*=1.1) for simple task and 8.6/10 (*SD*=0.7) for complex task. In complex environment, mean score were 7.8/10 (*SD*=1.1) for simple task and 8.0/10 (*SD*=0.7) for complex task. No significant interaction effect between task complexity and environment complexity (p=0.27). There was a main effect of environment complexity (*p*=0.003) but a non-significant effect of task complexity (*p*=0.02) on knowledge test scores after debriefing.

We performed a multivariate general linear model using task as the fixed factor for all five dependent variables to check for order effect. There were no significant effects, which indicates that the task order did not significantly affect any of the outcome variables. We also computed a multivariate general linear model using cluster (subgroup) as the fixed factor for all five dependent variables. There were no significant effects of clusters for performance score or cognitive load measures. However, there were significant effects on knowledge after the task (*p*<0.001), and knowledge after debriefing was borderline significant (*p*=0.04). Therefore, in this study, clusters did not significantly affect the majority of outcome variables, aside from knowledge after task and potentially knowledge after debriefing. We therefore refrained from interpreting knowledge after task with regards to modulation of complexity.

DISCUSSION

In this study, we demonstrated that task and environment complexity interact with each other and impact novices' performance in simulation. Students' performance was surprisingly good and cognitive load remained moderate in all conditions, which suggests that, despite increased complexity, students managed to learn from the simulations.

When struggling with the environment, students' focus seemed to shift from the task and was redirected towards managing the environment. As reflected by the effect of task complexity on intrinsic cognitive load, our students seem to strategically manage their own cognitive load - consciously or not - as complexity increases to ensure that they perform to a certain level and learn something relevant. This finding is in line with other studies that have described how the environment influence student learning in simulation (Tremblay et al., 2017). However, although this strategy prevents students from experiencing cognitive overload, it might also impede their capacity to meet all the intended learning goals. Moreover, learning to deal with the environment while solving a clinical problem is inherent to simulation-based education (Szulewski et al., 2020) or authentic clinical work. To ensure that novices meet the learning goals in complex environments, educators could allow more time and/or more trials to practice complex tasks. This strategy has been proven effective to rapidly improve clinical performance of advanced learners (Perretta et al., 2020). Future research needs to confirm whether similar results can be obtained in complex environments for novices.

From a theoretical perspective, our findings reinforce the idea that environmental complexity is associated with intrinsic cognitive load. As postulated by Choi et al. (2014), the learning environment, which had mostly been depicted as a source of extraneous cognitive load in the past, acts as a distinct causal factor of intrinsic cognitive load by directly contributing to the learning goal and not only acting as a distraction. This finding is also in line with other exploratory work in clinical settings that force us to reconsider the role of the environment (Tremblay et al., 2017; Vella, Hall, van Merrienboer, Hopman, & Szulewski, 2021), whether simulated or real, in the learning process.

LIMITATIONS

The knowledge tests used to measure learning outcomes in this study might not fully capture the nature and depth of learning in simulation. True or false questions were mostly related to clinical knowledge and hardly targeted environmental features, partially explaining the lack of large differences between conditions. We also acknowledge that features from the task and the environment in simulation can be easily distinguished in theory, but be difficult to discriminate in practice. Therefore, increasing environment complexity might actually affect task complexity, which can partly explain the limited yet significant differences between conditions.

Although we modified a tool widely used in simulation-based education to assess performance, we could not find a large difference between conditions. This could be the result of a ceiling effect, which is often the case when using such instruments. This could also be because the anchors may be unadapted for novices. In our observations, we noticed that students were often not necessarily putting the patient at risk (i.e., score of 1), but not performing above standards (i.e., score of 4) either, leaving very little room for all the nuances there can be between degrees of performance. However, we could not find a tool in the literature appropriate for novices to assess the quality of their performance with all the nuances required.

CONCLUSION

When designing simulation, the complexity of task and environment can be increased without jeopardizing novices' performance or creating cognitive overload. As complexity increases, novices' capacity to attend to the learning goals intended might be compromised. Educators could consider increasing the number of opportunities to practice with the same level of complexity to ensure that the learning goals are met.

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CHAPTER FIVE

Collaboration Scripts or Checklists to Engage Novice Observers in Immersive Simulation?

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ABSTRACT

Introduction In simulation, students often observe their peers perform a task. It is still unclear how different types of instructional guidance can turn the observational phase into an active learning experience for novices. This mixed-method study aims to understand similarities and differences between use of collaboration scripts and checklists by observers in terms of cognitive load and perception of learning.

Methods Second-year pharmacy students (*N*=162) were randomly assigned to one of four conditions when observing a simulation: collaboration scripts (heuristic to analyse in dyads while observing), checklists, both, or no guidance. We measured observers' intrinsic and extraneous cognitive load (ICL and ECL), and self-perceived learning, and conducted focus group interviews.

Results ICL was significantly lower for checklists (M=3.6/10) than for scripts (M=4.7/10) or scripts and checklists combined (M=4.7/10). ECL was significantly lower for checklists (M = 1.5/10) than for scripts combined with checklists (M=2.6/10) or no guidance (M=1.8/10). There was no statistical difference between conditions for self-perceived learning. Coding of focus group interviews revealed six themes on observers' perception of learning under different conditions of instructional guidance. Students explained that collaboration scripts felt more complex, whereas checklists were perceived as a simple fact-checking exercise. Observing the simulation, regardless of guidance, was a meaningful learning experience.

Conclusions With or without guidance, observers are actively engaged with the simulation, but their effort differed depending on instructions. When choosing between checklists or collaboration scripts, educators should be guided by the type of simulation task.

INTRODUCTION

Immersive simulations for undergraduate healthcare students allow participants to practice their skills safely and actively in an authentic clinical setting. However, due to logistical and financial constraints, a considerable amount of students' time is spent on watching peers perform a simulated task. While some learners value these observations, others find this experience rather uninteresting and disengaging (Harder, Ross & Paul, 2013). Since periods of observation during a simulation are often inevitable, it is important that these moments remain a valuable learning experience.

LEARNING BY OBSERVATION IN SIMULATION

Recent literature reviews and empirical studies showed that learning by observation in simulation leads to inconsistent learning outcomes when compared to active participation (Delisle, Ward, Pradarelli, Panda, Howard & Hannenberg, 2019; Johnson, 2019; O'Regan, Molloy, Watterson & Nestel, 2016; Reime, Johnsgaard, Kvam F et al, 2017). Observation in simulation seems to promote students' learning, particularly in the area of patient assessment and communication (Livsey & Lavender-StottStegmann, 2015; Stegmann, Pilz, Siebeck & Fischer, 2012). However, some learners do not perceive these observations as meaningful learning opportunities and even find them uninteresting (Delisle et al., 2019). When using an observing guide during simulation, Norman and colleagues (2018) have demonstrated that students are more satisfied with their learning experience than those who observe the simulation without guidance, although no differences in learning outcomes were detected. Experiential learning theories support the use of observation in simulation to promote learning (Johnson, 2020), but evidence on how best to foster attention and motivation during the observational phase remain scarce. By understanding how observers can be supported, we could maximize learning for all participants during a simulation whether they are actively involved in the simulation itself or simply watching.

COGNITIVE LOAD

Cognitive load experienced during a simulation highly depends on the interactions between the learner, the simulated task and the learning environment (Choi, van Merriënboer & Paas, 2014). The greater the interactions, the higher the cognitive load for that learner. Cognitive load theory distinguishes two types of cognitive load: intrinsic and extraneous. The former refers to the working memory resources allocated to schema construction and automation. Extraneous cognitive load refers to any additional load that does not pertain to the learning goals. The original cognitive load theory model describes a third type of load, namely germane load, which refers to the working memory resources involved in processing intrinsic cognitive load (Sweller, van Merrienboer, & Paas, 1998). In a clinical environment, whether simulated or real, germane cognitive load seems to play a limited role (Kalyuga, 2011; Szulewski, Howes, van Merriënboer & Sweller, 2020), and will therefore not be the focus of this research. Extraneous load is generated by suboptimal instructional design, and by emotions and distractions during a learning situation (Tremblay, Lafleur, Leppink, Dolmans, 2017). As both intrinsic and extraneous cognitive load occupy the same limited reservoir of cognitive capacity, to optimize learning, extraneous cognitive load must be minimized to allow the learner to allocate working memory resources to schema construction (i.e. intrinsic cognitive load).

Although observers necessarily have less interaction with the simulation task and the environment than an active participant, this does not mean that they do not experience any cognitive load during the simulation, and consequently cannot learn from this experience. Their 'back-seat' position during the simulation gives them a broader perspective of the clinical situation (Hober & Bonnel, 2015) and can bring their attention somewhere other than that of the active participant, who is by definition caught up in the task. For example, they might be more inclined to notice the non-verbal signs of a patient instead of being preoccupied with the glycemic results scrawled on a piece of paper. Their unique perspective on the situation contributes to their intrinsic cognitive load and allows them to benefit from the simulation. However, novice students, who have limited clinical experience, might struggle in discriminating what it worthy of attention in a scenario with many concurrent events (Tremblay, Lafleur, Leppink, Dolmans, 2017). As a result, they can potentially be at risk of experiencing cognitive overload when observing a simulation. This potential suggests that implementing strategies to bring observers' attention to the task and prevent cognitive overload may be needed.

INSTRUCTIONAL SUPPORT FOR OBSERVERS

Among the strategies to promote learning by observation in simulation, using checklists allows observers to focus their attention on their peer's performance (Rotgans & Schmidt, 2011). These tools may trigger their interest and prevent them from being distracted or bored, in addition to potentially increasing intrinsic cognitive load. However, checklists for observers have led to inconsistent results in term of improved learning outcomes (Delisle et al., 2019). Checklists enable observers to reflect in action and on action about the simulation they are watching (Hober & Bonnel, 2014), but they may not encourage them to explore and pursue their own learning goals. Qualitative research could clarify whether checklists can promote learning for observers, or if they are mostly helpful for critically appraising their peers' performance without improving learning.

Other instructional guidance to promote observers' engagement such as collaboration scripts have been proven useful to increase learning in the context of simulation (Stegmann, Pilz, Siebeck & Fischer, 2012; Zottmann, Dieckmann, Taraszow, Rall & Fischer, 2018). Collaboration or observation scripts are sets of scaffolds that help structure the learning process of observers during collaborative learning activities. As opposed to checklists, such scripts not only set the focus on specific observable content, they also promote interactions between learners. An example of collaboration scripts could be to assign specific task elements to each observer, to ask them to find examples for good and suboptimal performance, to compare their observations for a few minutes afterwards, and to agree on the top three points to include in a debriefing. These instructions should contribute to increase intrinsic cognitive load, but whether collaboration scripts promote learning for observers remains unclear. With respect to both techniques studied, how novices benefit from either checklists or collaboration scripts when observing in simulation is still not well understood.

OBJECTIVES OF THE CURRENT STUDY

This mixed-method study aims to understand the similarities and differences between collaboration scripts, checklists, the combination of both, and no guidance in terms of intrinsic and extraneous cognitive load, and self-perceived learning for novice observers during a simulation-based training. We also aimed to understand how these tools influence the observers' learning experience.

METHODS

SETTING

We conducted this study at Laval University Faculty of Pharmacy (Canada) in the Pharmacy Simulation Laboratory, which replicates ten pharmacy offices fully equipped with authentic material commonly found in community pharmacies (e.g. medications, electronic patient records, e-resources, and books).

PARTICIPANTS

One hundred-sixty-seven second-year undergraduate pharmacy students, in a four-year competency-based pharmacy program (Pharm.D.) taught in French, were eligible to participate on a voluntary basis. The simulation session was compulsory as part of their program. However, students were free to participate to the study. If they decided not to participate, they would still have to observe simulations, but would not fill in questionnaires related to the study. Given their limited clinical experience (i.e. four weeks of clinical internship) participants were considered novices regarding the clinical task being performed. Since they had experienced four immersive simulation trainings in the Pharmacy Simulation Laboratory prior to recruitment, they were considered to have moderate experience with simulation. The program had already divided the eligible cohort of 167 into groups of approximately 30 students for various educational activities. For this study, cluster-randomization was used to assign one of four quasi-experimental conditions (see below) to these predetermined groups. Within each group of 30, students were randomly divided into teams of three and were allocated a pharmacy office for a full simulation session. During a simulation session, each participant had the opportunity to observer a simulation twice for two different simulation tasks (i.e. cross-reaction drug allergy, drug-induced myopathy, or herpes simplex virus) but under the same experimental conditions (see Figure 1).

DESIGN

FOUR EXPERIMENTAL CONDITIONS

We tested four experimental conditions (see figure 1). In the first condition, we provided observers with a collaboration script, where dyads of observers were asked to collaborate after having watched a peer perform a simulation task as a pharmacist for approximately five minutes before the debriefing. This five-minute discussion was used in other study contexts to highlight the main observations to be discussed in the debriefing (Stegmann et al., 2012; Zottmann et al., 2018). Students were instructed to discuss together both positive and negative actions regarding a specific aspect of the task. For example, one observer would focus on observing and reporting all positive actions concerning data collection, while the other participant in the same subgroup would focus on elements that could be improved regarding data collection (i.e. positive and negative observers). They would then discuss their observations for five minutes after the scenario was finished (See Document, Supplementary Digital Content 1 which illustrates all collaboration scripts).

In the second experimental condition, guidance consisted of providing a checklist of observable actions relevant to the simulation task, for each observer to fill out individually. Observers analyzed their peer's performance in the pharmacist's role using the checklist to identify actions performed and reflect on their appropriateness. The checklists were adapted for each simulation task. They were fairly succinct (designed to fit in a one-page legal format) while comprising most possible options for one specific task—as in real-life, where there are many acceptable ways to solve a problem. For example, for a suspicion of cross-reaction drug allergy, the list comprised both changing the prescribed medication for a safer one (optimal choice) and keeping the original prescription while monitoring closely the reaction, depending on the pharmacist's risk assessment. Students were instructed to check the actions they witnessed during the simulation, regardless of their quality (See Document, Supplementary Digital Content 2, which illustrates all checklists).

For the third experimental condition, observers were provided with both checklists and collaboration scripts with the same instructions on how to use these tools. Finally, for the fourth condition, observers were provided with neither checklists nor collaboration scripts. They were simply asked to observe their peer perform and write down any notes they saw fit for their own learning experience.

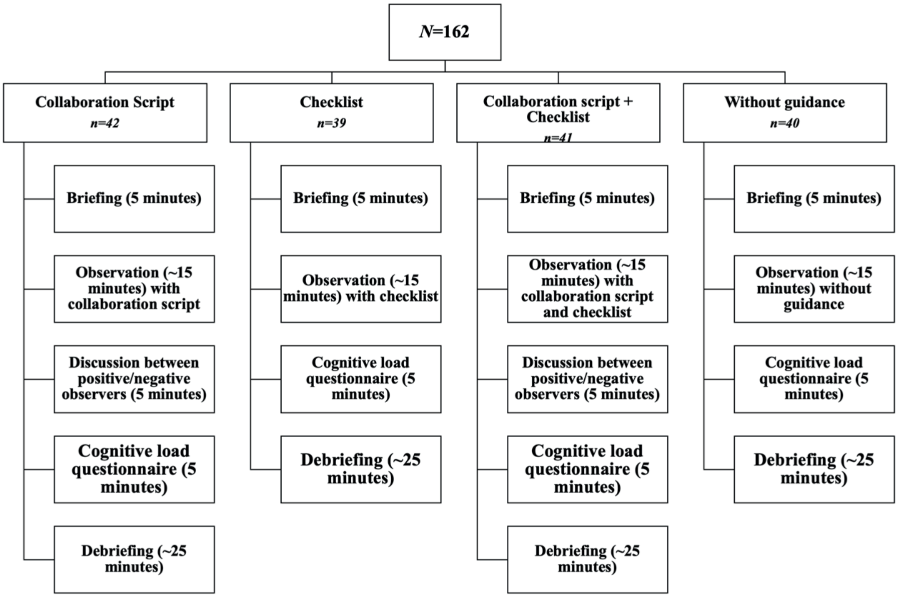

Figure 1. Progress of the simulation under different experimental conditions. Students experienced, as observers, the same experimental condition twice. A full simulation session lasts approximately 3h30. Conditions involving collaboration scripts typically lasted 5 more minutes because the discussion between observers was required.

PROCEDURE

A general briefing at the beginning of the simulation session explained the environmental features and logistical details to consider. A “fiction-contract” (i.e. baseline rules between learners and educators) was also verbally reviewed prior to the simulations, and the confidentiality policy at the simulation centre was reinforced (Dieckmann, Gaba & Rall, 2007; Rudolph, Raemer & Simon, 2014). At the beginning of the session, observers were also informed of the instructional support they were assigned for the session. During the simulation, 17 different actors with experience in simulated patients played the patients. They had previously received a two-hour training on the learning tasks and on the research procedure. Each learning task was followed by a 30-minute debriefing period conducted by a trained and experienced instructor. The debriefing targeted clinical and environmental aspects of the simulation task, and did not specifically discuss observation tools.

The simulation tasks were designed by two simulation designers and pharmacy clinicians. They had been piloted prior to the study. Clinical aspects of the case referred to concepts previously taught in the program.

INSTRUMENTS

COGNITIVE LOAD AND SELF-PERCEIVED LEARNING

We measured intrinsic and extraneous cognitive load and self-perceived learning after the simulations using a translated and adapted version of a cognitive load questionnaire (see Table, Supplementary Digital Content 3, which presents the adapted and translated version of the cognitive load questionnaire) developed and validated by Leppink, et al (Leppink, Paas, van Gog, van Der Vleuten & van Merrienboer, 2014). In its original version, items targeting self-perceived learning were meant to measure germane cognitive load. As explained before, this type of load plays a limited role in clinical environments (Szulewski, 2020), and our capacity to fully measure it remains unclear (Kalyuga, 2011). However, relevant items in the questionnaire were reframed as a measure of personal appreciation of learning, aka self-perceived learning. Our questionnaire consisted in 5 items targeting intrinsic cognitive load, 5 items relating to extraneous cognitive load, and 6 items targeting self-perceived learning. Participants rated each item on a scale of 0 to 10 (0 = not at all, 10 = completely the case). The tool used in this study had previously been tested in the context of simulation for undergraduate pharmacy students (Tremblay, 2017; Tremblay, Leppink, Leclerc, Rethans & Dolmans, 2019). This version was piloted prior to the intervention with the same students during a simulation session to familiarise participants with the terms and clarify any imprecisions.

FOCUS GROUP INTERVIEWS

As part of a sequential explanatory design, we conducted four focus group interviews after the simulation sessions with a random sample of participants from each of the four experimental conditions. The focus groups aimed at understanding the influence of checklists and collaboration scripts on observers’ learning. The interviewer asked questions about students’ experience as observers (see Interview guide, Supplementary Digital Content 4, which lists the focus group interview guide).

DATA ANALYSIS

COGNITIVE LOAD AND SELF-PERCEIVED LEARNING

Statistical analyses were conducted with SPSS Statistics 28 (IBM Corp, Armonk, NY). Exploratory factor analyses (EFA) were performed on cognitive load questionnaires and revealed a three-factor solution. Four items from the questionnaire did not consistently relate to one factor and were therefore removed from the analysis. The Cronbach's alpha for intrinsic cognitive load in this study was 0.9, 0.8 for extraneous cognitive load and 0.9 for self-perceived learning. We performed one-way ANOVA to determine whether there was a difference in cognitive load (intrinsic and extraneous cognitive load and self-perceived learning) between the four conditions. A p value significance was fixed at 0.05. A post-hoc power analysis confirmed a power of 0.76.

FOCUS GROUPS

All four focus group interviews were recorded and transcribed integrally. The qualitative analysis was conducted with NVivo qualitative data analysis software (QSR International Pty Ltd. Version 12, 2018). A thematic analysis was performed using a mostly deductive approach to code and analyse the transcripts. Using sensitizing concepts from the literature on causes of intrinsic and extraneous cognitive load in immersive simulation (Naismith, Cheung, Ringsted & Cavalcanti, 2015), we sought to identify themes to understand the observers' learning process when using instructional guidance, while remaining open to new emerging themes. Two authors analyzed the interviews (M-LT and AL), using an iterative approach. The authors compared and contrasted their analyses at many instances during the process to clarify the effect on learning of instructional guidance for observers during simulation. In case of disagreement, the authors discussed the issue until they reached consensus.

RESEARCHER POSITIONING

We believe that simulation for novices is a powerful learning experience that helps bridge the gap between theory and practice, which can be quite wide for such inexperienced learners. M-LT is a French-Canadian pharmacist and a researcher in health professions education. She has been acting as a simulation educator and instructor for over ten years. At the time of the research, she was not involved in any way with the participants. AL is a medical doctor with a master's degree in health professions education. He has experience with conducting and analysing qualitative research. DD, JJR and PD are well-established researchers and experienced medical educators with a positive bias towards simulation.

ETHICS

This study was approved by the Research Ethics Committee of Laval University (2019-230/03-09-2019).

RESULTS

QUANTITATIVE RESULTS

A total of 162 students agreed to participate to the study (response rate of 97%). They were mostly female (72%), with a mean 22 years of age (*SD* = 2.5), with a college degree (78%) prior to entering the Pharm.D. program.

Figure 2 presents observers' mean results for intrinsic cognitive load, extraneous cognitive load, and self-perceived learning on a scale from 0 to 10. There was a statistical difference between groups in intrinsic cognitive load as determined by the one-way ANOVA ($F(3,158) = 5.18$, $p = 0.002$). A Tukey's post hoc test revealed the intrinsic cognitive load was significantly lower for checklists (M = 3.6, SD = 1.4) than for scripts (M = 4.7, SD = 1.5, $p = 0.005$) or scripts and checklists combined (M = 4.7, SD = 1.4, $p = 0.004$).

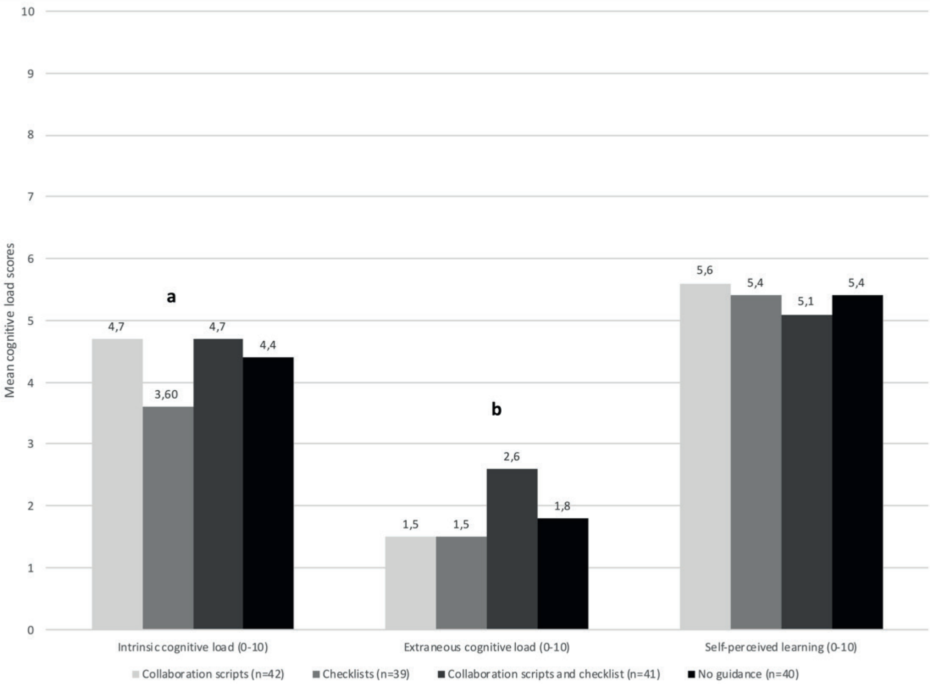

Figure 2. Students' mean scores (0 to 10) of intrinsic cognitive load, extraneous cognitive load, and self-perceived learning when observing an immersive simulation with or without instructional guidance.

Statistical differences between conditions: **a** ($F(3,158)=5.18$, $p=0.002$). **b** ($F(3,158)=5.85$, $p=0.001$.

There was a statistical difference between groups in extraneous cognitive load as determined by the one-way ANOVA ($F(3,158) = 5.85$, $p = 0.001$). A Tukey's post hoc test revealed the extraneous cognitive load was significantly lower for checklists (M = 1.5, SD =1.4) than for scripts combined with checklists (M = 2.6, SD = 1.4, $p = 0.002$) or no guidance (M = 1.8, SD = 1.3, $p = 0.042$). There was no statistical difference between conditions for self-perceived learning ($p = 0.5$).

QUALITATIVE RESULTS

Fourteen students participated in four focus group interviews resulting in 122 different codes, which led to six themes. After four interviews, the research team concluded that saturation of codes was obtained; no new code related to the research question emerged from the analysis (Hennink, Kaiser & Weber, 2019). Our study aimed to describe how students experienced the different experimental conditions. We therefore analyzed the comments made by at least one participant and did not distinguish further how frequently an opinion was mentioned.

COLLABORATION SCRIPTS DEEPEN UNDERSTANDING OF A SPECIFIC ASPECT OF THE TASK

Students who observed the simulation with collaboration scripts reported appreciating learning more about one specific aspect of the clinical situation—even if this meant they had to leave out other interesting parts of the task—saying it allowed them to have a deeper discussion on a specific element. When they had to focus on one heuristic, one participant mentioned that "it allowed [them] to be more precise on this item, to reflect more, whereas normally, [they] would try to have an overview of all parts of the consultation, but on a more superficial level." (P302)

ASSIGNING DIFFERENT ROLES FOR COLLABORATION SCRIPTS FEELS UNNATURAL AT FIRST, BUT STIMULATED DEEP DISCUSSIONS

Separating positive and negative feedback roles stimulated deep discussions among students, since they were not used to this method. These different roles (positive and negative observers) sometimes felt "unnatural" (P362), and "forced [them] to find something negative to say and be nitpicking." (P371) Being the negative observer appeared more difficult for students. Positive observers also found that inexperience with these tools led to some distraction.

> "It was not what we're used to, because only one person was focusing on the positive and one on the negative aspects. At first, I started writing down everything and then I realised that I was only supposed to focus on the positive." (P362)

CHECKLISTS HELP STRUCTURING THE OBSERVATION

The focus group interviews revealed that checklists were useful for "structuring the observation period" (P432). As checklists comprised many potential options, students reported that the list was helpful to consider other possible interventions that had not come to mind while observing the simulation. This allowed for rich small group discussions before the debriefing.

> "Normally, I am not thinking of what could have been done differently, I only focus on what was done. But with the checklist, it made me realize that there were other options." (P432)

USING A CHECKLIST IS MOSTLY A FACT-CHECKING EXERCISE

Students were distracted by the checklists as they included too many options, and while looking for the correct box to check, they "could not listen to what was happening" (P432). They also reported that using checklists was simple, but was less engaging in terms of reflection, since they were focusing on determining whether or not a task was done, rather than trying to formulate their own hypotheses.

> "It is much simpler to say 'this was done, this was not'. It is a fact-checking exercise. I feel like this is very simple." (P652)

CHECKLISTS AND COLLABORATION SCRIPTS POSE TIME MANAGEMENT CHALLENGES

Collaboration scripts seemed to impose an uneven workload during the simulation, as certain aspects of the scripts occurred only at a specific moment of the simulation, leading students to "have a lot of things to write at a certain point, and the remaining time, [being] very passive" (P371).

Participants combining simultaneously checklists and collaboration scripts all agreed that dealing with the two tools at the same time was very difficult in terms of time management.

> "Too many things at the same time: listen, watch, write down, think, check, etc." (P873), and not having time to do everything correctly."

GUIDANCE IS BENEFICIAL FOR LEARNING THROUGH OBSERVATION, REGARDLESS OF ITS FORM

Participants unanimously stated that they learn by observing their peer during immersive simulation, regardless of the guidance provided. Confirming their desire to learn when observing a simulation, participants felt that "not having the hot seat, yet still being involved, [their] reasoning skills are engaged and [they] can practice choosing the best actions." (P892). They agreed that it is preferable to have some form of guidance to support their observation rather than just watch and learn without support.

> "I would not like to have a blank page (no guidance), because I would have no idea what is important and what to say to the patient." (P653)

DISCUSSION

In this mixed-method study, we demonstrated that instructional guidance for novices during periods of observation in simulation can enhance active learning during this inevitable "time-off." With guidance, novices can focus on the simulation with a purpose that prevents them from missing the point of the situation, considering their limited clinical experience. Additionally, we found that the form of guidance influences what observers do and how it may be helpful for learning. More specifically, we came to better understand several limits of each tool, which can help us align the observer guidance provided with the learning goals of different types of simulation tasks.

In this study, observers reported investing substantial and varying mental effort in observing the simulation, as reflected by the different mean scores of intrinsic cognitive load. The focus group interviews allowed us to interpret the significant differences in terms of intrinsic cognitive load and understand how observers invest their cognitive resources differently with each form of guidance. Checklists, which generated the lowest scores of intrinsic cognitive load, were perceived as a simple fact-checking exercise. In contrast, collaboration scripts imposed the highest intrinsic cognitive load as collaborating and co-constructing knowledge with a peer during the discussion period was perceived as more complex. For novices, who have limited cognitive schemas, it seems more difficult to elaborate several hypotheses for one task than to simply check whether an explicitly listed option was actually executed, without necessarily having to reflect and generate hypotheses with a peer (Lafleur, Laflamme, Leppink & Côté, 2017; Weinberger, Stegmann & Fischer, 2010). Combining both collaboration scripts and checklists did not seem to add value in terms of stimulating intrinsic cognitive load; scores remained similar to those of collaboration scripts alone. It is possible that, since they reported having too many things to do at the same time, students did not use the two tools to their full potential. Interestingly, without guidance, observers also reported moderate intrinsic cognitive load. Observing without guidance required observers to build their own interpretation of the problem in the simulation. This study helps us understand that with or without instructional guidance, observers are actively engaged with the simulation, but their effort differs depending on the instruction they receive.

Extraneous cognitive load remained very low in all four conditions, although the combined approach resulted in significantly higher scores. Sources of extraneous cognitive load vary depending on the form of instruction. Participants who experienced checklists were distracted when having to read all items while listening, which sometimes led to missing small parts of the simulation. Those who had collaboration scripts felt unfamiliar with being the positive or negative advocates, sometimes distracting them from their actual task. Combining both checklists and collaboration scripts felt overwhelming as students had to process too much information at the same time, and split their attention between two separate instructions (Sweller, Ayres & Kalyuga, 2011). Nonetheless, considering the relatively low scores of extraneous cognitive load, we can assume that distractions were limited during observation periods, which is an essential condition for learning to occur (Sweller et al., 1998). Double instruction does not seem to bring much benefit in terms of both intrinsic and extraneous cognitive load.

This study focused on understanding what and how observers learn by observation in immersive simulation, when learning is supported by different forms of instructional guidance. Students described observation in simulation as a meaningful learning experience, as reflected by moderate scores of self-perceived learning for all conditions. Our qualitative findings suggest that students benefit differently from instructional guidance: collaboration scripts advance learning a specific objective; checklists foster a global approach to observational learning. Since both types of instructional support are appreciated by students and did not lead to significant differences in terms of self-perceived learning, it might be wise to align the form of observer guidance with the learning objectives of the simulation task. For example, when students are required to apply a step-by-step approach in a simulation task, observers could benefit from a checklist that reminds them of these steps. However, when students need to explore and solve a problem in a scenario, observers could benefit more from a collaboration script which helps them focus on one or two specific aspects of the scenario and deepen their understanding of these aspects. Future research using a two-way or cross-over design could inform us on how to align instructional guidance with simulation tasks.

LIMITATIONS

Although using mixed methods with a large number of participants brought a deeper understanding of vicarious learning in simulation, this study reports students' perceptions only. Although it is now clearer how collaboration scripts and checklists influence what observers do during a simulation, future research needs to establish how instructional guidance can rightfully increase learning. The cognitive load questionnaire used in this study was not originally designed for this context. However, the reliability of our results was very high as reflected by our Cronbach's alpha for each scale. We did not measure learning outcomes for students under different conditions. This study also did not investigate how the instructions provided on how to use the tool might impact their use. Finally, these results are also limited to novice observers only. Observers with more expertise would probably respond differently to the different forms of guidance. Further research in such context is required.

CONCLUSION

Regardless of its form, instructional guidance for novice observers in simulation contributes to the learning experience by cognitively engaging them. Their focus during the simulation differs depending on the guidance they receive. In our study context, collaboration scripts or checklists did not impose high extraneous cognitive load, unless they were combined. The choice between collaboration scripts and checklists for novices should be guided by learners' characteristics and the type of simulation task.

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CHAPTER SIX

Discussion

DISCUSSION

With the rise of competency-based education, simulation has become an educational imperative in healthcare curricula. Immersing novice learners in an authentic clinical setting to simulate professional activities allows them to safely practice and consolidate various clinical skills (Cook et al., 2011). Moreover, it increases their awareness of the environment in which these skills will be ultimately performed (Grierson, Norman, Monteiro, & Sibbald, 2019). Designing immersive simulations for novices requires adapting the learning environment and the learning task according to their level of expertise, without compromising on authenticity (van Merriënboer & Kirschner, 2017). To avoid cognitive overload, it could be tempting to oversimplify the clinical situation presented, but such adaptions risk losing clinical meaning in real life. On the other hand, managing a complex problem while dealing with the messiness of an authentic clinical setting might jeopardize learners' capacity to attend to the learning objectives of a simulation. Evidence is still very scarce as to what in practice constitutes complexity in clinical tasks and environmental features for novice students—even more so in specific disciplines such as pharmacy—which makes adapting the complexity of the simulation difficult.

In simulation, learners can be actively involved in the scenario and interact with the environment, but they also often, for various reasons, observe others perform a task. Observing students can still benefit from the simulation, but possibly in a different manner than those in the "hot seat" (Stegmann, Pilz, Siebeck, & Fischer, 2012). Given their limited clinical experience, novices might struggle to discern what is worthy of attention in a scenario with many concurrent events. Considering that conducting immersive simulations can be very costly, we cannot afford a poor instructional design that leads to deceiving results in assessing learning for both active participants and observing students. This PhD thesis aimed to explore the following research questions:

1. What are the effects of task and environment complexity in immersive simulation on novices' learning experience?
    a. What are the differences between immersive simulation and simulated patients in terms of cognitive load and emotions for undergraduate healthcare students? (Study 1)
    b. What are the effects of simple and complex tasks in immersive simulation in terms of cognitive load, self-perceived learning, and performance for undergraduate pharmacy students, and how does task complexity influence students' perception of learning? (Study 2)
    c. What is the impact of modulating the complexity of the task and of the environment on novices' cognitive load and performance in immersive simulation? (Study 3)

2. How to support the learning experience of novices in immersive simulation when they observe a peer perform in simulation?
    a. What are the similarities and differences between collaboration scripts, checklists, the combination of both, and no guidance in terms of intrinsic and extraneous cognitive

load, and self-perceived learning for novice observers during a simulation-based training, and how do these tools influence the observers' learning experience? (Study 4)

In the following sections, we will first answer our research questions based on the data contained within this thesis and then discuss practical implications, the strengths and limitations of this thesis, and directions for future research.

EFFECTS OF TASK AND ENVIRONMENT COMPLEXITY ON NOVICES' LEARNING EXPERIENCE IN IMMERSIVE SIMULATION (CHAPTERS TWO, THREE, AND FOUR)

In Chapter Two, we investigated the effect of the learning environment in simulation on novices' cognitive load, emotions, and learning experience. Our key finding from this study was that the highly authentic environment in immersive simulation was more cognitively challenging for novices, since it required them to be able to deal with more information at the same time as opposed to dealing with simulated patients only. As a result, the physical environment directly influenced the very nature of what students learn. When students are immersed in a highly authentic clinical environment, they experience stress and higher intrinsic and extraneous cognitive load than when facing a similar task without having to deal with the environment. They tend to focus on specific aspects of the task and environment, and ignore other aspects of the situation. For example, in immersive simulation, students concentrated on data collection and did not focus as much on solving the problem. With simulated patients only, students concentrated on practicing their clinical reasoning skills. This strategy, whether conscious or not, might prevent them from experiencing cognitive overload, but could potentially prevent them from seeing the big picture of the learning task and might lead to less than optimal results when the graduated student enters actual clinical practice.

In Chapter Three, we examined the effect of task complexity on students' cognitive load and performance, and we attempted to understand how task complexity influenced students' perception of learning. Our results demonstrated that factors contributing to increase the perception of task complexity, such as lack of knowledge, unfamiliar resources, and time limitation, were likely to impose higher intrinsic and extraneous cognitive load while hindering the problem-solving process. Simpler tasks helped students gain more self-confidence, whereas complex tasks further encouraged reflective practice during debriefings. Complex tasks in immersive simulation constitute an additional challenge in terms of clinical reasoning, thus providing a more valuable learning experience from students' perspective.

Although both the learning task and the learning environment can be modulated to take into account the learner's ability, increasing evidence shows that these two components act in synergy rather than as two separate instructional features (Brooks, 2011, 2012; Whiteside, Brooks, & Walker, 2010), meaning that the modulations made in the learning environment to accommodate learners' skill level might influence their capacity to attend to specific learning goals. However, learning to deal with the environment while solving a clinical problem is inherent to simulation-based education (Szulewski, Howes, van Merriënboer, & Sweller, 2020). This led us to design the third study presented in Chapter Four, in which we focused on understanding the interactions between task and environment complexity on novices' performance, cognitive load and learning outcomes. Students were randomly assigned to one of the four experimental conditions varying in complexity (simple or complex task, in simple or complex environment). Performance during the simulation remained good in all conditions, but we found an interaction between task and environment complexity, which indicated that performance of simple tasks decreases as environment complexity increases. When novices struggled with the environment during the simulation, their focus seemed to shift from the task and was redirected towards managing the environment, hence the decrease in performance in more complex environments. We also found that the higher the task complexity, the higher the intrinsic cognitive load. As complexity increases in simulation, students seem to strategically manage their own cognitive load to maintain an appropriate performance and learn something relevant. However, although this strategy prevents students from experiencing cognitive overload, it might also impede their capacity to meet all the intended learning goals.

With regard to the first overarching research question of this thesis, the combination of these three chapters indicates that both environment and task complexity influence the learning experience in simulation. Without careful planning of all features involved in the simulation, the learner can be easily diverted from the intended learning goals. Like a theatre director, simulation designers must pay attention to the scene that takes place in front of them and make sure that the décor, the lighting, the intensity of the supporting actors, and the sonic environment serve the purpose of the scene rather than distracting the actors and the audience. In addition to having independent effects on learners, the environment and the task interact with each other and influence what students will learn and how they will perform. For novices, complex environments appear more complex than clinical tasks, partly due to their lack of awareness and mastery of the clinical setting, which inevitably induces a certain amount of stress. It is therefore advisable to prepare students to deal with complex environmental features before introducing complex concepts in the learning tasks, in order to facilitate students' capacity to manage all information.

The journey behind these three experimental studies has prompted reflections on the importance of authenticity in simulation for novices and its relationship with complexity. Authenticity and complexity are two distinct concepts that each have different impact on learning. Complexity, as defined by cognitive load theory, is mainly determined by the number of information elements to process in the working memory, and the degree of elements' interactivity (Sweller, van Merrienboer, & Paas, 1998). Authenticity in simulation, or "fidelity" as suggested by Maran and Glavin (2003), is two-fold: *engineering fidelity* refers to whether the simulation *looks* realistic, whereas *psychological fidelity* refers to whether the simulation contains the critical elements that specifically trigger the behaviors required for the task. Although many authors have long thought of authentic simulations as complex ones (Maran & Glavin, 2003), our research has shown that authenticity can be found in simple tasks and simple environments, provided that *psychological* fidelity is preserved. Contrastingly, complex problems are not necessarily highly authentic; they may comprise many information elements to process without consideration for their engineering or psychological fidelity.

Our studies primarily focused on clarifying to what extent immersive simulations should be complex to stimulate learning for novices. Educators should provide problems that are complex enough to stimulate reflection, but not too complex to impede the problem-solving process. How authentic these simulations should be to promote learning needs to be further studied, especially through the lens of psychological fidelity. Informed by theories such as cognitive apprenticeship and situated cognition, many authors have postulated that practice in a realistic simulated environment will lead to better transfer of learning as a result of context similarity (Godden & Baddeley, 1975; Kneebone et al., 2005; Teteris, Fraser, Wright, & McLaughlin, 2012). Following that logic, we would assume that the more authentic the simulation, the more chance we have to enhance transfer of learning—a premise that has since been refuted (Hockley, 2008; Norman, Dore, & Grierson, 2012). If we aim to design highly authentic simulation assuming optimal transfer of learning and omit to carefully adjust complexity to the learners' level, we could compromise their capacity to attend to the learning objectives. In other words, authenticity is important up to a certain point, but should not represent the final destination of the simulation and mitigate the importance of careful design of complexity. Just like in a play, the theatre director should not focus solely on the realism of the décor at the expense of the credibility of the scenario.

SUPPORTING NOVICE OBSERVERS IN IMMERSIVE SIMULATION (CHAPTER FIVE)

In Chapter Five, we adopted a different perspective on novices' learning experience in simulation: we were interested in their learning while they act as observers. We studied the effect of different forms of instructional support—namely collaboration scripts and checklists—on novices' cognitive load and explored how these forms of guidance influence their learning experience. In our study, we found that observing in simulation, with or without guidance, was a meaningful learning experience from students' perspective, but their effort differed depending on the tool they used. Collaboration scripts are a form of guidance that requires working with peers to analyze a specific aspect of the simulation; checklists comprise a list of observable actions that can be performed with regard to the problem encountered in the simulation. Students described collaboration scripts as more complex due to the collaborative nature of the task, and said that scripts provide a deeper understanding of one aspect of the simulation. In contrast, checklists were described as simple fact-checking exercises that provided a general overview of all possible aspects of a simulation. The main conclusion is that providing instructional support for observing students in simulation promotes cognitive engagement and learning regardless of its form, but their experience varies depending on the tool they use to support their observation. Norman (2018) demonstrated that students who observe a simulation with guidance are more satisfied with their learning experience than those without guidance, although no differences in learning outcomes were detected. Our study contributed to the existing literature by exploring how students use the tools when observing the simulation.

Having students observe their peers perform in simulation is often perceived as a necessary evil, considering the logistical and financial constraints of simulation which often constrain us to accommodate large cohorts of students. Some researchers have attempted to demonstrate the differences in terms of learning between a more active position in simulation as opposed to a passive role, like that of an observer (Reime et al., 2017; Stegmann et al., 2012). Although these studies have mostly concluded that having an active role is more powerful in terms of learning, observing in simulation has still been associated with positive learning outcomes (O'Regan, Molloy, Watterson, & Nestel, 2016). Observing others perform a task has been proven effective to learn specific behaviors and skills (St-Onge et al., 2013). Some authors have expressed their concerns when the observed model is not necessarily an expert, but rather a person-in-training (Ste-Marie et al., 2012). Performances that are below standards can negatively impact a novice learner with limited experience, since they may not be able to recognize aspects of the performance that should not serve as a proper model. This emphasizes the importance of debriefing by an expert that can correct wrong behaviors in a timely manner so that both the active participant and the observer learn a more suitable approach.

Throughout our research program, although this was not always the focus of the research, students often spontaneously reported during the focus group or semi-structured interviews that they really appreciated acting the role of observers, since it provided them a wide perspective on the simulation in addition to being less stressful. Some participants even proposed that they were better able to analyze the situation since they did not experience performance anxiety. For novice learners, varying their roles and having them observe occasionally should not be overlooked, as it seems very meaningful for them. That is, they may learn, while not necessarily learning the same things as an active participant—which potentially explains why multiple studies have proven the superiority of an active role over a passive one (Delisle et al., 2019; O'Regan et al., 2016; Reime et al., 2017). The debriefing period is an opportunity to bring together all these various perspectives on the simulation and to benefit from everyone's insights. For more advanced learners, learning by observation may not be as meaningful as it is for novices, as suggested by the expertise reversal effect literature (Kalyuga, 2007). Nevertheless, offering periods of observation to a novice in simulation should not be frowned upon, but rather be perceived as a positive though different learning opportunity.

IMPLICATIONS

This dissertation has both theoretical and practical implications. From a theoretical perspective, our studies build on the reconceptualization of cognitive load theory (Choi, van Merriënboer, & Paas, 2014) by providing a better understanding of and empirical evidence for what constitutes complexity for novices in simulation. Complexity, as explained earlier, is mainly determined by the *number* of information elements to process and the *degree of interaction* between them (van Merriënboer & Sweller, 2010). In simulation, the amount of information that can be perceived by the learner is very high, as it is meant to reproduce a real clinical situation. When designing a simulation for novices, educators can deliberately decide to control the number of information elements to process. Our studies have helped to understand what is perceived as complex for a novice learner in pharmacy, both in the environment and in the clinical task, which can better inform the design and adaptation of immersive simulation for these students.

Naismith, Cheung, Ringsted, and Cavalcanti (2015) have attempted to determine sources of intrinsic and extraneous cognitive load in simulation-based education, and showed that prior experience and task complexity was associated with intrinsic cognitive load, while authenticity and anxiety were associated with extraneous cognitive load. Our studies demonstrated that being unfamiliar with either the task or the environment affected students' capacity to process the clinical situation. More importantly, we confirmed that the learning task and the learning environment can equally contribute to both intrinsic and extraneous cognitive load. The learning environment has long been improperly identified as a source of extraneous cognitive load because of its being a potential source of distractions or because of its relation with *fidelity* (Naismith et al., 2015). More precisely, cognitive load theory defines extraneous cognitive load as additional load that does not pertain to the learning goal (Sweller et al., 1998); it generally arises from suboptimal conditions for information presentation or instructional design (van Merriënboer & Sweller, 2010). Learning to manage the environment while solving the clinical problem is directly related to the purpose of immersive simulation (Szulewski et al., 2020), and so its cognitive load is not restricted to the extraneous. With our research, we demonstrate empirically that sources of intrinsic and extraneous cognitive load in simulation can emerge both from the task and the environment.

Our results also have practical implications for simulation designers. By understanding what constitutes complexity with respect to the environment and the task, we have developed a blueprint that can inform designers in developing simulations for similar learners. In this blueprint, we describe what contributes to complexity of the learning task and the learning environment in our student context. We also recommended several tips for designing effective simulation for novices with respect to complexity. For example, we recommend increasing the opportunities to practice complex tasks before increasing environment complexity, in order to prevent learners from shifting their focus towards the environment at the expense of the learning task. In addition, when simulating complex environments is the intended focus, we suggest providing a simpler task as complex tasks may not be productive. We also provide insights regarding the different tools for supporting learning by observation. The form of guidance should depend on the type of simulation being observed. For example, when students are required to apply a step-by-step approach in a simulation task, observers could benefit from a checklist that reminds them of these steps. However, when students need to explore and solve a problem in a scenario, observers could benefit more from a collaboration script which helps them focus on one or two specific aspects of the scenario and deepen their understanding of these aspects.

STRENGTHS AND LIMITATIONS

Some characteristics of our approach highlight certain strengths of this thesis. First, we have used diverse methodologies to conduct our four studies. Using both quantitative and qualitative methods has allowed us to gain a better understanding of how the different features of simulation influenced the learning experience of our students. Conducting these studies was logistically very challenging, considering the various parameters to control, the numerous variables to measure, the technology involved, and the large cohorts of students. Nevertheless, we succeeded in conducting experiments that were sound and rich in data. Second, we rooted our research in cognitive load theory and designed our simulations with respects to its principles. Third, our research focuses on novice learners and clearly associates the findings with their expertise level. Very few studies in simulation-based research focused on the learning processes for novices and described the added value of this teaching method for that population of learners. We have confirmed that immersive simulation can be helpful in many ways for novices but acknowledge that their limited clinical experience distinguishes them from more advanced learners.

This thesis also has its limitations. We have conducted all our studies with junior pharmacy students from one school and recognize that this population may not be fully representative of other healthcare disciplines. This may influence the generalizability and transferability of results. We also focused mostly on the cognitive processes in simulation for novices. Immersive simulation is a very powerful and rich learning instrument that is not restricted to cognitive aspects of learning. Healthcare professionals rarely work alone, which certainly influences how care plans are orchestrated. The social dimension has not been explored in this thesis. Finally, many of our findings are based on self-reported data, which may limit our interpretations, considering the equivocal relationship between perception of learning and actual learning outcomes.

SUGGESTIONS FOR FUTURE RESEARCH

Echoing the limitations of this dissertation, we offer several recommendations for future studies. First, we invite researchers from other healthcare disciplines to conduct similar studies to determine what constitutes complexity for novices in their professional context. Using mixed-methods and observational studies, participants could inform us on features specific to their fields that may contribute to increase their perception of complexity. Second, our findings justify further exploration of the learning experience of novices in immersive simulation. This thesis lies in the conceptualization of interactions between the learner, the environment, and the task, and their effects on cognitive load. These results fit a model where one learner is actively involved in a simulation. However, when at least one other learner joins the simulation, social interactions, just as in real life, become very important. Future research focusing on social interactions in simulation should be conducted to understand the dynamics at play when solving problems for novices (Dieckmann, Gaba, & Rall, 2007). This could also better inform the design of simulation to teach interprofessional learning for novices. Finally, this dissertation mostly focused on the learning processes in simulation and did not fully study the impact on transfer of learning in actual patient care. Using concepts such as the development of adaptive expertise (Carbonell, Stalmeijer, Könings, Segers, & van Merriënboer, 2014), studies investigating how simulation-based training better prepares novices for real clinical practice would help us refine instructional design guidelines in immersive simulation.

CONCLUSION

The research presented in this thesis contributes to our understanding of effective instructional design of immersive simulation for novices. Providing authenticity and complex problems is essential to stimulate learning, but careful consideration must be paid to not overwhelming the learner during the simulation. Like a theatre director, designers must manage the combination of all the features involved in the simulation, from the environment in which the scene takes place, the task that will be performed, up to how the environment will respond to this performance. Our findings support the use of immersive simulation for novices and stress the importance of managing complexity to promote learning.

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VALORISATION

1. WHAT IS THE SOCIAL AND SCIENTIFIC RELEVANCE OF YOUR RESEARCH RESULTS?

Research in health professions education is my way to advance pharmacy practice. New drugs are constantly released on the market and therapies become more and more complex. Competent pharmacists ready to embrace their full scope of practice can provide better healthcare and ensure a safe use of these new medications. In a world where everything goes fast, with distractions coming from everywhere at once, immersive simulation aims to help students learn to deal with a fast pace and a demanding environment during their training, before they graduate and start professional practice in the real world. Simulation-based education, i.e. simulating professional activities for learning purposes, allows training under safe conditions, for both learners and patients. The learner is allowed to make mistakes, since they will not compromise the safety of simulated patients. However, during our research, we found that the simulated clinical environments in which students practice are so highly stimulating that they can cause some distractions. Those distractions, mistakes they may generate, will have certain consequences, such as learning a suboptimal solution for a specific problem.

From a scientific perspective, our research has helped us gain a better understanding of how to optimally design simulation training for undergraduate students with limited clinical experience without overwhelming them with too-complex situations. This research is embedded in a learning theory that supports gradually exposing learners to complex problems, starting with simple situations, then increasing complexity as they become more skilled. Our research provides insights into what students find complex in simulation, helping us plan this gradual exposure considering their background and readiness.

2. TO WHOM, IN ADDITION TO THE ACADEMIC COMMUNITY, ARE YOUR RESEARCH RESULTS OF INTEREST AND WHY?

In educational research, specifying interest “in addition to the academic community” must, of course, begin within academia. Our immediate target group is educators involved in designing and facilitating simulation-based training for undergraduates. When designing a simulation, educators must be careful not to overwhelm students with unnecessary distractions in the scenario and in the environment. Instructors who facilitate these simulations might also benefit from the insights of our research by ensuring that they address students’ needs during the simulation and during the debriefing. When students face complex problems, they often choose to focus on certain aspects of the task and ignore others, and these choices are strategic. When debriefing these situations, facilitators need to be aware of these rationales for these choices and adapt their line of questioning accordingly.

Students themselves are the next presumable beneficiaries of this research. Our studies attempted to understand how students react when facing complex problems in simulation. We found that students are strategic when they struggle with elements of the simulation. They either focus their attention on things they have already mastered, to avoid losing face in front of their peers, or they challenge themselves and focus on aspects they have not fully mastered, from which they want to learn. This process occurs both consciously and unconsciously. Knowing how they react in these situations might help them deliberately pursue their learning goals according to their own educational needs, and might drive and focus debriefing discussions.

3. INTO WHICH CONCRETE PRODUCTS, SERVICES, PROCESSES, ACTIVITIES OR COMMERCIAL ACTIVITIES WILL YOUR RESULTS BE TRANSLATED AND SHAPED?

The dissemination of our results, and their practical consequences, has already started. Three studies (Chapters Two, Three and Four) are already available as published manuscripts in peer-reviewed journals and have already received citations. One study (Chapter Five) has been accepted in a similar journal. Our results have also been presented at several national and international conferences, either through posters or oral presentations. As a result of this dissemination and the interest it aroused, I am helping other Canadian pharmacy schools in building their own professional practice laboratories, and collaborating with nursing schools in the province of Quebec who are developing simulation in their undergraduate programs.

Findings from this research are already shaping the development of scenarios in the Doctor of Pharmacy program in Quebec. As mentioned earlier, the scope of practice in pharmacy has expanded greatly in Canada, which calls for the revision of the simulation curriculum and the development of new scenarios that comprise all professional activities pharmacists are now allowed to do. Over one hundred scenarios need to be reviewed to help students deal with complex clinical problems. The blueprint developed in Chapter Four is already guiding the development of these scenarios. In Chapter Five, we have focused on tools that can enhance the learning experience of students who are observing rather than being actively involved in the simulation. Our findings support the use of observation tools that align with the type of scenarios they are watching.

4. TO WHAT DEGREE CAN YOUR RESULTS BE CALLED INNOVATIVE IN RESPECT TO THE EXISTING RANGE OF PRODUCTS, SERVICES, PROCESSES, ACTIVITIES AND COMMERCIAL ACTIVITIES?

The context in which this research was conducted is innovative. Very little research had been conducted in simulation for undergraduate healthcare students, especially in fields such as pharmacy—that is, outside medical education strictly defined. Simulations that are highly realistic usually mirror the real setting in which healthcare is provided. These learning activities were mostly reserved for more advanced learners who have previously been exposed to such complex situations. Nowadays, more undergraduate programs have integrated them in their curriculum to teach clinical skills. In pharmacy education, very few institutions are equipped to reproduce a pharmacy environment and conduct simulations for their students. Our results therefore are very innovative for educators who design simulations for novice learners, since little was known on how to adapt and design the scenarios to account for this inexperience.

Combining various ways to collect data (quantitative and narrative) was also innovative in the field of simulation. Most studies in the field of simulation measure the effectiveness of the trainings by assessing performance with numbers or by quantifying specific aspects of the performance. Our focus on the learning during the simulation rather than on the outcome and gaining insights from students themselves through interviews makes this research original.

5. HOW WILL THIS/THESE PLAN(S) FOR VALORISATION BE SHAPED? WHAT IS THE SCHEDULE? ARE THERE RISKS INVOLVED? WHAT MARKET OPPORTUNITIES ARE THERE AND WHAT ARE THE COSTS INVOLVED?

The valorisation of this research can be divided into different streams. First, dissemination of the findings has already begun. To date, three of the chapters are publications available online and the last one has been accepted by a journal and should be published in early 2023. Our work has already been presented in local and international conferences. To increase our visibility, reach, and effect, our results are presented in both English and French, and at conferences in both pharmacy education and health professions education. I plan to increase my presence on social media over the next year to promote the manuscripts. This thesis is scheduled to be published as a book in 2023.

The second area of impact is the practical uptake of our findings, including the redesign of our simulation curriculum in Quebec. The process has already started and should expand over four years. Moreover, Laval University (my institution) is hosting the Canadian Pharmacy Education and Research Conference in Quebec in 2024, as we celebrate the centennial of our School of Pharmacy. We are planning to invite faculty members from across the country to visit our unique facilities and to exchange practices.

SUMMARIES

ENGLISH SUMMARY

Simulation-based education is a powerful learning method that prepares healthcare students and professionals for clinical practice. Immersive simulation allows the learner to practice tasks relevant to future practice within a realistically simulated clinical environment. In immersive simulations, learners rehearse clinical skills, followed by a debriefing period during which they analyze the performance. The simulation and the debriefing are complementary; combining them is essential for optimal learning.

Immersive simulations were first mostly used with more advanced learners with some clinical experience, which enabled them to cope with the unexpected and messy clinical context of authentic situations. Given the limited clinical experience of a novice, it is likely that the messiness of an authentic clinical setting overwhelms them and prevents them for fully reaching the intended learning goals of the simulation. Educators must adapt both the learning task and the learning environment to account for the learner's level. However, the cognitive impacts of these two features on an inexperienced learner remained vastly unexplored, making it more difficult to accurately adapt the simulations to account for the learner's level.

In **Chapter One**, we disentangle the effects of task and environment complexity on novice learners. We also acknowledge that the role played by the learner in a simulation, whether passive or active, influences their cognitive load and learning experience. We illustrate that evidence is still scarce as to what constitutes in practice a complex clinical task for novice students—even more so in specific disciplines such as pharmacy. By understanding how complex environments and tasks influence the learning experience of novices in simulation, we could design simulations specifically adapted for them, and provide guidance that promote learning. This state of affairs led to the development of two central research questions:

1. What are the effects of task and environment complexity in immersive simulation on novices' learning experience?
    a. What are the differences between immersive simulation and simulated patients in terms of cognitive load and emotions for undergraduate healthcare students? (Study 1)
    b. What are the effects of simple and complex tasks in immersive simulation in terms of cognitive load, self-perceived learning, and performance for undergraduate pharmacy students, and how does task complexity influence students' perception of learning? (Study 2)
    c. What is the impact of modulating the complexity of the task and of the environment on novices' cognitive load and performance in immersive simulation? (Study 3)

2. How to support the learning experience of novices in immersive simulation when they observe a peer perform in simulation?
    a. What are the similarities and differences between collaboration scripts, checklists, the combination of both, and no guidance in terms of intrinsic and extraneous cognitive load, and self-perceived learning for novice observers during a simulation-based training, and how do these tools influence the observers' learning experience? (Study 4)

"

The study presented in **Chapter Two** focuses on the cognitive and emotional impacts of the learning environment in immersive simulation for novices. In this mixed-methods study, we compared two different settings in a crossover design for 143 undergraduate pharmacy students: an *immersive simulation* in a fully authentic environment and a *simulated patient* activity in which participants did not need to use elements of the environment to solve the problems, such as telephones, electronic patient records or actual medications. After both simulation activities, participants rated their cognitive load and emotions using validated questionnaires. Thirty-five students met in focus groups to explore how features of the learning environment influenced their perception of learning. We found that intrinsic and extraneous cognitive load and negative-emotion scores, such as stress, in immersive simulation were significantly but modestly higher compared to simulated patients. Our qualitative findings revealed that the physical environment in immersive simulation generated more stress than with simulated patients. With simulated patients, students concentrated on clinical reasoning, while immersive simulation turned their attention to data collection at the expense of the problem-solving process. This study helped us demonstrate that the learning environment in which novice students experience the simulation influences what and how students learn. Immersive simulation was reported as more cognitively and emotionally demanding than simulated patients. More importantly, our findings emphasized the urgent need for the development of adapted instructional design guidelines in simulation for novices.

In **Chapter Three**, we investigated the effect of task complexity on undergraduate pharmacy students' cognitive load, task performance, and perception of learning in immersive simulation. In this mixed-methods study, 167 pharmacy students experienced consecutively one simple and one complex learning task. Participants' cognitive load was measured after each task and debriefing. Task performance and time-on-task were also assessed. As part of a sequential explanatory design, semi-structured interviews were conducted with students showing maximal variations in intrinsic cognitive load, in order to understand their perception of learning when dealing with complexity. Although the complex task generated significantly higher cognitive load and time-on-task than the simpler one, global performance was high for both tasks. Qualitative results revealed that a lack of clinical experience, an unfamiliar resource in the environment, and constraints—such as time limitations—inherent to simulation hindered the clinical reasoning process and led to poorer self-evaluation of performance. Simpler tasks helped students gain more self-confidence, while complex tasks further encouraged reflective practice during debriefings. Although complex tasks in immersive simulation were more cognitively demanding and took longer to execute, students indicated that they learned more from them as opposed to the simpler tasks. Complex tasks constitute an additional challenge in terms of clinical reasoning, thus providing a more valuable learning experience from students' perspective.

Building on the results presented in the previous studies, in **Chapter Four,** we designed a study that sought to determine the impact of modulating both task and environment complexity on novices' learning experience in immersive simulation. Second-year pharmacy students (*N*=162) were randomly assigned to one of four conditions (two-way factorial design) in an immersive simulation session varying in complexity: simple or complex tasks in simple or complex environments. Using video recordings of the simulation, two raters assessed students' performance. We measured intrinsic and extraneous cognitive load with questionnaires after the task, and tested knowledge after task and debriefing. Performance during the simulation remained good in all conditions, but we found an interaction between task and environment complexity, which indicated that performance of simple tasks decreases as environment complexity increases. When novices struggled with the environment during the simulation, their focus seemed to shift from the task and was redirected towards managing the environment, hence the decrease in performance in more complex environments. We also found that the higher the task complexity, the higher the intrinsic cognitive load. As complexity increases in simulation, students seem to strategically manage their own cognitive load to maintain an appropriate performance and learn something relevant. However, although this strategy prevents students from experiencing cognitive overload, it might also impede their capacity to meet all the intended learning goals.

In **Chapter Five**, we explored the learning process in immersive simulation of students with the role of observer. We designed a mixed-method study that aimed to understand similarities and differences in cognitive load and learning outcomes while comparing observers' use of collaboration scripts and checklists. Second-year pharmacy students (*N*=162) were randomly assigned to one of four conditions when observing a simulation: collaboration scripts (heuristic to analyze in dyads while observing), checklists, a combination of both instruments, and no guidance. We measured observers' intrinsic and extraneous cognitive load, and self-perceived learning, and conducted focus group interviews. Collaboration scripts imposed the highest intrinsic cognitive load because collaborating and co-constructing knowledge with a peer seemed more complex. Checklists, which generated the lowest scores of intrinsic cognitive load, were perceived as a simple exercise that did not require them to reflect on the relevance and quality of the box to check. Extraneous cognitive load scored significantly higher when both tools were combined, although scores remained very low in all four conditions. Observing the simulation, with or without guidance, was a meaningful learning experience resulting in moderate scores of self-perceived learning. With collaboration scripts, students learned more thoroughly about one specific aspect of the simulation, whereas checklists gave them a general overview of all possible options for the problems encountered in the simulation. Combining both tools seemed a bit overwhelming for students, as they had to deal with too many tasks at the same time. Without support, observers were free to reflect on their observations, but could easily be distracted or focus on irrelevant parts of the simulation. With or without guidance, we showed that observers were actively learning during the simulation, but our findings showed that their effort differed depending on the tool they used.

In **Chapter Six**, we answer our research questions by synthesizing the results of our studies and situate them in relation to the existing literature. We also discuss practical implications, strengths and limitations of this research, and provide suggestions for future study. In answer to our first research question, we can conclude that both environment and task complexity influence the learning experience in simulation. Without careful planning of all features involved in the simulation, the learner can be easily diverted from the initial learning objectives. They can strategically decide to pursue smaller goals more reachable or, undesirably, fail to detect the appropriate problems. Moreover, the environment and the task act in synergy and directly influence what students will learn and how they will perform in simulation. For novices, complex environments appear more complex than clinical tasks, partly due to their lack of awareness and mastery of the clinical setting, which inevitably induces a certain amount of stress. It is therefore advisable to prepare students to deal with complex environmental features before introducing complex concepts in the learning tasks, in order to facilitate students' capacity to manage all information.

With regard to our second research question, we can conclude that providing instructional support for students with an observer role in simulation ensures that they are actively engaged in the simulation and focus on relevant aspects. Throughout our research program, students often reported that they really appreciated acting the role of observers as it provided them a wide perspective on the simulation without experiencing performance anxiety. Some participants even proposed that they were more able to analyze the situation. For novice learners, varying their roles and having them observe occasionally should not be overlooked, as it seems meaningful for them.

The research presented in this thesis contributes to our understanding of effective instructional design of immersive simulation for novices. Providing authenticity and complex problems are essential to stimulate learning, but careful consideration must be paid to not overwhelming the learner during the simulation. Like a theatre director, designers must manage the combination of all the features involved in the simulation, from the environment in which the scene takes place, the task that will be performed, up to how the audience will respond to this performance. Our findings support the use of immersive simulation for novices and stress the importance of managing complexity to promote learning.

NEDERLANDSE SAMENVATTING

Simulatieonderwijs is een effectieve leermethode die studenten en professionals in de gezondheidszorg voorbereidt op de klinische praktijk. Simulatie stelt de student in staat om in een realistisch gesimuleerde klinische omgeving taken te oefenen die voor de toekomstige praktijk relevant zijn. In zulke simulaties oefenen studenten hun klinische vaardigheden, gevolgd door een nabespreking of *debriefing* waarin zij hun prestaties analyseren. Hierbij vullen de simulatie en debriefing elkaar aan; om optimaal te kunnen leren is het essentieel dat deze gecombineerd worden.

Simulaties die heel erg dicht bij de echte praktijk komen worden ook wel ‘immersie-simulaties’ genoemd. Deze werden aanvankelijk voornamelijk gebruikt bij meer gevorderde studenten die al enige klinische ervaring hadden, hetgeen hen in staat stelde om met de onvoorziene en complexe klinische context van authentieke situaties om te gaan. Gezien de beperkte klinische ervaring die beginners hebben, is het waarschijnlijk dat de onvoorspelbaarheid en complexiteit van een authentieke klinische setting hen overweldigt en verhindert dat zij de beoogde leerdoelen van de simulatie volledig bereiken. Het is dus zaak dat opleiders zowel de leertaak als de leeromgeving afstemmen op het niveau van de student. Desondanks is er tot op heden vrijwel geen onderzoek gedaan naar de cognitieve gevolgen van deze twee kenmerken voor een onervaren student, wat het nog moeilijker maakt om de simulaties nauwkeurig op diens niveau af te stemmen.

In **Hoofdstuk 1** ontrafelen we de gevolgen van taak- en omgevingscomplexiteit voor beginnende studenten. Hierbij erkennen we ook dat de rol die een student in een simulatie vervult, hetzij actief als deelnemer of passief als observator, van invloed is op diens cognitieve belasting en leerervaring. We tonen aan dat er nog steeds betrekkelijk weinig bewijs is van wat nu voor beginnende studenten in de praktijk een complexe klinische taak is, vooral in specifieke disciplines zoals farmacie. Wanneer we een beter begrip hebben van hoe complexe omgevingen en taken de leerervaring van beginners tijdens simulaties beïnvloeden, kunnen we specifiek op hen afgestemde simulaties ontwerpen en daarbij de begeleiding bieden die het leren bevordert. Deze stand van zaken leidde tot de ontwikkeling van de volgende twee centrale onderzoeksvragen:

1. Welke gevolgen hebben taak- en omgevingscomplexiteit bij ‘immersiesimulatie’ voor de leerervaring van beginners?
    a. Wat zijn de verschillen tussen immersiesimulatie en simulatiepatiënten ten aanzien van de cognitieve belasting en emoties voor bachelorstudenten in de gezondheidszorg? (Studie 1)
    b. Wat zijn de gevolgen van eenvoudige en complexe taken bij immersiesimulaties wat betreft de cognitieve belasting, eigen beleving van het geleerde en de prestaties voor bachelorstudenten Farmacie, en welke invloed heeft taakcomplexiteit op de leerervaring van deze studenten? (Studie 2)

   c. Welke invloed heeft afstemming van de complexiteit van de taak en van de omgeving op de cognitieve belasting en prestaties van beginners bij immersiesimulatie? (Studie 3)
2. Hoe kan de leerervaring van beginners worden ondersteund wanneer zij een medestudent observeren tijdens immersiesimulatie?
   a. Wat zijn de overeenkomsten en verschillen tussen samenwerkingsscripts, checklists, een combinatie van beide en helemaal geen begeleidend hulpmiddel ten aanzien van de intrinsieke en irrelevante (*extraneous*) cognitieve belasting en eigen beleving van het geleerde voor beginnende observeerders tijdens een simulatietraining, en welke invloed hebben deze hulpmiddelen op de leerervaring van de betreffende observeerders? (Studie 4)

De in **Hoofdstuk 2** gepresenteerde studie richt zich op de cognitieve en emotionele gevolgen van de leeromgeving voor beginners in immersiesimulatie. In dit 'mixed-methods' onderzoek vergeleken we twee verschillende situaties aan de hand van een cross-over-onderzoeksopzet met 143 bachelor studenten Farmacie: een *immersiesimulatie* in een volledig authentieke omgeving en een activiteit met *simulatiepatiënten* waarbij de participanten geen middelen uit de omgeving hoefden te gebruiken voor het oplossen van de problemen, zoals telefoons, elektronische patiëntendossiers of echte medicijnen. Na afloop van beide simulatieactiviteiten beoordeelden de participanten hun cognitieve belasting en emoties met behulp van gevalideerde vragenlijsten. Vijfendertig studenten kwamen in focusgroepen bijeen met het doel te onderzoeken hoe bepaalde kenmerken van de leeromgeving hun leerervaring beïnvloedden. We constateerden dat bij immersiesimulatie de intrinsieke en irrelevante (extraneous) cognitieve belasting en scores voor negatieve emoties, zoals stress, significant doch gematigd hoger waren dan bij simulatiepatiënten. Uit onze kwalitatieve bevindingen bleek daarenboven dat de fysieke omgeving meer stress opleverde bij immersiesimulatie dan bij simulatiepatiënten. Met simulatiepatiënten concentreerden de studenten zich op het klinisch redeneren, terwijl bij immersiesimulatie hun aandacht uitging naar het verzamelen van gegevens wat ten koste ging van het probleemoplossende proces. Deze studie hielp ons aan te tonen dat de leeromgeving waarbinnen beginnende studenten de simulatie ondergaan, van invloed is op wat en hoe zij leren. De studenten gaven aan dat immersiesimulatie zowel cognitief als emotioneel meer belastend was dan simulatiepatiënten. Nog belangrijker is dat onze bevindingen wezen op de dringende behoefte aan richtlijnen voor het ontwerpen van simulatieonderwijs afgestemd op beginners.

In **Hoofdstuk 3** onderzochten we welk effect taakcomplexiteit heeft op de cognitieve belasting, de uitvoering van de taak en de eigen beleving van het geleerde bij bachelorstudenten Farmacie tijdens immersiesimulatie. In dit 'mixed-methods' onderzoek verrichtten 167 studenten Farmacie achtereenvolgens een eenvoudige en een complexe leertaak. Na elke taak en nabespreking werd de cognitieve belasting van de participanten gemeten. Daarbij beoordeelden we ook de uitvoering van de taak en de tijd die de student hieraan besteed had. Als onderdeel van een sequentiële, verklarende onderzoeksopzet hielden we semigestructureerde interviews met studenten waarbij maximale verschillen in intrinsieke cognitieve belasting werden aangetoond, teneinde meer inzicht te verkrijgen in hoeveel zij van de in complexiteit verschillende taken dachten te hebben geleerd. Hoewel de complexe taak gepaard ging met een significant hogere cognitieve belasting en tijdsinvestering dan bij de eenvoudigere taak het geval was, presteerden de studenten in het algemeen goed op beide taken. Uit de kwalitatieve resultaten bleek dat een gebrek aan klinische ervaring, een onbekend hulpmiddel in de omgeving evenals beperkingen zoals tijdsdruk die inherent waren aan de simulatie, het proces van klinisch redeneren belemmerden en tot een slechtere beoordeling van de eigen prestaties leidden. Terwijl de eenvoudigere taken de studenten hielpen om meer zelfvertrouwen te krijgen, zetten de complexe taken hen tijdens de nabespreking aan tot meer reflectie. Ondanks het feit dat de complexe taken bij immersiesimulatie cognitief meer belastend waren en meer tijd vergden, gaven de studenten aan dat zij er meer van hadden geleerd dan van de eenvoudigere taken. Complexe taken vormen een extra uitdaging als het gaat om klinisch redeneren, en daarmee bieden zij volgens de studenten een waardevollere leerervaring.

Voortbouwend op de resultaten uit de voorgaande studies, hebben we in Hoofdstuk 4 een onderzoek opgezet waarmee we trachtten te onderzoeken welke invloed afstemming van zowel de taak- als omgevingscomplexiteit heeft op de leerervaring van beginners bij immersiesimulatie. Tweedejaars studenten Farmacie (*N*=162) werden willekeurig toegewezen aan een van de volgende vier condities (two-way-factorial design) in een immersiesimulatiesessie die in complexiteit van elkaar verschilden: eenvoudige of complexe taken in een eenvoudige of complexe omgeving. Met behulp van video-opnames van de simulatie beoordeelden twee beoordelaars de prestaties van studenten. We maten intrinsieke en irrelevante (extraneous) cognitieve belasting met behulp van vragenlijsten na afloop van de taak en toetsten kennis na de taak en de nabespreking. Hoewel tijdens de simulatie de prestaties in alle condities goed bleven, vonden we een interactie-effect tussen de taak en de omgevingscomplexiteit, wat erop duidde dat de prestaties op eenvoudige taken naar beneden gingen naarmate de omgevingscomplexiteit toenam. Wanneer beginners tijdens de simulatie moeite hadden met de omgeving, leek hun aandacht van de taak te worden afgeleid en te verschuiven naar het managen van de omgeving, wat verklaarde waarom de prestaties in een meer complexe omgeving verminderden. Ook constateerden we dat hoe hoger de taakcomplexiteit, des te groter de intrinsieke cognitieve belasting. Naarmate de complexiteit van de simulatie toeneemt, lijken de studenten hun eigen cognitieve belasting strategisch zo te managen dat zij adequate prestaties blijven leveren en iets nuttigs leren. Hoewel zij met deze strategie voorkomen dat zij cognitief overbelast raken, zou een dergelijke aanpak hen ook wel eens kunnen beletten alle beoogde leerdoelen te behalen.

In **Hoofdstuk 5** hebben we het leerproces onderzocht van studenten die tijdens de immersiesimulatie een observerende rol vervulden. Hiertoe hebben we een ‘mixed-methods’ onderzoek opgezet dat ten doel had de overeenkomsten en verschillen in cognitieve belasting en studieresultaten inzichtelijk te maken door het gebruik van samenwerkingsscripts en checklists door deze observeerders met elkaar te vergelijken. Tweedejaars studenten Farmacie (*N*=162) werden willekeurig toegewezen aan een van de volgende vier condities terwijl zij een simulatie observeerden: samenwerkingsscripts (heuristische methode waarmee studenten tijdens het observeren in tweetallen analyseren), checklists, een combinatie van beide instrumenten en geen hulpmiddel. We maten de intrinsieke en irrelevante (extraneous) cognitieve belasting van de observeerders, alsmede hun eigen beleving van het geleerde, en namen focusgroepinterviews af. Samenwerkingsscripts zorgden voor de hoogste intrinsieke cognitieve belasting omdat het lastiger leek om met een medestudent samen te werken en gezamenlijk kennis op te bouwen. Checklists, die de laagste scores voor intrinsieke cognitieve belasting opleverden, werden beschouwd als een eenvoudige opdracht waarbij studenten niet hoefden na te denken over de relevantie en de kwaliteit van het aan te kruisen vakje. De scores voor irrelevante (extraneous) cognitieve belasting waren significant hoger wanneer beide hulpmiddelen werden gecombineerd, hoewel de scores in alle vier de condities zeer laag bleven. Het observeren van de simulatie, met of zonder hulpmiddel, was een zinvolle leerervaring die resulteerde in matige scores voor de eigen beleving van het geleerde. Terwijl samenwerkingsscripts de studenten in staat stelden één specifiek aspect van de simulatie verder uit te diepen, gaven de checklists hun een algemeen overzicht van alle mogelijke opties voor de problemen die zich tijdens de simulatie voordeden. Het combineren van beide hulpmiddelen leek een beetje overweldigend voor de studenten, omdat zij zich dan met te veel taken tegelijkertijd moesten bezighouden. Zonder hulpmiddel waren de observeerders weliswaar vrij om over hun observaties na te denken, maar zij konden ook gemakkelijk afgeleid worden of zich concentreren op onderdelen van de simulatie die er niet toe deden. Wij hebben aangetoond dat observeerders gedurende de simulatie actief leerden ongeacht of zij nu wel of geen hulpmiddel kregen, hoewel onze bevindingen lieten zien dat de mate van inspanning die van hen gevergd werd, afhing van het hulpmiddel dat zij hanteerden.

In **Hoofdstuk 6** beantwoorden wij onze onderzoeksvragen door de resultaten van onze studies te bundelen en ze ten opzichte van de bestaande literatuur te positioneren. Voorts bespreken we de implicaties voor de praktijk, de sterke punten alsmede de beperkingen van dit onderzoek, en doen aanbevelingen voor toekomstig onderzoek. Ter beantwoording van onze eerste onderzoeksvraag kunnen we concluderen dat zowel de omgevings- als de taakcomplexiteit van invloed zijn op de leerervaring tijdens een simulatie. Zonder vooraf alle aspecten die bij de simulatie betrokken zijn zorgvuldig te plannen, kan de student gemakkelijk van de oorspronkelijke leerdoelen worden afgeleid. Zij kunnen strategisch besluiten om kleinere doelen na te streven die beter haalbaar zijn of, in het onwenselijke geval, zelfs de relevante problemen over het hoofd zien. Bovendien versterken de omgeving en de taak elkaar en hebben zij een directe invloed op wat de studenten zullen leren en hoe zij tijdens de simulatie zullen presteren. Voor beginners lijken complexe omgevingen complexer dan klinische taken, deels vanwege hun gebrek aan inzicht in de klinische setting en gebrek aan hun beheersing ervan; dit zorgt onvermijdelijk voor een zekere mate van stress. Daarom is het raadzaam om studenten te leren hoe met complexe omgevingsaspecten om te gaan, alvorens complexe begrippen in de leertaken op te nemen. Dit zal de studenten beter in staat stellen om alle informatie ineens te verwerken.

Met betrekking tot onze tweede onderzoeksvraag kunnen we concluderen dat het aanreiken van hulpmiddelen aan studenten met een observerende rol ervoor zorgt dat zij actief bij de simulatie betrokken zijn en zich op de relevante aspecten concentreren. Gedurende ons onderzoeksprogramma gaven de studenten vaak aan dat zij het erg waardeerden om de rol van observeerder te vervullen, omdat deze hun een breder beeld van de simulatie gaf zonder dat zij zich zorgen hoefden te maken over hun prestaties. Sommige participanten opperden zelfs dat zij beter in staat waren om de situatie te analyseren. Kortom, voor beginnende studenten is het essentieel dat zij een wisselende rol krijgen toebedeeld en dat wij ze af en toe laten observeren, want dit lijkt zinvol voor hen.

Het onderzoek in het onderhavige proefschrift draagt bij aan ons begrip van hoe we effectief immersiesimulatieonderwijs kunnen ontwerpen voor beginners. Hoewel het ter bevordering van het leren essentieel is dat in een authentieke setting complexe problemen worden aangereikt, moet er eveneens voor gewaakt worden dat de student tijdens de simulatie niet wordt overweldigd. Net als de regisseur van een theatervoorstelling moeten onderwijsontwerpers alle bij de simulatie betrokken aspecten afstemmen, van de omgeving waarin de scène plaatsvindt en de taak die wordt uitgevoerd tot aan hoe het publiek hierop zal reageren. Onze bevindingen ondersteunen het gebruik van immersiesimulatie voor beginners en wijzen erop hoe belangrijk het is dat de complexiteit wordt afgestemd teneinde het leren te bevorderen.

ADDENDUM

Acknowledgements
About the author
List of publications
SHE dissertations series

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Marie-Laurence Tremblay (Jonquière, September 17, 1985) completed a bachelor's in pharmacy in 2008, and graduated with distinction from a master's in hospital pharmacy in 2009 at Laval University, Quebec city, Canada. She worked as a clinician for a few years in both hospital and community settings while obtaining a certification in advanced pharmacotherapy from the Board of Pharmacy Specialties of the American Pharmacy Association (2011). She joined the Faculty of Pharmacy at Laval University in 2011 to design curriculum in simulation as part of the new competency-based Doctor of Pharmacy program.

With a passion for simulation-based education and devoted to forming competent pharmacist who embrace their full scope of practice, she completed a Master's in Health Professions Education from Maastricht University in 2015 where she started studying instructional design in simulation for novices. She kept on conducting research in that aera as part of her PhD project. She became assistant professor at Laval University in 2019 and became chairholder of the Educational Leadership Chair *Familiprix* in Community Pharmacy which focusses on innovative teaching and learning in pharmacy education. She is currently leading various initiatives aiming at training competent pharmacists.

In addition to being a researcher, Marie-Laurence is also a mom, a wife, a daughter, and a friend. She enjoys literature, cinema, theatre, and music. She loves learning new languages, although her attempt at learning Dutch turned out to be a disaster. Fortunately, she can order a cup of coffee in The Netherlands, which was very useful during her travels for her PhD.

LIST OF PUBLICATIONS

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À mes amours, Sarah-Jeanne,
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