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Simulation-based education for novices

Citation for published version (APA):

Tremblay, M.-L., Leppink, J., Leclerc, G., Rethans, J.-J., & Dolmans, D. H. J. M. (2019). Simulation-based education for novices: complex learning tasks promote reflective practice. *Medical Education*, *53*(4), 380-389. https://doi.org/10.1111/medu.13748

Document status and date:
Published: 01/04/2019

DOI:
10.1111/medu.13748

Document Version:
Publisher's PDF, also known as Version of record

Document license:
Taverne

Please check the document version of this publication:

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Simulation-based education for novices: complex learning tasks promote reflective practice

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CONTEXT Simulated clinical immersion (SCI), in which clinical situations are simulated 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 misleading learning outcomes. Although task complexity should be adapted to the learner's level of expertise, many factors, both intrinsic and extraneous to the learning task, can influence perceived task complexity and its impact on cognitive processes.

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

METHODS A total of 167 second-year pharmacy students were randomly assigned to undertake one simple and one complex learning task in SCI consecutively. 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 elucidate their perceptions of learning when dealing with complexity.

RESULTS Although the complex task generated significantly higher cognitive load and time on task than the simple 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. Simple 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 than they did from simple tasks. Complex tasks constitute an additional challenge in terms of clinical reasoning and thus provide a more valuable learning experience from the student's perspective.

Medical Education 2019: 53: 380–389
doi: 10.1111/medu.13748

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INTRODUCTION

Simulated clinical immersion (SCI) is a simulation modality in which real-life situations are reproduced in realistic simulated clinical settings.[1] For undergraduate health care students, SCI allows unique opportunities for early exposure to authentic clinical problems when 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 misleading learning outcomes.[2–4] To maximise learning, task complexity should be adapted to the learners' level of expertise and should increase progressively as they become more proficient.[5] However, even if the learning task itself remains relatively simple and requires the processing of only a limited number of information elements, many factors, both intrinsic and extraneous to the learning task, will determine the complexity of the learning experience.[6,7] This may explain why multiple studies have failed to consistently demonstrate enhanced learning among novices in complex skills learning in the context of simulation.[2,3] This study focuses on the relationship between task complexity and the learning of novices in SCI.

The complexity of a task, as defined by cognitive load theory, is mainly determined by the degree to which its elements interact.[4] 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.[8] The sources of cognitive load imposed on a learner can be either intrinsic or extraneous to the learning task. Intrinsic cognitive load refers to the processing of new information to be learned and the construction of schemas.[9] Conversely, extraneous cognitive load pertains to the use of working memory resources on information unrelated to the goals of instructions, such as information related to an unfamiliar, malfunctioning or unsuitable learning environment, and emotions felt during a simulation that distract from the task at hand.[6,7] To optimise the learning process, extraneous cognitive load must be minimised to allow learners to focus their working memory resources on dealing with intrinsic cognitive load.[10]

When studying the relationship between cognitive load measures and students' perceptions of cognitive load in simulation-based training, Naismith et al.[6] demonstrated that task complexity is accurately detected through self-reported intrinsic cognitive load measures. The authors also revealed that a lack of prior experience and the need to integrate multiple skills in one scenario contribute to increasing the perception of task complexity.[6] 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.[11] 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 generalised 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.[2,3,12] This divergence between the intended learning goals and observed learning outcomes may be partly explained by the fact that students' learning processes in simulation are still misunderstood, but could be clarified by qualitative data indicating what students really learn. Moreover, other factors known to have impact on learning processes, such as intrinsic motivation and sources of extraneous cognitive load in simulation, still need to be investigated.[6] Given that simulation-based education is very resource intensive, it is imperative that we understand how task complexity influences undergraduate health care students' cognitive load, performance and perceptions of learning to improve our capacity to design SCI trainings that promote learning.

Research questions

We designed this mixed-methods study to determine the effects of simple and complex tasks in SCI in terms of cognitive load, self-perceived learning and performance in undergraduate pharmacy students (research question [RQ] 1). We hypothesised that students would experience higher intrinsic cognitive load (hypothesis [H] 1), higher extraneous cognitive load (H2) and higher self-perceived learning (H3) when facing a complex task in SCI as opposed to a simple task. Moreover, we postulated that complex tasks would lead to poorer performance (H4). As part of a sequential explanatory design, we also aimed to understand through semi-structured interviews, how task

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complexity influenced students' perceptions of learning (RQ2).

METHODS

Setting

We conducted this study in the Faculty of Pharmacy, Laval University (Quebec, Canada) in the pharmacy simulation laboratory, which replicates 10 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

A total of 172 second-year undergraduate pharmacy students, in a 4-year, competency-based pharmacy programme (PharmD) delivered in French, were eligible to participate on a voluntary basis. Given their limited clinical experience (i.e. 3 weeks of clinical clerkship) and the completion of only one-quarter of the programme prior to the experiment, the participants were considered novices in this study context. They had experienced four simulation activities similar to those used in 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 or four students (see Fig. 1 for information on study design). Each participant took turns to act as the pharmacist for two consecutive SCI learning tasks, one simple and one more complex (Table 1). Students' turns to perform were determined randomly in the small groups. The student's turn dictated the clinical topic for the series of simple and complex tasks (i.e. the first student to perform in a group undertook both tasks on dyslipidaemia, starting with the simple task and following with the complex task; the second student then undertook both the simple and complex tasks 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.[13] When not playing the pharmacist, participants observed other students' simulations and listed actions executed by the pharmacist using a checklist developed for each task (can be found online in the Supporting Information Appendix S1). To ensure that all participants had the same learning experiences and were not biased when observing their peers, each series of tasks (i.e. A, B, C and D) addressed a completely different topic and therefore should not have had influence on how future tasks were resolved.

Experienced actors played as standardised patients (SPs) and received a 2-hour training session, which involved clear explanations to the goals of each task and the acting tips. The Maastricht Assessment of Simulated Patients (MaSP) tool[14] 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 (M-LT) assessed each actor twice using video-recordings of the actor playing different roles. 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 10–15 minutes per case), which were immediately followed by the respective debriefing periods (approximately 15–25 minutes).

Learning tasks

All learning tasks were based on real-life whole tasks, meaning that the clinical situations were authentic, reliable and complete.[15] 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 appropriate for novice pharmacy students). Task complexity was modulated through patient characteristics, clinical context and requirements to interact with the physical environment. Simple tasks generally involved friendly encounters, patients presenting with fewer co-morbidities or potential drug interactions, and fewer interactions with the environment than did complex tasks (Table 1). Learning tasks were piloted prior to the experiment to confirm the level of complexity and to ensure they were suitable for our facilities.

Data collection: measurements and instruments

Cognitive load and self-perceived learning (RQ1)

Intrinsic and extraneous cognitive load and self-perceived learning were measured four times for

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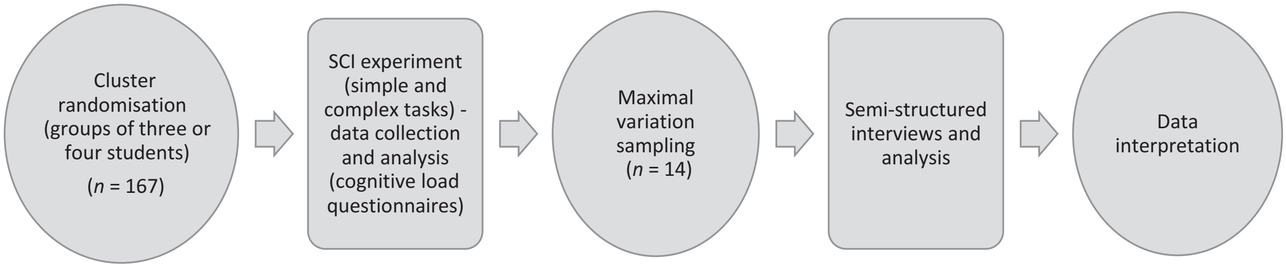

Figure 1 Study design. After each simulation task (both simple and complex), students rated their cognitive load using an adapted and validated questionnaire. Students' time on task and performance were assessed using a checklist of predictable actions. Semi-structured interviews were then conducted with 14 students to investigate their perceptions of task complexity in SCI. SCI = simulated clinical immersion

Table 1 Learning task characteristics

Learning tasks	Simple	Complex
(A) Dyslipidaemia	• Initiation of therapy (statin) • Patient counselling • No drug-related problem • Friendly patient	• Statin myopathy (side-effect management) • Prescribing laboratory tests, writing a drug prescription • Communicating with the physician to explain the management plan (verbally or in writing) OR elaborating the 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 in writing to elaborate the 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 the patient's file • Friendly patient, aware of his condition	• Initiation of therapy (severe renal failure) • Adjustment required • Creatinine levels available, but GFR not calculated • Communication with the physician (or not required if the pharmacist adjusts the dosage independently) • Writing a verbal drug prescription • Patient friendly but unable to provide a lot of information • Communicating with the physician verbally and in writing to elaborate the plan collaboratively (or not required if the pharmacist adjusts the dosage independently)
(D) Vaginitis	• Initiation of therapy (pregnant patient) • No adjustment needed – prescribed by the physician • Friendly patient	• Initiation of therapy (breastfeeding patient) • Prescription by the pharmacist after investigation • Writing a verbal drug prescription

GFR = glomerular filtration rate.

each participant using a translated and adapted version of a cognitive load questionnaire developed by Leppink et al.[16] can be found online in the Supporting Information (Appendix S2). 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 (M-LT) associated each reported action taken by the student with a corresponding score (i.e. appropriate, inappropriate but not damaging, damaging for the patient) (can be found online in the Supporting Information Appendix S3). 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 in the course of developing the checklists. Finally, time on task was 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 elucidate how task complexity affected student perceptions of learning (can be found online in the Supporting Information Appendix S4). Maximal variation sampling was used to select participants for interviews (those showing the smallest and biggest differences in intrinsic cognitive load between the simple and complex tasks [both positive and negative differences]) to ensure a wide representation of perspectives. Data were collected until the authors agreed that saturation of themes had been reached.

Data analysis

Quantitative analysis

Statistical analyses were conducted using JAMOVI Version 0.9.1.7[17] (i.e. confirmatory factor analysis [CFA] and mixed-effects analysis) and JASP Version 0.9.0.1 (Department of Psychological Methods, University of Amsterdam, Amsterdam, the Netherlands)[18] (i.e. correlations and paired *t*-tests for differences between simple and complex cases). Intraclass correlations attributable to students working in groups frequently require multi-level analysis (i.e. lower level: students; upper level: groups).[19] However, in the current study, the intraclass correlation was close to zero (can be found online in the Supporting Information Appendix S5 and Appendix S6) and therefore paired *t*-tests were performed (i.e. differences between simple and complex cases).

Confirmatory factor analysis yielded support for which questions in the cognitive load questionnaire could be grouped together to create scale scores (i.e. intrinsic and extraneous cognitive load, and self-perceived learning). (Appendices 2 and 6, respectively, give more information on the questionnaire and question grouping based on CFA.) Cohen's *d* values were computed to assess the effect sizes of the results. Values of 0.2, 0.5 and 0.8, respectively, reflect small, medium and large effects.[20]

Qualitative analysis

All interviews were audiorecorded and transcribed integrally. A thematic analysis was performed using both deductive and inductive approaches to code and analyse the verbatim. Using sensitising concepts from the literature on causes of intrinsic and extraneous cognitive load in SCI, we sought to identify specific themes to understand students' perceptions of task complexity,[6,7,21] at the same time remaining open to new emerging themes. Two authors analysed the interviews verbatim (M-LT and GL), using an iterative approach and constant comparative analysis to elucidate the effects of task complexity in SCI. In cases of disagreement, the authors discussed the issue until they reached consensus.

Ethics

This study was approved by the Research Ethics Committee of Laval University (no. 2016-254/23-09-2016). Written informed consent was obtained prior to randomisation. 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 programme. The investigators were not directly involved with students' training at the time 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: 97.1%), they had obtained a college degree (n = 141, 84.4%) prior to entering

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the PharmD programme, and the majority of which were female (n = 120, 71.6%). Their mean ± standard deviation (SD) age was 21.6 ± 2.05 years. Table 2 presents means, SDs and effect sizes (Cohen's d) for intrinsic and extraneous cognitive load, self-perceived learning and time on task for simple and complex tasks.

Most of the participants (n = 153 , 92.1%) had previous work experience as pharmacy technicians prior to the study (mean ± SD: 16.5 ± 17.8 months). Of note, our results indicate a small correlation between previous work experience and intrinsic cognitive load for both the complex (Spearman's $\rho = -0.048$, 95% confidence interval [CI] −0.207 to 0.113) and simple (Spearman's $\rho = -0.128$, 95% CI −0.282 to 0.032) tasks.

In line with H1, H2 and H3, our findings indicate (Table 2) significant differences in terms of intrinsic (mean = 1.97, 95% CI 1.72–2.23) and extraneous (mean = 1.29, 95% CI 0.95–1.62) cognitive load and self-perceived learning (mean = 0.86, 95% CI 0.54–1.17) between the complex and simple tasks. We also found a statistically significant difference between the debriefings of complex and simple tasks in terms of intrinsic cognitive load (mean = 1.50, 95% CI 1.23–1.77), extraneous cognitive load (mean = 0.30, 95% CI 0.18–0.42) and self-perceived learning (mean = 1.29, 95% CI 0.96–1.66).

In terms of performance, our findings show that 95.8% (n = 159) of the participants performed only appropriate actions on the simple task, compared with 85.5% (n = 142) on the complex task (Table 3). On the simple tasks, only one participant (0.6%) performed a damaging action and six participants (3.6%) executed a mix of appropriate and inappropriate actions that were not damaging to the patient. On the complex tasks, 17 participants (10.2%) performed actions that would damage the patient, whereas seven participants (4.2%) performed a mix of appropriate and inappropriate but not damaging actions. Given the restricted range in students' performance, especially on the simple cases, we were unable to subject the difference in performance between the simple and complex tasks to statistical testing, which left H4 unanswered. Even when damaging and non-damaging actions were merged to perform a McNemar test on the difference in inappropriate and appropriate actions between the simple and complex tasks, the results remained difficult to interpret as a result of this restriction of range (95.8% of appropriate actions for the simple task). However, we found a statistically significant difference in time on task between the complex and simple tasks, and a small positive correlation between the difference in time on task and difference in intrinsic cognitive load between the simple and complex tasks (Spearman's $\rho = 0.188$, 95% CI 0.029–0.339).

Qualitative results

Fourteen semi-structured interviews were conducted to elucidate students' perceptions of learning when dealing with complexity. Saturation of themes was reached after 12 interviews.

Lack of clinical experience leads to poorer problem representation and an arbitrary decision-making process

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

Unfamiliar resources, such as unknown computer functions, e-resources and reference books, all contributed to increased time on task. Although all of the interviewed participants had worked in community pharmacies prior to the study, when confronted with new resources that might be useful for the task, students were easily distracted and often unable to find the information they were looking for to solve the problem. They felt that they

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Table 2 Means (M), standard deviations, [sample size n], and effect size (Cohen's d) for intrinsic and extraneous cognitive load, self-perceived learning, and time on task for simple and complex tasks

Condition	Simple	Complex	Mean difference	Confidence Interval for mean difference	Cohen's d	Confidence Interval for Cohen's d
Intrinsic cognitive load (0–10)						
Case	2.82 (1.49) [*n* = 159]	4.81 (1.88) [*n* = 157]	1.97 (1.61)	1.72–2.23	1.23	1.02–1.43
Debriefing	1.82 (1.15) [*n* = 157]	3.25 (1.85) [*n* = 153]	1.50 (1.66)	1.23–1.77	0.90	0.71–1.09
Extraneous cognitive load (0–10)						
Case	1.69 (1.58) [*n* = 158]	2.98 (2.16) [*n* = 153]	1.29 (2.11)	0.95–1.62	0.61	0.44–0.78
Debriefing	0.63 (0.74) [*n* = 157]	0.91 (1.00) [*n* = 152]	0.30 (0.76)	0.18–0.42	0.39	0.23–0.56
Self-perceived learning (0–10)						
Case	5.05 (2.08) [*n* = 158]	5.96 (1.90) [*n* = 157]	0.86 (1.99)	0.54–1.17	0.43	0.27–0.60
Debriefing	6.05 (2.22) [*n* = 156]	7.30 (1.85) [*n* = 152]	1.29 (2.00)	0.96–1.61	0.64	0.47–0.82
Time for task (seconds)	448.90 (98.94) [*n* = 164]	769.28 (158.38) [*n* = 161]	321.30 (150.79)	297.69–344.92	2.13	1.85–2.41

Software: JASP Version 0.9.0.1.18.
CIC, confidence interval; ECL, extraneous cognitive load; ICL, intrinsic cognitive load; SD, standard deviation; SPL, self-perceived learning.

spent too much time trying to understand the resource rather than focusing on the clinical problem. Time spent on this resource prevented them from organising a complete and appropriate solution:

> When I realised that the patient had renal failure, I knew I had to do 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 me like . . . 2 or 3 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 in SCI (e.g. time limitation, being observed, pride, 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 reorganise and prioritise the tasks that had to be completed within the limited time available. This time restriction was perceived as a realistic yet stressful parameter with which to cope. However, some students reported 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:

*Table 3 Distribution of performance (students, n) for simple and complex tasks**

Performance score†	Simple tasks	Complex tasks
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 (10.2%)

* The restriction of range in students' performance, especially on the simple cases, did not allow statistical testing of the difference in performance between simple and complex tasks.
† There was missing data for one participant for the performance score.

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> 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 help students gain more self-confidence, whereas complex tasks further encourage reflective practice during debriefings

Simple tasks are useful for rehearsing skills and concepts that students have already mastered, and thereby increase students' self-confidence. However, the debriefings of simple tasks seemed less stimulating as students were less interested in analysing why their performance was adequate. In complex tasks, students are more prone to making mistakes because they have not yet fully integrated some aspects of the tasks. Debriefings of complex tasks were reported as more valuable as they helped students decontextualise 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 increased task complexity are likely to impose a higher cognitive load when affecting the problem-solving process. These findings build on current evidence regarding the various factors in simulation that contribute to increasing either intrinsic or extraneous cognitive load in medical students, such as lack of knowledge, unfamiliar resources and time limitations.[6] The richness of our mixed-methods design helped to clarify how these factors can either impede or improve student performance in the training phase. The impacts of task complexity on transfer of learning in the context of non-procedural simulations remain to be studied. Nonetheless, students perceived that they learned more from the complex tasks even though these tasks constituted an additional challenge in terms of clinical reasoning and generated more mistakes. From the students' perspective, complex tasks represent a more valuable learning experience because the associated debriefings stimulate deeper reflection.

Although the learning environment in SCI has typically been associated with extraneous cognitive load,[6,22] it seems to contribute to both 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 and examination instruments can certainly mobilise learners' cognitive resources if they are unfamiliar. However, if the learning goal of the simulation is that the student actually learns how to use and integrate these resources 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 learners are expected to have mastered 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 room temperature and noises.[22] Therefore, sources of intrinsic and extraneous cognitive load in simulation essentially depend on the learning goals. This observation has also been recognised in learning contexts other than simulation.[23,24]

Although the vast majority of students found the complex tasks more complex as reflected by a higher intrinsic cognitive load, the aspects of these tasks that made them more complex for students sometimes differed from our expectations, which may explain why some participants designated the simple tasks as being more complex for them. Although we designed the complex tasks to include more challenging patient encounters, surprisingly students did not report this aspect as complex for them. This finding reinforces the idea that task complexity is a dynamic concept that results from the interactions between a given learning situation and the learner.[25,26]

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Limitations

Despite our relatively large sample size, we were unable to subject differences in performance between simple and complex tasks to statistical testing because the vast majority of students performed only appropriate actions on both tasks. The instrument used to grade performance did not focus on the quality of each action, but, rather, on its acceptability. Therefore, some actions may be acceptable and not damaging in today's practice, but may not be ideal. We chose this type of instrument mainly because we did not want to assess the quality of students' actions on tasks they had not performed before. Making mistakes and debriefing on 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 perceptions of learning and did not measure learning outcomes because these were not the focus of this study. Whether complex SCI learning tasks lead to better learning outcomes or increased transfer of learning remains to be studied.

Providing a wide range of task complexity has been associated with better learner engagement and positive learning outcomes in simulation-based education.[27] 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 the student's perspective.

Contributors: M-LT conducted the interviews and contributed to the statistical and qualitative analyses. JL contributed to the statistical analyses. GL contributed to the qualitative analyses. J-JR and DHJMD provided feedback on the whole research project. All authors contributed to the conception of the study and approved the final manuscript for submission.
Acknowledgements: we are grateful for the help of research assistants Sabrina Iannone, Faculty of Pharmacy, Laval University, Quebec, Quebec, Canada, and Audrey Thibault, Department of Information and Communication, Faculty of Literature and Human Sciences, Laval University, Quebec, Quebec, Canada. We are also thankful for the support of the programme director of the Faculty of Pharmacy at Laval University in authorising this research. We would like to thank the staff at the Apprentiss Simulation Centre (Pharmacy) for supervising the technical aspects of this study. Finally, we want to thank Gilles Chiniara, Department of Anestesiology and Intensive Care, Faculty of Medicine, Laval University, Quebec, Quebec, Canada, and Marie-Claude Boivin, Faculty of Pharmacy, Laval University, Quebec, Quebec, Canada, for their feedback on the learning tasks.
Funding: none.
Conflicts of interest: none.
Ethical approval: this study was approved by the Research Ethics Committee of Laval University (no. 2016-254/23-09-2016).

REFERENCES

1 Chiniara G, Cole G, Brisbin K, Huffman D, Cragg B, Lamacchia M, Norman D, Canadian Network for Simulation in Healthcare, Guidelines Working Group. Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. *Med Teach* 2013;**35** (8):e1380–95.

2 LaRochelle JS, Durning SJ, Pangaro LN, Artino AR, van der Vleuten C, Schuwirth L. Impact of increased authenticity in instructional format on preclerkship students' performance: a two-year, prospective, randomized study. *Acad Med* 2012;**87** (10):1341–7.

3 La Rochelle JS, Durning SJ, Pangaro LN, Artino AR, van der Vleuten C, Schuwirth L. Authenticity of instruction and student performance: a prospective randomised trial. *Med Educ* 2011;**45** (8):807–17.

4 Van Merriënboer JJ, Sweller J. Cognitive load theory in health professional education: design principles and strategies. *Med Educ* 2010;**44** (1):85–93.

5 Van Merriënboer JJ, Kester L, Paas F. Teaching complex rather than simple tasks: balancing intrinsic and germane load to enhance transfer of learning. *Appl Cogn Psychol* 2006;**20** (3):343–52.

6 Naismith LM, Cheung JJ, Ringsted C, Cavalcanti RB. Limitations of subjective cognitive load measures in simulation-based procedural training. *Med Educ* 2015;**49** (8):805–14.

7 Tremblay M-L, Lafleur A, Leppink J, Dolmans DH. The simulated clinical environment: cognitive and emotional impact among undergraduates. *Med Teach* 2017;**39** (2):181–7.

8 Leppink J, Duvivier R. Twelve tips for medical curriculum design from a cognitive load theory perspective. *Med Teach* 2016;**38** (7):669–74.

9 Leppink J, van den Heuvel A. The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ* 2015;**4** (3):119–27.

10 Leppink J, van Gog T, Paas F, Sweller J. Cognitive load theory: researching and planning teaching to maximise learning. In: Cleland J, Durning SJ, eds.

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Researching Medical Education. Chichester: Wiley-Blackwell 2015;207–18.
11 Haji FA, Cheung JJ, Woods N, Regehr G, Ribaupierre S, Dubrowski A. Thrive or overload? The effect of task complexity on novices' simulation-based learning. *Med Educ* 2016;**50** (9):955–68.
12 Norman G, Dore K, Grierson L. The minimal relationship between simulation fidelity and transfer of learning. *Med Educ* 2012;**46** (7):636–47.
13 Van Merriënboer JJ, Kirschner PA. *Ten Steps to Complex Learning: A Systematic Approach to Four-Component Instructional Design*. London: Routledge 2012.
14 Wind LA, van Dalen J, Muijtjens AM, Rethans JJ. Assessing simulated patients in an educational setting: the MaSP (Maastricht Assessment of Simulated Patients). *Med Educ* 2004;**38** (1):39–44.
15 Van Merriënboer JJ, Kester L. Whole-task models in education. In: Spector JM, Merrill MD, van Merriënboer JJ, Driscoll MP, eds. *Handbook of Research on Educational Communications and Technology*, 3rd edn. London: Routledge 2008;441–56.
16 Leppink J, Paas F, van Gog T, van der Vleuten CPM, van Merriënboer JJ. Effects of pairs of problems and examples on task performance and different types of cognitive load. *Learn Instr* 2014;**30**:32–42.
17 Jamovi Project. JAMOVI (Version 0.9.1.7). https://www.jamovi.org/ [Accessed 24 July 2018.]
18 Love J, Selker R, Marsman M, Jamil T, Dropmann DVAJ, Wagenmakers EJ. JASP 0.8.5.1. 2017. https://jasp-stats.org/ [Accessed 24 July 2018.]
19 Leppink J. Data analysis in medical education research: a multilevel perspective. *Perspect Med Educ* 2015;**4** (1):14–24.
20 Cohen J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd edn. Hillsdale, NJ: Lawrence Erlbaum Associates 1988.
21 LeBlanc VR. The effects of acute stress on performance: implications for health professions education. *Acad Med* 2009;**84** (10):S25–33.
22 Choi H-H, van Merriënboer JJ, Paas F. Effects of the physical environment on cognitive load and learning: towards a new model of cognitive load. *Educ Psychol Rev* 2014;**26** (2):225–44.
23 Kalyuga S, Singh A-M. Rethinking the boundaries of cognitive load theory in complex learning. *Educ Psychol Rev* 2016;**28** (4):831–52.
24 Leppink J. Managing the load on a learner's mind: a cognitive load theory perspective. *Med Sci Educ* 2017;**27** (1):5–7.
25 Davis B, Sumara DJ. What is 'complexity'? In: *Complexity and Education: Inquiries into Learning, Teaching, and Research*. Mahwah, NJ: Lawrence Erlbaum Associates 2006;3–16.
26 Bleakley A, Cleland J. Sticking with messy realities: how 'thinking with complexity' can inform healthcare education research. In: Cleland J, Durning SJ, eds. *Researching Medical Education*. Chichester: Wiley-Blackwell 2015;81–92.
27 Cook DA, Hamstra SJ, Brydges R, Zendejas B, Szostek JH, Wang AT, Erwin PJ, Hatala R. Comparative effectiveness of instructional design features in simulation-based education: systematic review and meta-analysis. *Med Teach* 2013;**35** (1):e867–98.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section at the end of the article:

Appendix S1. Example checklist: Dyslipidaemia (complex task: A).
Appendix S2. Cognitive load questionnaire.
Appendix S3. Task performance: scoring list.
Appendix S4. Interview guide.
Appendix S5. FIxed effect plots of mixed-effects modelling.
Appendix S6. Confirmatory factor analysis for cognitive load questionnaire.

Received 8 May 2018; editorial comments to authors 31 July 2018; accepted for publication 7 September 2018

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