Screen-Based Virtual Simulation in Medical Laboratory Science Education: Findings from a National Program

EFREM VIOLATO, BRADY ROSE, MARGARET VERKUYL, LYNDA ATACK

ABSTRACT

Curricular limitations on clinical placements in medical laboratory technology (MLT) education have increased interest in health care simulation, particularly virtual simulation (VS). This study explored learner experience, perceived learning, and readiness for clinical application among MLT students through an end-of-course survey in a work-integrated learning program across 8 Canadian institutions (N = 145, 2023-2024). Using a mixed-methods design, measures included satisfaction, psychological safety, inclusivity, skill development, engagement, usability, and debriefing quality, supplemented by open-ended comments and interviews. Students reported high satisfaction (87.9%), strong psychological safety ($\bar{x} = 4.55$; SD = 0.75), and inclusivity ($\bar{x} = 4.38$; SD = 0.85). High engagement and usability scores indicated effective functionality and positive debriefing experiences. Perceived learning gains were greatest for critical thinking and problem solving, with smaller improvements in communication and teamwork; cross-program differences were minimal and nonsignificant. Qualitative data highlighted VS as a valuable, low-risk environment enabling repetition, feedback, and knowledge application. Students with repeated VS exposure reported deeper learning and increased confidence. Overall, VS was associated with favorable learner experiences, enhanced perceived learning, and greater self-reported readiness for clinical practice. Findings support its use as an effective adjunct and potential partial substitute for traditional clinical placements in MLT education.

ABBREVIATIONS: CPD - continuing professional development, DES - Debriefing Experience Scale, MLT - medical laboratory technology, PXI - Player Experience Inventory, RT - respiratory therapy, VS - virtual simulation, Virtu-WIL - Virtual Work-Integrated Learning.

***Efrem Violato**, Northern Alberta Institute of Technology*

***Brady Rose**, Northern Alberta Institute of Technology*

***Margaret Verkuyl**, Centennial College*

***Lynda Atack**, Centennial College*

***Address for Correspondence: Efrem Violato**, Northern Alberta Institute of Technology, efremv@nait.ca*

INDEX TERMS: simulation training, clinical laboratory personnel, students, health occupations, computer-assisted instruction, debriefing.

Clin Lab Sci 2025;38(1):68–74

INTRODUCTION

Global health care workforce shortages are placing increasing pressure on training programs, including medical laboratory technology (MLT).[1,2] Clinical placement shortages limit the number of students who can achieve the hands-on experience required for competent clinical practice. In Canada, institutions struggle to provide adequate clinical placement opportunities because of staffing shortages, rising attrition rates, and increased demand for health care services.[3-6]

MLT training is uniquely challenged because of specialized and resource-intensive equipment, procedural complexity, and proficiency required in multiple fields of study. Clinical training spans a wide range from foundational skills, such as phlebotomy and specimen processing, to highly specialized procedures and equipment operation. This complexity is compounded by the centralization of specialized procedures, which limits the number of available training sites.

A promising method for addressing these challenges is through health care simulation. Health care simulation is "[a] technique that creates a situation or environment to allow persons to experience a representation of a real event for the purpose of practice, learning, evaluation, testing, or to gain understanding of systems or human actions."[7] In addition to traditional manikin-based simulation, screen-based virtual simulation (VS), characterized by interactive and scenario-based virtual environments, has been recognized as an effective educational strategy in nursing and other health care disciplines[8-10]; however, evidence specific to its efficacy within MLT education is limited. Recently, the Canadian Society for Medical Laboratory Science approved that 70% of competencies may be addressed through simulation, underscoring the importance of simulation and VS as an educational tool.[6]

To address challenges facing the MLT profession, this study examined the use of VS as a curriculum-integrated modality within a national Virtual Work-Integrated Learning (Virtu-WIL) program. The goal was to examine how screen-based VS affected skill development, learner

satisfaction, and readiness for practicum. The study addressed 4 questions:

1) Is a Virtu-WIL program an innovative and effective Work-Integrated Learning model for MLT students?
2) Does a Virtu-WIL program for MLT students increase learner readiness for the labor market?
3) Does a Virtu-WIL program promote learning for MLT students?
4) Does a Virtu-WIL program promote learner competency in MLT students?

METHODS

Virtu-WIL

Virtu-WIL is a project led by Colleges and Institutes Canada, the national organization for Canadian publicly supported colleges, institutes, and polytechnics, in collaboration with Simulation Canada.[10,11] The Virtu-WIL project uses virtual screen-based simulations to enhance health care education. VSs were developed for the Virtu-WIL project by expert educators in their respective fields. The VSs underwent extensive usability testing; peer review; and diversity, inclusion, equity evaluation before deployment.[10,11] The newly developed VSs are provided for free, with open access to approximately 200 VSs designed to provide students in nursing, medical laboratory sciences, paramedicine, respiratory therapy (RT), and sonography with experiential learning experiences and practical competencies.

VSs were hosted on several platforms, such as PCS Spark and Affinity Learning.[12,13] At the time of publication, there are 25 VSs available for medical laboratory science (eg, *Mass Spectrometry Troubleshooting*, *Flow Cytometry in a Hematology Analyzer*, and *A Virtual Simulation Game on the Communication of Laboratory Results*). For an example simulation, follow this link: Blood Cultures - Simulation Canada.[14] The full list of simulations is available at the Simulation Canada website.[15]

A VS experience will begin before accessing the VS, when the learner is presented with the title, time required, and a brief description of the purpose of the VS. After accessing the VS, learners are provided with a prebrief that follows simulation best practices, including a fiction and confidentiality contract, establishment of psychological safety, learning objectives and competencies, an explanation of how the simulation will work, and scenario background. Depending on the VS, participants may be provided with multimedia resources, knowledge questions, decision points, and didactic moments as they move through a variety of scenes in the scenario. VSs are presented in a variety of ways, such as first-person video; avatar-based content; or a mixture of pictures, videos, and character-based actions. After completing the simulation, the students complete a self-debriefing that includes reflective questions and feedback on performance. Later, an in-person debriefing can occur; how the in-person debriefing is conducted depends on the context and the educator's choice.

Some students participating in the Virtu-WIL program completed VSs as a part of their curriculum, while others completed it as an optional extracurricular. Implementation and use of the VS followed simulation best practices,[16] which ensured students received a prebriefing before the VS and a debriefing after the VS. Prebriefings were both built into the VS or completed in person, whereas the debriefing style varied from synchronous in-person to asynchronous virtual debriefing. All students were required to play at least 3 VSs, although students were free to complete any individual VS as many times as desired.

Study Design

A cross-sectional mixed-methods analysis was conducted, using quantitative survey data and qualitative open-ended responses and interviews. The survey was cohort based. All students participating in the Virtu-WIL program were asked to complete an exit survey. Completion of the survey questions was voluntary. Participants were from multiple schools located across Canada. Participants were offered compensation for participation in the program and completion of the survey. Data for the MLT students were extracted from the larger sample of health care students for this analysis.

The broader evaluation of the Virtu-WIL program used 2 evaluation frameworks—the Evaluation Framework for the Change Foundation Grants Program[17] and the Kirkpatrick model—focusing on the first 3 levels of evaluation: reaction, learning, and behavior.[18] This study represents a focused secondary analysis of data within the pan-Canadian Virtu-WIL initiative; thus, it deviates from the program evaluation framework, focusing on specific outcomes for MLT participants. The findings for MLT participants were compared with the results of other health programs in the Virtu-WIL program to contextualize and provide a relative comparison for MLT student outcomes. Data were collected throughout the 2023-2024 academic year.

As the project's goals included evaluation, for quality improvement purposes, the Tri-Council Policy Statement on the Ethical Conduct of Research, which governs research ethics in Canada, determined that survey data for the project were exempt from ethics review. Institutional review and approval for interviews were provided by Centennial College Research Ethics Board (#2022/23–10). Participants were advised of the purpose of the evaluation and that data collected would be kept strictly confidential when completing any surveys or when participating in interviews. Participants were advised that data would only be reported in aggregate and no individuals would be identified when reporting. Informed consent

and data collection occurred only after the nature of the procedures was fully explained to participants.

Measures

Student exit survey data were collected using Hosted in Canada,[19] a survey administration tool. The survey comprised custom items and validated tools, including the mini–Player Experience Inventory (PXI)[20] and Debriefing Experience Scale (DES).[21] Custom items were developed through a process of expert review and pilot testing with an initial sample of students. The mini-PXI consists of 11 items divided into 2 subscales. Five items measure players' perceptions of the functional aspects of gameplay, 5 items measure the psychosocial consequences of gameplay, and a single item measures enjoyment. The mini-PXI scores are reported as a raw total score and subscale scores. The DES measures students' perceptions of the quality and utility of the debriefing experience and comprises 7 items aggregated as a single global score. All survey items were rated on a 1-to-5 Likert scale. Qualitative data were obtained through open-ended survey questions and interviews with educators and facilitators.

Analysis

Data were analyzed using frequency, descriptive, and inferential statistics. All analyses were conducted in R[22] using the psych[23] and dplyr[24] packages. All comparative analysis was conducted using analysis of variance. Based on the unbalanced program sample sizes, all inferential statistical analyses were conducted using a randomly stratified equal-n subsample with 30 data points from each program. This approach balances the sample, leading to more accurate and robust estimates of variance, and reduces sensitivity to violations of model assumptions, reducing the influence of large programs.[25] A sample size of 30 was selected based on the inclusion of maximal data from the smallest program sample (sonography) while meeting a level appropriate for detecting group differences.[25] Based on the central limit theorem, a sample size of 30 is adequate for a sampling distribution whose mean approaches a normal distribution for independent samples.[26] A consistency check found no significant differences for each program's stratified and unstratified scores. Open-ended items were analyzed using a descriptive category coding scheme, which organizes responses into clear, concrete categories for systematic interpretation.[27]

RESULTS

Participants included 145 MLT students (14.3% of the total 2023-2024 Virtu-WIL student cohort, n = 1015) from 8 Canadian institutions in 6 provinces. The sample represented all MLT students in the program who were invited to complete the survey. Students varied by year of study and previous VS experience. Of the 145 MLT participants, 33% had prior experience with VS, with 33% (n = 48) having repeated Virtu-WIL program exposure across multiple terms.

Learner Satisfaction

Overall satisfaction among MLT students was high, with 87.9% reporting satisfaction or high satisfaction with Virtu-WIL simulations. This was comparable with the overall sample, which rated satisfaction/high satisfaction at 88.3%. MLT students rated psychological safety, inclusivity, and likelihood to recommend the program positively. No significant differences existed across programs on psychological safety, inclusivity, or recommending the program (Table 1).

Skill Development

MLT students rated the Virtu-WIL program's impact on critical thinking and problem-solving skills as high. Lower, though still high, ratings occurred for time management, teamwork, oral communication, and written communication. The trend of higher scores on critical thinking and problem-solving skills and lower scores on teamwork, oral communication, and written communication was observed in the other 4 programs as well. A significant difference was observed compared with RT students ($\bar{x} = 3.34$; SD = 0.97) in written communication skills, with MLT students scoring higher. The same pattern was observed for paramedicine and nursing students compared with RT students (Table 1). It should be noted that VSs were designed to address different learning objectives to varying extents.

Functionality and Engagement

Good reliability was demonstrated for the total mini-PXI ($\alpha = .93$), and the functional ($\alpha = .86$) and psychosocial ($\alpha = .89$) subscales. The total mini-PXI score for MLT students was 40.6/55, which is slightly lower than other professions, though only nearing a significant difference compared with nursing 46.1/55. The functional and psychosocial usability subscales indicated positive perceptions, highlighting ease of use and engagement. No significant differences were observed between MLT and other professions on the subscales (Table 1).

Prebriefing and Debriefing Experience

Prebriefing for the VS was rated highly. Good reliability was demonstrated for the DES ($\alpha = .95$), and debriefing was positively rated, with no significant differences between MLT and the other 4 programs (Table 1). In open-ended responses, students highlighted the role of the prebriefing and debriefing experience in making meaningful connections for learning and as an essential part of the VS experience (Table 2).

Table 1. Outcomes for MLT learners and program comparisons

Outcome Area	Measure[a]	MLT Ratings[b], $\bar{x}$ (SD)	Program Differences, η^2p, *P*
Learner satisfaction	Psychological safety	4.55 (0.75)	.012, .77
	Inclusivity	4.38 (0.85)	.023, .49
	Likelihood to recommend	4.31 (0.94)	.04, .20
Skill development	Critical thinking	4.09 (0.87)	.02, .68
	Problem-solving skill	4.11 (0.89)	.02, .58
	Time management	3.61 (1.09)	.09, .01[c]
	Teamwork	3.49 (1.19)	.03, .33
	Oral communication	3.57 (1.19)	.008, .9
	Written communication	3.61 (1.05)	.13, <.001 Versus RT: *d* = .77, *P* = .029, $\bar{x}$ diff = .67
Functionality and engagement	Mini-PXI total	40.6 (10.4)	.002, .08. Versus nursing: *d* = .69, *P* = .059, diff = 5.5
	Mini-PXI functional	4.09 (0.76)	.03, .33
	Mini-PXI psychosocial	4.11 (0.69)	.04, .13
Prebriefing and debriefing	Prebriefing	4.13 (0.89)	.03, .3
	DES	4.08 (0.76)	.21, .04

[a]All scales rated on a 5-point Likert scale.
[b]$\bar{x}$ = mean; η^2p = partial eta squared; $\bar{x}$ diff = mean difference.
[c]A significant main effect occurred, although post hoc comparisons were only significant between RT and paramedicine (*d* = .87; *P* = .01; $\bar{x}$ diff = .76). No significant post hoc comparisons existed for MLT.

Table 2. Supporting participant quotes for each outcome area

Outcome Area	Quote
Learner satisfaction	"The VSs are now perfectly aligned with content in lab and theory. And the students are so happy because it's a really beautiful opportunity to consolidate their learning of what they're actually learning in lab and theory." – Facilitator
Skill development	"When performing antibody elution in cases with a positive Direct Antiglobulin Test (DAT), I became more mindful of potential pre-analytical and technical errors." – Student
	"It gives faculty the chance to introduce students to different concepts and work through different problems and build critical thinking skills." – Facilitator
Functionality and engagement	"Making it really hands on . . . .bringing the clinical environment into the classroom as much as possible." – Student
Pre-briefing and debriefing experience	"The support I received during the simulation included opportunities to debrief with peers and instructors, which allowed me to reflect on my actions, discuss the rationale behind clinical decisions, and identify areas for improvement. This debriefing process fostered a safe space to share experiences, learn from others, and develop valuable critical thinking skills."
	"I find, with our clinical instructors they have buy in, because these are their students." – Facilitator
Repeated use and impact on clinical practice	"Students saw how some basic things that they're learning now were going to be put together in the future." – Facilitator
	"One time, a patient refused a blood draw, and I recalled back to the simulation and used what I learned there to talk to the patient." – Student
Professional outcomes	"In our university microbiology lab we were not able to go over blood cultures even though it is a sample we are likely to receive during clinal practice. The Virtu-WIL will be my only experience with this sample going into clinical and it is extremely helpful. A lot better than just learning theory." – Student
	"It gave me a realistic outlook on what day-to-day workload is like in each discipline. It prepared me to see all the different professionals come together to work on one patient." – Student

Repeated Use and Impact on Clinical Practice

Four items measured impact on clinical practice: (1) the Virtu-WIL VS scenarios reflected what I see in clinical practice, (2) I learned a lot from the program, (3) I will be able to apply the knowledge and skills in practice, and (4) I now feel more competent and ready for practice. For the 4 questions, MLT mean scores ranged from 4.01 to 4.2 and were comparable with other programs; the 4 other programs' scores ranged from 3.9 to 4.44. No significant differences existed between MLT and any other programs.

Of the 48 students in the MLT program who had completed VS in multiple terms, most strongly agreed (41.7%) or agreed (45.8%) that repeated use enhanced their learning experience in the program. Similarly, most students strongly agreed (29.2%) or agreed (39.6%) that they had the opportunity to apply knowledge and skills obtained from the VS to clinical practice. Qualitative feedback underscored VS's value—for example, offering experience with procedures such as phlebotomy and equipment operation. Practicum supervisors echoed the benefits of the VS on student preparation and performance during clinical placements.

Professional Outcomes

MLT students found the Virtu-WIL program helped them to develop a professional network (81.7% strongly agree or agree), gain experience that would help them in the workplace (86.2% strongly agree or agree), and better prepar to find a job in their field (73.1% strongly agree or agree). The frequency of agreement or strong agreement was comparable with the overall sample, wherein agreement or strong agreement on the 3 items was 79.4%, 92.5%, and 73.6%, respectively. Across programs the outcome was comparable as well, wherein agreement or strong agreement ranged from 71.7% to 91.4%, 85.5% to 100%, and 62.5% to 80% for the 3 items, respectively.

DISCUSSION

The study addressed the 4 research questions. First, the Virtu-WIL program was an innovative and effective WIL model for MLT students. The VSs were a scalable, safe, and accessible preparation for traditional clinical training for MLT students, providing valuable experiential learning. Second, the Virtu-WIL program increased learner readiness for the labor market, with students feeling enhanced readiness for the labor market along with beneficial professional opportunities. Third, MLT students in the Virtu-WIL program reported positive learning and the development of skills relevant for clinical placement, including critical thinking and problem-solving skills. Outcomes for MLT students were consistent with other programs engaged in the Virtu-WIL program, indicating the general benefits of VS. Finally, students who participated in multiple iterations of Virtu-WIL and completed a clinical placement indicated the VS promoted self-reported competency and ability during clinical placement. Comments from practicum supervisors supported these findings.

The study demonstrates good generalizability. While the sample size was moderate, the sample represented multiple schools in multiple Canadian provinces. The broad distribution of participants represents different learning environments and, for those who had clinical experience, practice sites. The positive outcomes, findings from the 4 other professions, and alignment with other research on VS indicate the potential for VS to enhance learning and preparation and potentially address clinical placement constraints.[8,10,11]

VS can be an effective tool to prepare students for clinical practice, as the VS bridges the classroom and skills laboratories into clinical practicum, filling a gap by providing preparation that would not otherwise be available. VS can be an important tool to provide experiential learning before practicum, allowing for the expansion and consolidation of knowledge. By enhancing readiness for practicum, the practicum experience itself can be improved and, potentially, student success can be increased.

As with any simulation activity, it is necessary to follow simulation best practices[16] from development to implementation. Beyond the development of the VS itself, it is important to consider curriculum integration, prebriefing, and debriefing. To be effective, preparation for clinical practice VS should be deliberately integrated into curriculum to enhance skill and knowledge development. VS can be used at various points throughout a student's education, as long as it is used meaningfully. The VS may be used as just-in-time learning before practicum, it may be integrated with course work, or it could be used as spaced recall to consolidate knowledge and skills after a course or learning module is complete. VS may even be used during clinical practicum as preparation for certain activities or for repeated practice.

Proper prebriefing and debriefing are necessary to realize the utility of VS; each VS must be prebriefed and debriefed. Debriefing is an essential aspect of simulation in which a substantial proportion of learning occurs and should be done by an instructor with experience in debriefing and, ideally, with specific training for debriefing.[28] A method to enhance debriefing for VS intended for WIL is to incorporate practicing professionals in the debriefing.[11] Practicing MLTs can increase the credibility of the VS, confirming and supporting that the VS aligns with the realities of practice. As the MLS profession expands, the use of simulation faculty must be trained in simulation pedagogy so that best practices will be used.

Limitations

There are 2 primary limitations to the present study. First, the results are self-reported. Students' perceptions of their level of development in learning, knowledge, skills and competency, and preparation may be biased, as students

may overestimate these abilities in themselves. Second, how debriefing was conducted varied by site—facilitators could choose to conduct debriefing online or in person, vary group size, and use their preferred debriefing model. Guidelines and recommendations were made for debriefing; however, based on considerations of academic freedom, no specific debriefing methods were mandated.

These limitations were partly addressed through interviews conducted with instructors and practicum supervisors. The interviews helped to triangulate findings, identifying consistency in responses between instructors, supervisors, and students. The interviews largely corroborated the findings of the survey and student interviews in the present study and the broader evaluation, providing some validity to the self-reported data.[10,11]

Future Directions

To determine the transfer of learning that occurs using a VS, actual behavior and performance during practicum must be examined. Longitudinal studies can assess the impact of VS on practice behavior and objectively assess competency attainment as well as long-term competency outcomes. Longitudinal assessment should also compare practicum outcomes and licensure examination scores of students who use VS and those who do not. Timing of use and repeated use of VS are variables with high potential impact on outcomes that should also be investigated.

With further assessment and evaluation of objective behavior in practicum, VS may present a viable method for replacing certain aspects of clinical practicum or reducing time in practicum. By replacing or reducing parts of practicum with VS, clinical sites can free up time and provide the opportunity to train more students while decreasing the burden on practicum sites and supervisors. Simulation has been previously shown to be a valid replacement for clinical time. Prior work in nursing has shown that up to 50% of clinical time can be replaced with high-quality simulation,[29] and multiple other professions have demonstrated that clinical time can be replaced with no detriments to competency development.[30]

The lower scores in written skills, oral skills, and teamwork highlight opportunities to tailor VS scenarios to the unique communication and collaborative demands of laboratory settings. While, in part, the lower scores in these areas may be an artifact of the medium used, it is possible to enhance these skills through VS development. For example, VSs may be built with a specific focus on developing these skills—for example, VSs with multiple learners in the same virtual space may be used to enhance communication and teamwork skills.

Finally, VS may be used for continuing professional development (CPD) for practicing MLTs. The ease of accessibility provides the opportunity for interactive and experiential CPD, which may be preferable to other forms of CPD. VS may also present a better option for knowledge and skill retention and development than other forms of CPD.

CONCLUSION

Screen-based VS presents a promising modality to effectively address MLT training challenges. VS is a low-cost option for providing experiential learning with minimal downsides. VSs can be accessed by learners from any location and provides the opportunity for repeated practice, enhancing equity by providing accessible experiential learning opportunities that may not otherwise be available, with computer and internet access as the only requirements. High satisfaction levels and skill gains reported by students indicate strong potential for broader implementation, positioning VS as an integral component of future MLT education.

ACKNOWLEDGEMENTS

Funding for the Virtu-WIL project was provided by the Canadian government and led by Colleges and Institutes Canada. No funding was provided for the present article.

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