

12 Heuristics for Learning Analytics in Simulation-Based Professional Learning

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Abstract

This study aims to develop a set of heuristics tailored for evaluating learning analytics in simulation-based professional learning, focusing on the following research questions: (1) What heuristics are appropriate for evaluating learning analytics in simulation-based professional learning contexts? (2) How can theoretical frameworks and empirical findings be combined in the development of such heuristics? (3) How can expert evaluation inform their refinement and applicability? The study combines a top-down approach, drawing on a theoretical framework for learning experience design, with a bottom-up analysis of empirical findings from prior studies in the context of a design project. An initial set of heuristics was iteratively reviewed and refined in collaboration with experts in user and learning experience design. The outcome is a detailed heuristic framework that supports the evaluation of learning analytics in simulation-based settings and accounts for the technological, pedagogical, and social dimensions of professional learning.

Notes for Practice

- The 12 heuristics support UX and LX designers in evaluating learning analytics systems for simulation-based professional learning.
- The heuristics should be applied during early prototyping to align design decisions with intended learning goals.
- When applying the heuristics, focus on how the system supports learning outcomes, not only on technical usability.
- When developing new heuristics tailored for your domain, combine top-down (theoretical) and bottom-up (empirical) approaches to address both pedagogical and domain-specific requirements.

Keywords: Heuristics, heuristic evaluation, learning experience design, professional learning, simulation-based training, human-centred learning analytics

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1. Introduction

In safety-critical domains such as maritime, healthcare, and aviation education and training, simulators have been established as a key component of professional skills training (Lehtinen, 2023). By enabling learners to engage with complex, dynamic, high-risk scenarios, simulation-based training aims to develop professional competence and expertise. However, designing effective simulation-based learning environments requires balancing technical and pedagogical considerations, particularly when integrating new technologies in current training practices. As digital learning technologies and data-driven educational approaches continue to evolve, multimodal learning analytics (MMLA) are increasingly integrated into simulation-based training in professional domains (Martinez-Maldonado et al., 2023; Schwengel et al., 2024; Yan et al., 2024). Defined as “a set of techniques that can be used to collect multiple sources of data in high frequency (video, logs, audio, gestures, biosensors), synchronize and code the data, and examine learning in realistic, ecologically valid, social, mixed-media learning environments” (Blikstein, 2013, p. 105), MMLA can be used in assessing student knowledge, and discerning student intentions (Blikstein & Worsley, 2016). These advancements hold promise in enhancing feedback, assessment, and adaptive learning, yet their effective implementation requires careful alignment with pedagogical principles (Buckingham Shum et al., 2019) and policy frameworks.

In an ongoing project focused on designing, developing and implementing a learning analytics dashboard (LAD) to provide automated feedback for maritime students engaged in navigation training in high-fidelity simulators, the need for an appropriate benchmark to evaluate the integration of an LAD in simulation-based professional learning became evident. Through an iterative, user-centred design process, a set of learning experience design (LXD) heuristics was developed and iteratively tested to support professional learning in simulation-based training across different domains. This paper outlines our process for creating, designing, and validating these heuristics, beginning with an introduction to the design of MMLA for simulation-based professional learning. To prioritize the needs and perspectives of the instructors and students using the planned MMLA, we have adopted a human-centred approach to learning analytics (LA) (Alfredo et al., 2024), whereby participation and co-design are emphasized throughout the design process.

1.1. Designing MMLA for Simulation-Based Professional Learning

While LA has traditionally been used to analyze students’ engagement with computers, MMLA draws on a variety of sources to analyze collaboration in virtual learning environments (Blikstein & Worsley, 2016). Appropriate data sources vary depending on the educational context and learning objectives. In simulation-based maritime education and training (MET), where our empirical work is situated, student collaboration in high-fidelity navigation simulators is the focus, making multimodal data such as movement, gestures, and speech potentially valuable for data collection (Sellberg & Sharma, 2024). Sellberg and Sharma’s (2024) design ethnography served as a foundation for exploring the design problems associated with automating feedback in the simulator and provided recommendations for MMLA in simulation-based professional learning. To capture collaboration in the simulator, which involves both analogue artifacts and digital tools, multiple technologies are proposed. For example, body sensors tracking actions and movement on the bridge can analyze how students move, revealing important information about teamwork. Eye-tracking, capturing areas of interest and joint visual attention as events unfold in the simulator, is also highlighted as an important source, revealing much about how students direct attention during navigation, how they integrate information from navigational instruments and visual lookout, and how they orient toward each other during teamwork. Speech recognition has potential in analyzing linguistic coordination, verbal coherence, and meaningful contributions to decision-making on the bridge and with external actors, such as Vessel Traffic Services (VTS), and crews on other ships. Each of these elements of student performance is considered central to effective simulator-based MET, where students assume the dual role of student and future professional (Sellberg & Sharma, 2024). MMLA may also encompass log data generated by the hardware and software used, i.e., the simulators (Spikol et al., 2017). However, although these data sources are relevant to the learning context, we encountered problems while attempting to assess their impact on actual learning during simulation. Effective implementation of MMLA requires the correct technology and a focus on appropriate pedagogy.

1.2. Learning Experience Design (LXD) and LXD Heuristics

In professional learning, it is not enough to have technologically advanced simulators—simulation must facilitate an overall learning experience (LX) encompassing “all aspects of a learner’s interaction with: (a) the digital technology/service/space; (b) the pedagogical components, such as course type, learning goals, learning activities, process-based assessment, and learner control; and (c) the social dimension, such as quality of communication forms, collaboration, sociality, social presence, and social interactivity” (Jahnke et al., 2021, p. 431). As such, when employing heuristics during the design process, we must go beyond heuristics that focus solely on usability issues (Nielsen, 1994) and ensure they also address factors such as pedagogical values and learning objectives (Nokelainen, 2006). The need for heuristics appropriate for evaluating MMLA in simulation-based professional training became evident early in the project, as the complexity of the educational setting is not captured by current heuristic frameworks. Table 1 provides an overview of LX in the MET context, thus illustrating the foundations of our heuristic framework.

Table 1. LXD in the Context of MET

LX	MET
Digital technology/service/space	Simulator team training on full-mission bridge; individual on desktop
Pedagogical components	Training students as future professionals who can think and act as seafarers
Social dimensions	Collaboration during team training; communication on the bridge; social norms

To ensure that evaluation is conducted in a way that captures the core concerns of simulator-based professional learning, our heuristics have been developed on the level of the three main dimensions outlined by Jahnke et al. (2020):

- **Socio-Pedagogical Usability:** How social interactions and pedagogical practices are supported by the learning design.
- **Socio-Technical Usability:** How the technical features of the system or tool facilitate or hinder social interactions among users.
- **Technical-Pedagogical Usability:** How well the technical features support the pedagogical objectives of the learning environment.

In developing LXD heuristics, we aim to help ensure that LA for professional learning contexts avoids the common issues highlighted by Jahnke et al. (2020), namely, designs that lack the flexibility needed to accommodate diverse teaching and learning needs and the socio-cultural factors impacting technology use. In the next section, as we provide a background to the study, we outline the core concerns in simulation-based professional learning that shaped the development of our heuristics.

1.3. Heuristic Evaluation: Background and Emerging Approaches

Heuristic evaluation began in human–computer interaction as a method for identifying usability issues in interface design. Developed by Nielsen and Molich in the early 1990s, it provides a structured yet flexible approach to evaluating digital systems without extensive user testing (Nielsen & Molich, 1990). The method relies on a set of usability principles, or heuristics, that a small group of experts use to assess an interface, identifying potential problems based on established design guidelines. While heuristic evaluation is efficient and cost-effective, its effectiveness depends on evaluators’ expertise and their ability to anticipate user challenges.

Over time, the approach has been refined and expanded, influencing broader usability practices and informing the design of interactive systems across various domains. Current approaches expand Nielsen and Molich’s traditional heuristics to address emerging interaction paradigms, including AI-driven interfaces (Banks et al., 2021), immersive virtual environments (Derby & Chaparro, 2022), and conversational agents (Langevin et al., 2021). Additionally, there is growing interest in incorporating user diversity into heuristic evaluation to ensure that assessments account for diverse cognitive, cultural, and accessibility needs (Paddison & Englefield, 2004). Hybrid approaches that combine heuristics with user testing, eye-tracking, or physiological measures offer deeper insights into usability challenges (e.g., Zardari et al., 2021). These developments reflect an ongoing effort to adapt heuristic evaluation to the increasing complexity of digital interactions.

Against this background, this study aims to develop and validate a set of heuristics for assessing LA in simulation-based professional learning, ensuring that such systems capture the complexity of learning experiences by integrating pedagogical, technological, and social dimensions important for LX design. The study is guided by the following research question: How can a user-centred design methodology, combining theoretical guidelines, empirical synthesis, and expert evaluation, inform the development of heuristics for assessing LA systems in simulation-based professional learning environments?

2. Methods

2.1. Development of LXD Heuristics for Simulation-Based Professional Learning

The LXD heuristics developed during this study were informed by several stages in an iterative design process—namely, a design ethnography (Sellberg & Sharma, 2024), focus groups with experienced maritime simulation instructors (Harrington et al., 2024; Harrington & Sellberg, 2024), and a participatory design workshop and subsequent testing of a paper prototype with maritime students regularly engaging in simulation-based professional learning (Harrington et al., 2025). An initial set of LXD heuristics was based upon findings from these studies.

The heuristics were then revised through evaluation, redesign, and validation, resulting in the LXD heuristics presented in this paper. In the results and discussion sections, we explore in more detail how this was achieved through both a bottom-up approach, using findings from previous studies, and a top-down approach, drawing on Jahnke et al. (2021) to pinpoint key dimensions of educational technology. An overview of our research process is shown in Figure 1.

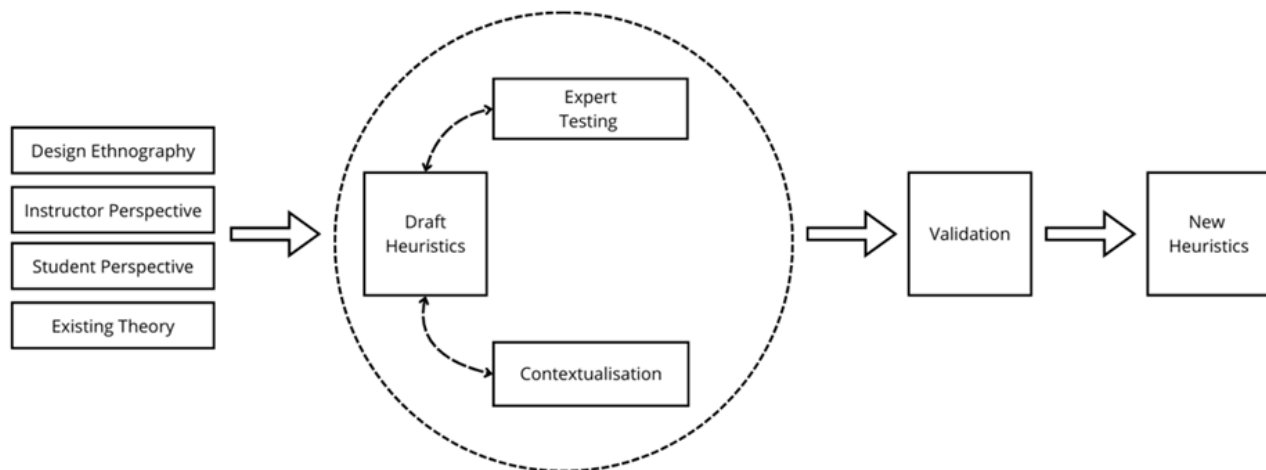


Figure 1. Overview of the Development and Testing Process

2.2. Creating Heuristics Using Previous Empirical Findings

The initial heuristics were situated across three usability dimensions on which the proposed MMLA was to be assessed (see Table 2): namely, technical-pedagogical, socio-technical, and socio-pedagogical, outlined as fundamental dimensions of learning experience design (Jahnke et al., 2020), in addition to ethical dimensions highlighted by simulator instructors (Harrington & Sellberg, 2024).

Table 2. Explaining the Dimensions

<p>Technical-Pedagogical Dimensions</p> <p>Students’ activities on the simulated bridge are distributed among technological instruments and tools, analogue artifacts like the paper chart, and the bridge team members. The instructor uses on a variety of social, material, and technological resources to provide embedded assessments of the students’ performance. To capture the dynamic, multimodal interactions during collaborative training in full-mission simulators, Sellberg and Sharma (2024) propose an MMLA design that uses of the following sensors and technologies. This formed the basis of the concept discussed at the participatory workshops.</p> <ul style="list-style-type: none"> • Body sensors: Capturing the amount of movement, student position in the spatial workspace, distance between students, active posture, and head, hand, and wrist movements. • Eye-tracking: Gaze plots capturing area of interest and joint visual attention during the temporal unfolding of events in the simulated scenario. • Speech recognition: Capturing linguistic coordination, verbal coherence, similarity of within-group speech, equal contribution to the discussion, readability, intentional verbs or using an active voice, and prosodic features of speech.
<p>Socio-Technical Dimensions</p> <p>Delivering feedback in the simulator draws on a multitude of social and material resources. These include deictic hand gestures toward the instruments on the bridge, inscriptions such as nautical paper charts, and verbal descriptions of the situation. Hence, feedback in the full-mission simulator often becomes a demonstration of professional vision¹ and reasoning—highlighting and explaining how to think, perform and act as a professional seafarer.</p>
<p>Socio-Pedagogical Dimensions</p> <p>In simulation-based training, the role-playing character of simulations, i.e., training as if the educational activity is a professional encounter in combination with the maritime instructors’ practices of clarifying corrections, creates shifts between the professional realm and the educational context during training. The recurring movements between these activity contexts: the professional (<i>in-role</i>) and the educational (<i>out-of-role</i>) are important for simulation training to fulfill its pedagogical potential of training students how to think, perform, and act as professionals. For this reason, simulation-based training is an important part of becoming a seafarer, i.e., the process of being socialized into the profession’s norms and standards. Hence, it is important to consider socialization in the design process to create a learning experience tailored to the specific needs of educating students for work in the maritime industry.</p>
<p>Ethical Dimensions</p> <p>During participatory design workshops held separately with instructors (Harrington & Sellberg, 2024) and students (Harrington et al., 2025), ethical concerns around the use of multimodal data collection and visualization were highlighted. These fall into two broad categories: firstly, general privacy and data security, where users were concerned, for example, with GDPR compliance and the potential for multimodal data to reveal health conditions.</p>

2.3. Methods and Key Findings From Empirical Studies Informing the Heuristics

Here, we briefly outline the methods employed in each empirical study informing the heuristics, along with the key findings on which the heuristics are based. The draft heuristics presented to participants during the initial round of expert evaluation were jointly developed by the authors through discussion and reflection on the studies outlined in Table 3.

Table 3. Methods and Findings Informing Draft Heuristics

Focus	Method	Analysis	Key Findings
Appropriate usability dimensions and MMLA design	Design ethnography Video data	Multimodal interaction analysis	Proposed an MMLA design comprising body sensors, eye-tracking, and speech recognition (Sellberg & Sharma, 2024). Proposes assessment using the three dimensions outlined by Jahnke et al. (2020)

¹ Where the term “professional vision” is used, it is as per Goodwin (1994). Specifically, what Gegenfurtner et al. (2020, p. 59) refer to as “knowledge-based reasoning about the noticed information.”

Focus	Method	Analysis	Key Findings
Instructor perspective	Series of focus groups with instructors at three Nordic universities aimed at understanding core concerns around the use of MMLA in the simulator.	Thematic analysis of interview transcripts	Key themes of wants, needs, and resistances to MMLA in the simulator. Any use of LA in this context should: <ul style="list-style-type: none"> • Support instructors’ practice and the fundamental role of their professional expertise • Use the available data from the simulator • Allow for reasoning around student performance, rather than providing an assessment (Harrington & Sellberg, 2024)
Student perspective	Participatory co-design workshop with maritime students at a Swedish university aimed at exploring their perception of MMLA and meaningful automated feedback.	Engeström’s (1987) theory of tensions as an analytic approach	Identified three tensions in the design of effective automated feedback: <ul style="list-style-type: none"> • Students as students vs. students as future professionals • Collaborative reflection vs. personalized feedback • Focus on learning and learners vs. focus on technological innovation (Harrington et al., 2025)

Our approach was guided by prior findings from these studies and a growing recognition of the need to develop an evaluation tool that accounts for the complexity of professional learning in simulated environments. In this context, complexity refers to the layered interplay between technological systems (e.g., simulators, the instructors’ monitoring technologies, learning analytics dashboards), pedagogical design (e.g., learning objectives, instructional intent, feedback strategies), and the social and embodied dimensions of learner activity (e.g., collaboration, tool use, and gaze patterns). Our goal was to ensure that the developed heuristics could support the evaluation of LA systems that are sensitive to these interrelated dimensions.

2.4. Expert Evaluators

An iterative approach to evaluating our LXD heuristics involved think-aloud sessions with a group of experts (Chang & Johnson, 2021). Purposeful sampling (Campbell et al., 2020) was used to recruit these participants to obtain a range of perspectives from experts in specific fields. The expertise of the participants is detailed in Table 4.

Table 4. Experts Participating in Initial Validation

Expert	Formal Education	Affiliation	Expertise
E1	PhD in IT and learning	Academic	Gamification designer, UXD and LXD expert
E2	PhD in human–computer interaction	Academic	UX researcher, diversity and inclusivity expert
E3	PhD in nautical operations	Academic	Domain professional, learning scientist
E4	MSc in cognitive science	Industry	UX designer, usability expert

Each session involved one expert, with one researcher presenting them with the draft heuristics, an explanation of the dimensions, and an overview of the paper prototypes (see Figure 2 for an example). The paper prototypes provided context for both the LA system under development and the empirical findings that inform the heuristics. Each evaluation took approximately 45 minutes and was audio-recorded and transcribed. Participants were also invited to make notes on a paper copy of the heuristics and to send any further comments to the researcher via email. Three of the four participants provided notes in this way.

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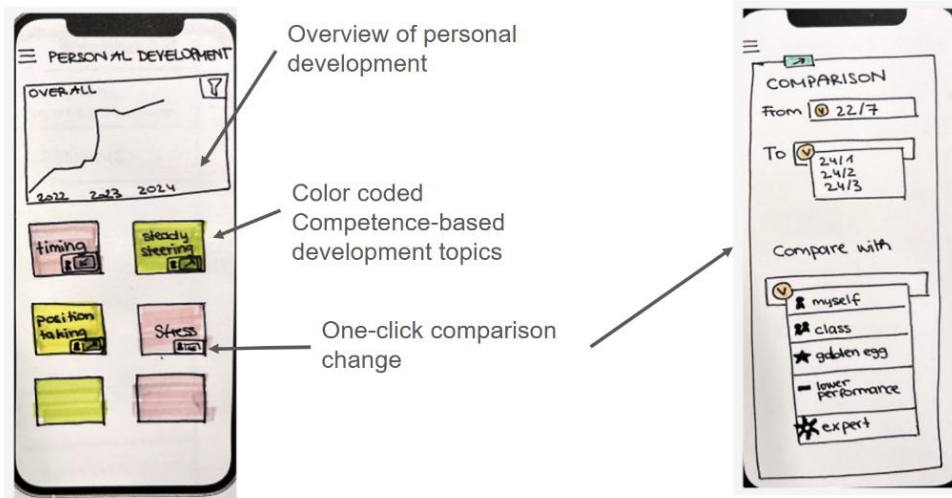


Figure 2. Example of Paper Prototypes

2.5. Initial Validation

During Phase 1 of testing, the draft heuristics (see Table 5) were presented to the experts. Experts were asked to consider how they would apply the heuristics to evaluating an MMLA dashboard for professional learning, highlighting any concerns as well as strengths. Overall, the heuristics were well received, with experts offering feedback to aid the design process. Key findings from this phase included feedback around (1) clarity of language, (2) differentiating between usability and accessibility, and (3) meaningful interpretation of data. Evaluators also provided positive feedback on the strengths of the initial draft, such as its suitability for the MET context and its focus on learning and development.

Table 5. Version 1 of New Heuristics

Dimension	Heuristic
Technical-Pedagogical Usability	Enable real-time automated assessment of individual and group performance
	Support temporal and spatial awareness of unfolding scenarios
	Provide detailed feedback on professional communication and coordination
Socio-Technical Usability	Allow customization of information to align with varying skill levels and learning objectives
	Highlight and explain key visual objects to foster professional vision
	Integrate new technologies seamlessly with existing professional tools
Social-Pedagogical Usability	Ensure accessibility and usability for diverse learners, including those with varying levels of familiarity with the technology
	Facilitate smooth transitions between “in-role” and “out-of-role” activities
	Support socialization into the shared values of the professional community
Ethical	Use professional language, concepts, and discourse to reinforce authenticity
	Use user data as appropriate for specific activities
	Protect privacy of users, including disclosure of health-related information

2.5.1. Clarity of Language

With the exception of E3, who has a background as a maritime professional and a researcher within the learning sciences, each of the expert evaluators highlighted the use of very specific language in some of the draft heuristics. All three highlighted “*professional vision*” and “*in-role and out-of-role*” as being peculiar to specific domains and therefore requiring explanation for those in other fields. While the ease with which E3 understood the terms indicates their suitability for the MET context in which our empirical studies were situated, additional explanations were added to the updated heuristics.

E2 also highlighted a lack of clarity about whether certain heuristics indicated that the student’s or the system’s actions were in focus. For example, “It confused me if it is the system or the people, so if you can underline that the systems do that. So here I thought in-role and out-role people, and then in-role and out-role activities of the system, and here I go to share the same values of the professional community, I start thinking, so the system will observe if they share the same values and, if they don’t, they will give feedback.” E2 went on to recommend that it be stated clearly which elements are intended to be performed by the system and which relate to student actions.

2.5.2. Differentiating Between Usability and Accessibility

While evaluators gave positive feedback on the inclusion of a heuristic focusing on accessibility, E1, E2, and E4 strongly recommended that accessibility and usability be considered separately. This was primarily due to the complexity of both usability and accessibility, and the resulting difficulty in evaluating them under a single heuristic. E2 suggested that accessibility alone could require its own set of heuristics, given the range of cognitive profiles, abilities, and disabilities impacting how students interact with technology and the learning environment.

2.5.3. Meaningful Interpretation of Data

Each evaluator mentioned the importance of presenting data to students in a way that facilitates meaningful interpretation. This echoed a major consideration in developing the heuristics—that learning should be at the core of any educational technology. For example, video, audio, or log data from simulators or MMLA should be accompanied by prompts or similar guidance that directs students on how to consider these in the context of their own learning and development.

2.5.4. Strengths of the LXD Heuristics

Each evaluator reported an overall positive perception of the draft heuristics, recognizing the need for tailored heuristics, and the strengths of using a combination of empirical data and existing theory on LXD and educational technology as the foundation. E3 was particularly positive, stating that the heuristics were closely aligned with the needs of MET and demonstrating a full understanding of the language used and the reasoning behind each heuristic. While this validated the heuristics for use in the given context, it also highlighted the need for evaluation by experts with diverse backgrounds, as the intention is for the heuristics to be applicable beyond the MET domain. Each evaluator also commented on the prototype’s general usability, which will be considered as development progresses; however, discussion of these elements is beyond the scope of this paper.

3. Results

Feedback from the first iteration informed the second version, which was again evaluated by experts. This involved providing experts with an updated version of the heuristics and again requesting their feedback and perspectives. Consequently, the LXD heuristics presented here comprise empirical data on the learning context, both instructor and student perspectives of learning and the use of MMLA within that context, evaluation by appropriate experts, and an iterative process of evaluation and updating.

3.1. Learning Experience Design Heuristics for Simulation-Based Professional Learning

Following two rounds of expert evaluation, we arrived at a set of LXD heuristics that capture the essential elements of MMLA for simulation-based professional learning (see Table 6).

Table 6. 12 Learning Experience Design Heuristics

Dimension	Heuristics for Designing MMLA to Enhance Learning Experience in Simulation-Based Professional Learning
Technical-Pedagogical	<p>1. Enable appropriate assessment of individual and group performance</p> <ul style="list-style-type: none"> • <i>Build in tools that automatically check how well both individuals and groups are performing during simulation (where appropriate)</i> • <i>Give feedback at the right time: offer instant alerts and notifications when appropriate (e.g., for more basic tasks), while saving more detailed feedback for the post-simulation debriefing to avoid interfering with learning</i>

Dimension	Heuristics for Designing MMLA to Enhance Learning Experience in Simulation-Based Professional Learning
	<p>2. Support temporal and spatial awareness of unfolding scenarios</p> <ul style="list-style-type: none"> • <i>Help participants understand what is happening, when, and where during a simulation, and how to act accordingly</i> • <i>Use clear visual, auditory, or haptic cues to help individuals and teams maintain situational awareness, coordinate their actions, and make better decisions in a complex environment</i> <p>3. Provide relevant and actionable feedback on professional communication and coordination</p> <ul style="list-style-type: none"> • <i>Offer clear, practical feedback on how participants speak and work together during tasks</i> • <i>Focus on both verbal and non-verbal cues to help learners improve their clarity, teamwork, and role understanding for more effective collaboration</i> <p>4. Allow customization of information to align with varying skill levels and learning objectives</p> <ul style="list-style-type: none"> • <i>Adjust the amount and type of information displayed based on the learner’s skills level and current learning goals</i> • <i>Make the simulation engaging and appropriately challenging by highlighting only the relevant details, and hiding unnecessary data</i> <p>Recommendation: <i>Use appropriate instructional design models in developing scenarios for simulation</i></p>
Socio-Technical	<p>5. Highlight and explain key visual objects to foster professional vision</p> <ul style="list-style-type: none"> • <i>Identify and draw attention to important visual details within a scenario</i> • <i>Explain why these elements matter so that students learn to spot critical cues and make informed decisions—developing the “professional vision” needed in real-life practice</i> <p>6. Integrate new technologies seamlessly with existing professional tools</p> <ul style="list-style-type: none"> • <i>Ensure that new technology works well with the tools already used in the professional setting and the simulator environment</i> • <i>Smooth integration minimizes disruption, makes the system easier to use, and encourages learners to adopt new systems. It also ensures that the new technology does not negatively impact the learning process</i>
Socio-Pedagogical	<p>7. Facilitate role-playing activities</p> <ul style="list-style-type: none"> • <i>Design training experiences that help learners act as they would in their professional role</i> • <i>Maintain engagement in the professional task</i> <p>8. Support socialization into the shared values of the professional community</p> <ul style="list-style-type: none"> • <i>Create opportunities that encourage learners to adopt the values, norms, and practices of their profession</i> • <i>Promote activities such as teamwork, mentoring, and reflection on professional standards to help learners transition toward becoming part of the community</i> <p>9. Use professional language, concepts, and discourse to reinforce authenticity</p> <ul style="list-style-type: none"> • <i>Incorporate the actual language, ideas, and communication styles used in the field</i> • <i>This authentic approach adds to the realism of the simulation, and better prepares learners for professional interactions</i>
Ethical	<p>10. Use user data as appropriate for specific activities</p> <ul style="list-style-type: none"> • <i>Only use data from users when it is directly needed for a specific training activity</i> • <i>Handle all data responsibly, following all applicable regulations including local, national, and EU laws</i> <p>11. Protect the privacy of users, including disclosure of health-related information</p> <ul style="list-style-type: none"> • <i>Keep all user data—such as sensitive health-related details—secure and private</i> • <i>Ensure that data is managed transparently and ethically to maintain trust and comply with privacy standards</i> <p>12. Ensure accessibility for diverse learners, avoiding exclusion through technology design</p> <ul style="list-style-type: none"> • <i>Design training tools and systems that are easy for students to learn to use, regardless of technical ability</i> • <i>Design both physical tools and learning materials in line with EU accessibility guidelines to enable all students to participate equally and to avoid excluding competent individuals through design choices</i>

4. Discussion

This study set out to develop a set of heuristics tailored for evaluating LA in simulation-based professional learning, guided by three research questions: (1) What heuristics are appropriate for evaluating LA in simulation-based professional learning contexts? (2) How can theoretical frameworks and empirical findings be combined in the development of such heuristics? (3) How can expert evaluation inform their refinement and applicability?

4.1. Heuristics for Evaluation LA in Simulation-Based Professional Learning

Previous studies emphasize the need for heuristics to assess pedagogical, not just technical, usability in learning technologies (Jahnke et al., 2021; Nokelainen, 2006). Jahnke et al. (2020, 2021) provides guidance for considering social, pedagogical, and technical requirements when designing learning experience, discussing the common disconnect between what designers intend users to do, and how users do—or do not—make use of the technology once it has been implemented. As part of a project developing an intelligent learning system with LA for use in simulation-based MET, the core concern of several empirical studies conducted over two years was maintaining and enhancing the core values established in existing simulation practices.

The 12 heuristics presented here have been developed to encompass a range of perspectives from simulator instructors, MET students, and experts across several disciplines (see Table 3 for more information on the experts). Using empirical findings from the overall project, we took an empirically driven, bottom-up approach. Empirical findings highlighted the need for a design that accounts for MET’s complexity, a view reinforced by each study. When discussing the design of LA, the importance of balancing the requirements of various stakeholders is well known (Alfredo et al., 2024), and the complexity of simulator-based professional learning amplifies this. In professional education, students receive instruction through a combination of lecture-based classes, simulator-based training, and apprenticeships. The goal is not just to equip students with practical and theoretical knowledge but to help them into their future profession. The focus is not on rote learning and memorization, but on developing a repertoire of knowledge, skills, and attitudes that are transferable to professional practice (Sellberg et al., 2022). Thus, a traditional approach to LA, using predictive, descriptive, and prescriptive measures, would not capture the core elements of the educational program. While it is, of course, important for students to master basic tasks, the instructional focus during simulation tends more toward non-technical skills such as collaboration, communication, and decision-making, as well as assessing performance holistically. At a surface level, multimodal data sources such as eye-tracking, body sensors, and speech recognition have potential but also present shortcomings and new risks.

4.2. Bottom-Up: Previous Empirical Findings

In bringing together the findings from previous empirical studies (Harrington et al., 2024, 2025; Harrington & Sellberg, 2024; Sellberg & Sharma, 2024), the heuristics presented here are informed by perspectives of experienced maritime simulator instructors and maritime students with both simulator-based and ship-based experience. All participants spoke about their own experiences and how the proposed MMLA could work with and impact their current teaching and learning practices. A core concern among instructors was the role of their own professional intuition in monitoring and assessing student performance in the simulator. During team-based training, there is rarely one absolute correct approach to the simulated scenario; rather, students must demonstrate that they can perform safely, in accordance with relevant regulations, and as part of a functioning bridge team. This means that the ability to reason about and reflect on decisions made, and to learn from them for future reference, is often emphasized.

Table 7. Examples of Empirical Findings Informing Heuristics

Heuristic	Instructor Perspective	Student Perspective
3. Provide relevant and actionable feedback on professional communication and coordination	Instructors highlight the team-based nature of the training: “This type of training is more like how do we work together as a team. . . . and I suppose that would be the core principle of what you train this for. So, it’s more like there is a very, very, distinguished difference between measuring the individual competence of a person, and the competence of a team.”	Students value individual and relevant feedback, but do not always recognize reflective discussion or instruction as feedback they can relate to and learn from. They highlight that instructors usually give “a general sort of feedback that applies to everyone in the group, but that might mean not actually learning anything yourself because it doesn’t apply to your specific problems.”

Heuristic	Instructor Perspective	Student Perspective
<p>6. Integrate new technologies seamlessly with existing professional tools</p>	<p>The instructor’s room already contains numerous data sources to consider during simulations. Instructors expressed concern about adding to this load, both in terms of the sheer volume of data to track—“I already have about . . . how many screens do I have to observe? . . . And then I have an additional screen, so I have plenty of data and I’m just . . . bloody hell”—and the potential benefits of adding new technology: “I’m sitting here monitoring on a ship handling exercise and not sure what the dashboard could give me. I have the CCTV. I have the view, I can see all the movement of the vessel, so I have no idea what else to add, actually.”</p>	<p>Students recognized the importance of not introducing LA that interrupted them during the simulation, preferring it to take the format of a mobile application that could be referred to during revision or to reflect upon their learning progress over time.</p>
<p>7. Facilitate smooth transitions between “in-role” and “out-of-role” activities</p>	<p>Instructors’ current practice centres on facilitating students’ development as reflective (future) professionals. Emphasis is placed on designing scenarios that encourage students to switch between professional and student roles, as appropriate. Instructors tend to favour a “data collection system” that supports their work and makes better use of technology already available to them (e.g., simulator log data).</p>	<p>Balancing the ability to take on their simulated role as a professional—“I become the captain . . . I’m not afraid to give orders . . . and it will be more my boat”—with the ability to reflect during debriefing discussions and learn as a student.</p>

Instructors taking part in our focus groups spoke of the “grey areas” in assessment, where they may have expected students to take one course of action, whereas students’ explanations for a different decision could render a seemingly incorrect response acceptable. Instructors also spoke of providing feedback at the correct time—which varies from bridge to bridge, even during the same simulator session—and at a level appropriate for the students in question—again, a factor which varies individually. Observing simulations from the instructors’ control room allows instructors to adapt scenarios to adjust difficulty appropriately or to draw students’ attention to an important component of the exercise they may be overlooking. For example, the courses of other vessels can be adjusted to affect the students’ vessel, requiring them to take action. This guidance and expert judgment, based on professional experience, is an essential component in nurturing students in their roles as future professionals; hence, instructors express significant concern about any automated assessment or the use of MMLA to monitor student performance. In brief, instructors supported a potential LAD that made better use of the extensive data already produced by the simulator, facilitating its use to support their teaching practices. The value of MMLA in specific circumstances is recognized, but outweighed by the potential impact on learning.

Conversely, students were broadly in support of MMLA, particularly in the context of comparisons, for example, of gaze patterns during simulation. Students were enthusiastic about the potential to compare their own data over time to see how they were progressing, and also welcomed the opportunity to compare themselves with particularly strong “golden egg” students. However, despite this enthusiasm, students shared instructors’ concerns around the value of introducing MMLA during the simulation itself. While students were generally more in favour than instructors, they echoed concerns around issues such as real-time use of an LAD impacting the immersive simulated experience. Instead, they preferred to receive on-demand access to data and visualizations via a mobile application. Students’ perspective tended toward valuing this data for its ability to enable revisiting and reflecting on feedback to improve future performance. The use of data produced by the simulator was also emphasized by students, with potential MMLA viewed positively but not as essential.

4.3. Top-Down: Existing LXD and Educational Technology Literature

As mentioned earlier, previous work by Jahnke et al. (2020, 2021) was influential in shaping our approach to ensure that we encompassed the important dimensions of educational technology. This is shown in our use of social, technical, and pedagogical dimensions, as well as in elements of the heuristics that go beyond those directly reflecting our previous findings. For example, our first heuristic, *which enables appropriate assessment of individual and group performance*, includes a reference to automatic performance checks, although this was opposed by both instructor and student groups. This is in recognition of the importance of selecting measures appropriate to a specific technology within a specific educational context. Although real-time and automatic assessment are not appropriate in our MET context, they should not be dismissed outright for other contexts. For new educational technology to be adopted by users, it must reflect the socio-cultural environment in which learning occurs and be flexible enough to adapt to various and evolving teaching and learning requirements (Jahnke et al., 2020). The heuristic framework has deliberately been formulated to offer the flexibility needed to adapt to the variety of complex situations that may be encountered during simulator-based training—it is intended to be used as a type of mnemonic in prompting the evaluator to think carefully and critically about features of the LA system, and how they may complement or hinder best practices.

4.4. Expert Evaluation

The expert evaluation of our draft heuristics yielded valuable insights, not least of which was their highlighting of certain language which seemed intuitive to us as researchers familiar with the underlying context. This further demonstrated the importance of co-creation and the active involvement of relevant stakeholders throughout the design process—in this case, the experts who would be tasked with evaluating the usability of the system under development. As we anticipate the use of heuristics across different areas of simulation-based professional training, it is important that they not only reflect the key components of evaluation but also do so in a way that is intuitive to evaluators. It also served as a useful reminder that, although we placed utmost importance on the instructors' and students' perspectives, we were still immersed in the context, thus reemphasizing the need for a heuristic framework suitable for the purpose. Accordingly, we recommend that the heuristics are used by experts external to the process when evaluating a potential MMLA system, thereby avoiding the inadvertent biases of those close to the development process and enabling an in-depth, meaningful consideration of each element's strengths and areas for improvement. Of course, the experts do need some level of familiarity and domain knowledge to identify potential challenges and usability issues.

4.5. Limitations of Our Approach

While we are confident in the value of the heuristic framework presented in this paper, we acknowledge several limitations. First, the heuristics were developed with input from a relatively small group of experts and only two iterations. Additional rounds of evaluation could further refine the heuristics and possibly strengthen their applicability. Second, the heuristics do not address potential technical issues related to system functionality or usability. Such aspects should be evaluated using established heuristics, such as those developed by Nielsen (1994). Our work is intended to complement, rather than replace, existing heuristic evaluation approaches by focusing specifically on the complexities of learning and collaboration in simulated environments. Finally, as the proposed MMLA system is still under development, it has not yet been possible to evaluate the heuristics on a fully functional implementation. Our application of the framework has been limited to early-stage prototypes, and further testing in a simulator setting with an interactive prototype is needed to assess its usability for professional training.

5. Conclusion

In this paper, we have outlined and discussed the methodological rationale for developing new heuristics focused on learning experience design (LXD) in simulation-based professional learning. Our contribution lies not only in identifying the limitations of existing heuristic frameworks for evaluating LA in such contexts, but also in proposing a systematic approach to address this gap. The 12 heuristics developed and validated in this study synthesize empirical findings from several studies on human-centred design of MMLA for simulation-based professional learning, along with established prior research on LXD and heuristics that consider its social, technical, and pedagogical elements. In this context, the emphasis is on cultivating students as reflective practitioners and on transferring that disposition to professional practice, which requires a specific approach to MMLA. While automated elements of LA may be appropriate for routine parts of training, much of the value of simulation-based training comes from instructors' professional experience and expertise, meaning that any effective MMLA must support their work and the development of students into competent professionals.

Declaration of Conflicting Interest

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