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REVIEW ARTICLE

Motor learning theory can benefit seafarers

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Abstract
Safe and effective navigation of the world's oceans and waterways relies on maritime education and training. This involves the learning of motor, procedural and verbal components of complex skills. Motor learning theory evaluates training variables, such as instructions, feedback and scheduling, to determine best practices for long-term retention of such skills. Motor learning theory has come a long way from focusing primarily on underlying cognitive processes to now including individual and contextual characteristics in making predictions about instructional strategies and their role in performance and learning. A remaining challenge in applying recent motor learning theory to maritime education and training is a lack of empirical testing of complex vocational skills, such as simulation scenarios, with delayed retention and transfer tests. Incorporating theory-based understanding of beneficial instructional practices, through both cognitive approaches and those considering context and environment, task complexity and learner characteristics is a fruitful way forward in advancing maritime education and training.

1. Introduction

Training in maritime and other industries involves learning a combination of hands-on skills and procedural and verbal knowledge (Sanli and Carnahan, 2018). Training in the maritime domain can include large-scale simulations, such as using a fully equipped bridge simulator to practice navigational skills or extinguishing a live fire in a simulated ship's galley (IMO, 2011; Sanli and Carnahan, 2018; Kim et al., 2021). Training also includes smaller-scale simulations expected to transfer on the job, such as practicing use of the Global Maritime Distress and Safety System on a standalone unit or practicing the tying of knots in a classroom (IMO, 2011; Kim et al., 2021). Hands-on training opportunities at sea, such as learning the operation of an anchor winch for the first time or the various prescribed safety drills to maintain earlier training, are also important (Martes, 2020). This training can require significant human, physical and time resources. To be both effective and efficient, planning instructional time is of benefit to maritime education and training institutions and their learners.

Maritime education and training, through the Seafarer's Training, Certification and Watchkeeping (STCW) Code, has placed an emphasis on skill-based requirements for competency, even specifying how competence is to be demonstrated (IMO, 2011; Manuel, 2017). Recently, the International Association of Maritime Universities and the Nippon Foundation published a *Global Maritime Professional Body of Knowledge* document which considered the knowledge, skills and attitudes required of future global maritime professionals, including skills in the psychomotor domain (2019). The *Body of Knowledge* document intentionally does not address ways in which to achieve the learning outcomes it describes. It does, however, in the *International Association of Maritime Universities Basic Agreement* (IAMU, 2019, p. 1), describe a shared understanding among maritime education and training institutions that effective training is a result of scientific development.

The focus on competency-based training and measurement of hands-on skills and procedural and verbal knowledge in maritime education and training (Balaji and Venkadasalam, 2017; Ghosh et al., 2017; Martes, 2020) suggests a clear synergy between fundamental motor learning research and evidence-based practice in training seafarers (Sanli and Carnahan, 2018). A long history of motor learning theory and accompanying empirical work has addressed questions of how to organise training sessions effectively and efficiently for learning hands-on (motor) skills (Guadagnoli and Lee, 2004; Wulf and Lewthwaite, 2016; Sanli and Carnahan, 2018; Lee and Carnahan, 2021; Hodges and Lohse, 2022).

Recently, there has been some urgency expressed in the need to understand the effects of changes due to social and technological influencers (e.g. changing social norms around education, autonomous shipping) in the maritime industry, and the need to use that understanding to facilitate optimal education and training opportunities in the sector (Manuel, 2017; Sellberg et al., 2018; IAMU, 2019; Bolmsten et al., 2021). Likewise, there have been calls for social context and other environmental factors to be better represented in contemporary motor learning theory (Wulf and Lewthwaite, 2016; Karlinsky and Hodges, 2018a, 2018b; Hodges and Lohse, 2022; Kaefer and Chiviacowsky, 2022).

This paper first highlights well-established motor learning concepts, supported by empirical work, that are relevant to teaching hands-on skills in the maritime domain. Next, it introduces more recent frameworks and models of motor learning which focus on applying research to practical training contexts. These frameworks and models have potential to influence maritime education and training. The paper also discusses how frameworks and models can be further developed using recent and future research in the maritime education and training domain. This paper begins to address the gaps between motor learning theory, laboratory-based empirical work, and an education and training context where demonstration of motor skill competence is essential for seafarer certification. Examples, mostly drawn from the STCW Code, are given throughout to help link theoretical and practical concepts to current training.

2. Motor practice, performance and learning

Motor skills can be defined as the processes involved in producing a goal-oriented action or learned task using one or more body parts (Gallahue et al., 2012, p. 14) or as coordinated, accurate, perceptual motor performance (Anson et al., 2005). Motor performance is the act of doing the skill in a way that can be directly observed and the outcome measured (Gallahue et al., 2012, p. 15). In contrast, motor learning refers to the underlying processes resulting in change in performance of the skill over time due to experience and practice (Schmidt and Lee, 2011, p. 327). Motor learning is inferred through motor performance under specific conditions, namely after a period of non-practice. The distinction between performance and learning is an important one for maritime education and training for several reasons. Retaining the ability to perform important skills over time, and in the intended context, requires learning. To judge whether sufficient learning has occurred, a test of the skills after a period of non-practice is needed. This allows for dissipation of temporary effects of practice conditions, such as fatigue and motivation. It is also important to acknowledge that some instructional conditions have been shown to benefit temporary performance during training, but hinder learning and later performance (Magill, 1994; Kantak and Winstein, 2012; Sanli and Carnahan, 2018; Lee and Carnahan, 2021).

Learning is a result of practice, and not all practice is created equally. Ericsson et al. (1993) have distilled conditions of practice in a given domain that are required to improve performance. This collection of practice conditions is called deliberate practice (Ericsson et al., 1993; Ericsson, 2008). In deliberate practice, learners, who are motivated to improve, work on a task with a well-defined goal and are provided both feedback and lots of opportunities for repetition (Ericsson et al., 1993; Ericsson, 2008). Once learners develop a basic level of reliable achievement, they need new challenges with these conditions in place to improve performance (Ericsson, 2008). Deliberate practice is clearly relevant to maritime education and training and its set of specific skills that require practice and progressive levels

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Discrete	Serial	Continuous
Pressing emergency stop button	Rigging and unrigging pilot ladders	Steering survival craft
Catching a line	Using a fire extinguisher	Walking on patrols
Opening a hatch	Reassembling machinery	Rowing
Throwing a lifebuoy	Fuel transfer operations	Maintaining vessel position with manual controls

Figure 1. *Examples of maritime education and training skills placed in a timing-in-task-execution continuum.*

Closed		Open
Pressing emergency stop button	Rigging and unrigging pilot ladders	Steering survival craft
Routine radio communications	Fire drill duties	Navigating in high traffic areas
Splicing rope	Fuel transfer operations	Deck work in poor weather
Testing safety equipment	Routine crane operations	Retrieving a person overboard

Figure 2. *Examples of classification along the continuum of consistency versus adaptability of the environment.*

of achievement (IMO, 2011; Manuel, 2017). Note that the principles of deliberate practice are relevant to training in and with simulators as well as on the job and in other instructional contexts (Ericsson, 2008).

2.1. Motor skill examples and classifications

Many examples of specific motor skills can be drawn from the *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers* (see Figures 1–3) (IMO, 2011).

A given motor skill and the environment it is performed in can be classified in different ways to better describe their characteristics. A continuum referring to the role of timing in task execution (discrete vs. serial vs. continuous) can help dictate the ways the task itself is practiced as well as how the training session and feedback provided to the learner are organised (Schmidt and Lee, 2019, p. 9). A discrete skill has a clear beginning and end to it, such as connecting a hose. A serial skill involves multiple discrete tasks performed in a specific order, such as reassembling equipment. A continuous skill has no clear beginning and end, but is instead stopped arbitrarily, such as steering a ship. See Figure 1 for examples of each classification.

A continuum referring to consistency versus adaptability of the environment where the skill is performed (closed vs. open) can help choose the appropriate training environment or progression through different training contexts (Schmidt and Lee, 2019, p. 8). A closed environment is relatively consistent, wherein a task is performed the same way each time, with little need for adaptation. For example, routine radio communications from the bridge might be considered a relatively closed skill. An open skill takes place in a changing and relatively unpredictable environment, and therefore adaptation is important. An example of a relatively open skill would be steering survival craft. Many skills, such as using a fire extinguisher, might be classified somewhere in the middle. See Figure 2 for examples of classification along the continuum of consistency versus adaptability of the environment.

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			Action Requirements			
			No Body Transport		Body Transport	
			No Object Manipulation	Object Manipulation	No Object Manipulation	Object Manipulation
Environmental Demands	Stationary Regulatory Conditions	No Intertrial Variability	Standing on a flat surface to view a gauge	Tightening a bolt with a wrench	Climbing a ladder	Using a flashlight while walking
		Intertrial Variability	Using crane, winch, and hoist signals	Tying more than one type of knot	Avoiding rope while walking on deck	Carrying supplies to the galley
	In Motion Regulatory Conditions	No Intertrial Variability	Viewing charts in changing lighting	Donning an immersion suit in poor weather	Walking a hallway with changing lighting	Rolling up firehose in poor weather
		Intertrial Variability	Standing on deck in poor weather	Radio communication in noisy engine room	Climbing a staircase in poor weather	Advancing while operating fire nozzle in smoke

Figure 3. *Examples of tasks of varying complexity form a maritime context organised using Gentile's taxonomy. The light shading represents the least complex tasks, and the dark shading represents the most complex tasks.*

Much of the skill acquisition research from a cognitive perspective has been situated in these one-dimensional classification systems. Gentile (1972, 2000) took a two-dimensional approach to classifying motor skills, and this taxonomy has been used in many practical contexts in an attempt to better capture the complexity of the types of skills found outside of the laboratory (e.g. Koon et al., 2017; Rudd et al., 2019; Espy et al., 2021). Gentile's taxonomy considers action requirements of whether body transport and whether object manipulation is involved in a task. Inclusion of each of these action requirements increases the complexity of the task. The taxonomy also considers the amount of variability between attempts of a given task with more variability increasing complexity. The environmental context is also considered, with an environmental context in motion being more complex than one that is stationary, because a performer must then adjust movements to conform to the environment. The combination of these considerations results in 16 different skill categories used for classification (Edwards, 2011, p. 60). Figure 3 presents some examples from maritime contexts.

Koon et al. (2017) used Gentile's taxonomy to help distinguish simpler and more complex physical activities, and their definitions of motoric and cognitive complexity are useful to keep in mind as we discuss motor learning theory. They define motoric complexity as activities that include coordination of multiple limbs, balance and stability requirements, movement speed and flexibility, as well as variability between trials and object manipulation (p. 22). They define cognitive complexity as requiring high levels of anticipation, reaction and variability, as well as novel experiences and opportunities for learning (Koon et al., 2017, p. 23).

The role of simulators for training and evaluation in maritime education and training is at the forefront of research in the maritime domain (Sellberg et al., 2018; Kim et al., 2021), and yet readers should consider a broad definition of simulation that encompasses exercises in full-scale bridge simulators, cardiopulmonary resuscitation using simple manakins, and donning an immersion suit with the lights out. Simulations will include differing configurations of open and closed, discrete, serial and continuous tasks and many of the skill categories from Gentile's taxonomy.

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3. Motor learning theory and its relevance to maritime education and training

Lee and Carnahan (2021) underscore how both theoretical and applied motor learning research are complementary in addressing societal concerns, such as worker training and retraining. Over many decades, motor learning research has addressed questions of how to optimise scheduling, feedback and instructions in training to reach and maintain competency over time (e.g. Salmoni et al., 1984; Magill and Hall, 1990; Ste-Marie et al., 2012). This is accomplished by testing hypotheses about these instructional factors through repeated trials in one or more practice sessions before measuring performance in retention and transfer tests to infer learning (Lee and Carnahan, 2021). These tests of retention and transfer are completed after a period where practice does not take place (retention interval) to allow temporary influences of performance during training, such as fatigue and motivation, to fade and allow relatively permanent changes in performance due to practice to be inferred (Sanli and Carnahan, 2018). Most motor learning theories and frameworks in the information processing tradition have been developed based on this type of empirical work. Anson et al. (2005) describe these designs as emerging from experimental and cognitive psychology, and Sellberg et al. (2018) describe these research designs as a classic cognitive approach when comparing them to situated/sociocultural perspectives (p. 253).

3.1. Earlier cognitive approaches and principles for consideration in maritime education and training

Prominent motor learning theoretical approaches and theory throughout the 1970s (e.g. Closed-Loop Theory, Adams, 1971; Schema Theory, Schmidt, 1975) incorporated an information-processing approach (Anson et al., 2005). Experiments testing predictions of these theories throughout the following decades were primarily interested in determining the cognitive processes underlying motor performance and learning and used relatively simple tasks to do so (see Christina, 2017; Lee and Carnahan, 2021 for informative discussions of this work and its impact on current research). Much of the empirical work and principles resulting from testing of these theoretical approaches is worth considering when designing training sessions for hands-on skills in maritime education and training. The best use of demonstration, instructions and other guidance for providing instruction and feedback prior to and during practice is important for effective and efficient training (Sanli and Carnahan, 2018; Sellberg et al., 2018).

One area of maritime education and training that can be easily controlled by an instructor is the provision of feedback to learners. The motor learning research discusses augmented feedback as a source of information for the learner (Guadagnoli and Lee, 2004). Augmented feedback is additional information, provided from an external source (instructor, computer, etc.) to a learner about the movement patterns or outcomes of their skill performance. Differences in the timing, modality and content when providing feedback for skill learning and performance have been examined. The cognitive approach emphasises the importance of information about error for learning. Experimentation found that while frequent feedback can improve performance during training, too much can interfere with the learner's interpretation of their own inherent feedback and can deter learning (Salmoni et al., 1984; Magill, 1994; Lee and Carnahan, 2021; Petancevski et al., 2022). Augmented feedback can be beneficial for learning if intrinsic feedback is unavailable for a skill (e.g. vision is blocked while manipulating hand tools) (Magill, 1994; Petancevski et al., 2022). A recent review cautions that we have yet to fully understand the impact of reduced feedback frequency on learning (McKay et al., 2022). Summarising feedback after a series of attempts, instead of providing feedback for a single trial, can also be effective, whether presented visually (e.g. time taken to complete the attempts in a graph) or as a mathematical average. The optimal frequency of augmented feedback and an ideal number of attempts to include in a summary seems to depend on the complexity of the skill being practiced (Magill, 1994; Schmidt et al., 2019; Petancevski et al., 2022, p. 359–360).

Another aspect of practicing skills in maritime education and training that instructors can control is the order and timing of practice attempts within and between training sessions. The empirical work in motor learning relies on the assumption that learners will complete multiple attempts at performing a

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skill. Spacing out practice within a given training session has been well studied. For discrete motor skills, such as opening a valve, practice attempts with relatively short breaks (measured in milliseconds) and relatively long breaks (measured in seconds or minutes) between attempts have had a similar influence on the learning of skills. For continuous skills, such as steering, longer breaks between attempts have been shown to benefit both short-term performance and learning. There is also evidence that spacing out training sessions over time (e.g. across a term) can benefit the learning of hands-on skills (Lee and Genovese, 1989; Shea et al., 2000).

Especially for open skills, it will greatly benefit learners to create new variations (large and small) of a skill. For example, performing a task with a larger or smaller tool, with greater or lesser force or in a different physical orientation from one ship to another may be required. Research shows that practicing multiple variations of a task is more beneficial than practicing with a single variation for learning. This is despite performance typically being better when practicing only a single variation (Schmidt, 1975; Lee et al., 1985; Shea and Kohl, 1990). Whether in the laboratory, classroom or at sea, novices are expected to learn multiple skills simultaneously. A large body of evidence indicates that interleaving to-be-learned tasks within a training session can benefit learning, though again at the cost of short-term performance (Shea and Morgan, 1979; Magill and Hall, 1990). The cognitive approach provides some explanations for why interleaving tasks benefit the learning of many tasks. The two most prominent explanations are (1) it allows for the different tasks to be compared and creates meaning beneficial to learning (Shea and Zimny, 1983), and (2) it allows for forgetting of task-specific solutions between attempts, allowing for repeated practice in creating solutions, leading to better learning than single-solution repetitions (Lee and Magill, 1983). Like the research findings examining the provision of augmented feedback, the complexity of the to-be-learned task seems to play a role in determining how effective variable and interleaved schedules are for learning (Guadagnoli and Lee, 2004).

3.2. Learner, task and context characteristics for consideration in maritime education and training

While some earlier motor learning theories favoured the study of cognitive processes underlying the learning of psychomotor skills, more recent theoretical approaches in the information processing tradition (building on this previous work) and those from a constraints-based approach have begun to take into consideration other aspects of the learning context as well. This is a significant advancement when we consider how complex some of the skills and the contexts in which they are performed can be in maritime education and training. Consider all that is involved in a practical exercise for a navigation course (Sellberg et al., 2018). The motor and cognitive aspects of many navigational tasks would be challenging to equate to learning to putt in golf, press keys or throw a rugby ball (the skills on which the previously discussed theory is based). Often, principles developed from studying simple motor skills do not generalise to more complex ones, especially in training course contexts (Wulf and Shea, 2002; Sanli and Carnahan, 2018). Another consideration is the prescriptive nature of many required courses in the maritime context (e.g. IMO model courses), which differs from sport or laboratory practice design.

The following two sections present two different theoretical perspectives that lead to many practical recommendations in common. Both focus on addressing the complexity of tasks and environments and appropriately designing training sessions for specific learners.

4. The challenge point framework and the extended challenge-based framework

The Challenge Point Framework (Guadagnoli and Lee, 2004) attempts to address the influence of challenge (or task difficulty) on choosing the most appropriate training context (scheduling, feedback, instructions) for learning. Guadagnoli and Lee (2004) account for both the inherent (nominal) difficulty of a task to be learned and the difficulty relative to the experience of the learner and the environment (functional) in determining effective training organisation and feedback. The Challenge Point Framework was developed to consider empirical work (including the work discussed in the previous section) addressing practice organisation and feedback, espousing the importance of new and interpretable

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information for learning. Opportunities in a practice context to acquire this new information are equated to challenges, which can both be detrimental to short-term performance and beneficial to long-term learning. Also integral to the framework is that the amount of information that a learner interprets (and the amount optimal for learning) depends on the individual's current performance level and experience (Guadagnoli and Lee, 2004). No learning can occur if the practice context lacks information, or there is too much information to interpret for a given learner and context. As discussed in previous sections, feedback (when it reduces uncertainty) can provide information and limit problem-solving and information when provided too often. Differing practice schedules can result in greater problem-solving and information than others (variable and/or interleaved vs. repetitive).

In terms of organising training sessions in maritime education and training, if we again consider practical exercises in a navigation course, the nominal task difficulty could be altered in several ways, such as increasing information and challenge through navigation in shallow water or high traffic (Sellberg et al., 2018). Likewise, functional task difficulty (and information/challenge) could be altered by the composition of the team, the number of times a scenario has been practiced, and the years and level of training completed by the learners (Sanli and Carnahan, 2018; Sanli et al., 2019). As trainees gain experience with the simulator, the types of decision-making required, the scenario-types, and the functional difficulty of a given scenario will decrease. At this point, the nominal difficulty can be increased to maintain the ideal amount of learning challenges. Starting novices in a high-traffic, poor weather scenario will likely result in too much information to interpret for optimal learning, whereas starting experienced mariners in a simple scenario of maintaining a given heading will likely result in too little challenge for learning.

The results of a recent simulator study that trained students under progressive complex ocean currents at two levels of complexity while docking appear to support the challenge point framework from maritime education and training research. Hjelmervik et al. (2018) found that students who progressed through increasingly complex ocean current contexts, starting with less complex conditions during training, performed better on the final test trial than those who progressed from initially more complicated conditions. The authors conclude that introducing too much complexity too early can be detrimental to learning. However, it is important to note that the retention interval was not described, and these results may be more indicative of performance than learning.

While this framework can be useful for understanding changes in task difficulty as well as the relationship with learner experience, there are challenges in using it to prescribe specific training to target a specific optimal challenge point.

The Challenge Point Framework (Guadagnoli and Lee, 2004) has recently been expanded to increase accessibility of the theory to practice in the applied sports domain (Hodges and Lohse, 2022). This helps apply the understanding of the optimal challenge to maritime education and training, as it brings the concepts into a formal training environment. Hodges and Lohse (2022) consider the role of challenge in the motivation of the learner, as well as the similarity between practice and target context (specificity), alongside the idea that practice goals can differ within a sports context.

The Extended Challenge-Based Framework (Hodges and Lohse, 2022) states that challenges can benefit learning and have a motivational cost. Increasing functional task difficulty to optimise challenge can prompt errors in performance. These errors can provide useful information (Sanli and Lee, 2014) and engage the learner (Clark et al., 2009), but they also have the potential to degrade feelings of competence (Deci and Ryan, 2008) and lessen persistence (Hodges and Lohse, 2022). Hodges and Lohse (2022) recommend using feedback (provide feedback after good attempts; allow learners to choose when to request feedback) to offset motivational issues related to errors.

The similarities between practice and performance contexts determine which challenges during training are desirable. To maximise transfer from training to independent performance at sea, the practice context should be as similar as possible to the performance conditions expected at sea. A good example of this is well-designed, realistic, on-board drills. While physical and environmental similarity are important, the similarity of cognitive, sensory and affective components of skills can be even more so (Hodges and Lohse, 2022). This concept is most obviously illustrated in the maritime education and training literature through the many studies of maritime simulator fidelity (see De Oliveira et al., 2022, for a recent review). Both physical and psychological (termed functional by Wahl, 2020; De Oliveira et al., 2022) fidelity are discussed in detail in the maritime education and training literature. For example, environmental details, such as use of a motion platform, including reflection and sunlight effects, and specific current types, have been recommended. Recommended functional details include progressing from simple to more complex conditions, the role of instructors in providing feedback and variability in scenarios (Wahl, 2020; De Oliveira et al., 2022). De Oliveira et al. (2022) caution that though numerous research papers espouse the benefits of high-fidelity simulators, objective evidence, especially for measures of learning, is rare.

Like in the sports context, discussed by Hodges and Lohse (2022), maritime education and training incorporate distinct training goals at different times in a seafarer's career and for competence in various skills. The practice goals can differ based on emphases on learning, transfer or maintenance of skills. Hodges and Lohse (2022) use these three training emphases to prescribe both the level of functional difficulty and the amount of specificity to competition in sports. To apply this to maritime education and training, we can consider functional task difficulty and specificity to expectations of independent performance at sea. Poorly designed training has a low level of functional task difficulty and low specificity to performance on the job. For example, unchallenging onboard drills, where details such as attaching hoses or having zippers on immersion suits done up correctly are ignored. Training designed to maximise learning involves medium specificity and medium to medium-high functional task difficulty.

An example of this could be practicing the boarding of a life raft in a weather-controlled pool or sheltered harbour while wearing an immersion suit. To maximise transfer to on-the-job performance, high specificity and functional difficulty are best. For example, complex scenarios in a motion-capable simulator could meet these requirements. For maintenance of skills, medium to high specificity is required, but functional task difficulty can be lower (Hodges and Lohse, 2022). One example of this could be well-designed and frequently practiced on-board drills.

5. Constraints-led approach

The Constraints-Led Approach is rooted in ecological theories that focus on the interaction of individual, task and environmental constraints, leading a learner to self-organise movement solutions (Renshaw and Chow, 2019). Renshaw and Chow (2019) put forth a practical framework using the Constraints-Led Approach to guide practitioners (specifically in physical education and sport) in planning training. They suggest first understanding the skill level of the learners, distinguishing between the early (searching and exploring) phase where basic coordination patterns with others and the environment are developed, and the later adaptation phase focused on optimising performance by exploiting the individual–environment system and more attuned use of information. Next, they describe a process of the practitioner providing constraints that direct learners to desired outcomes without being overly prescriptive. These constraints can be in the form of changing the equipment or the environment. Revisiting practical navigation exercises in a simulator, you might limit the number of active displays while still providing more than necessary to complete a scenario, or you may strategically place other vessels to guide learners to a specific set of safe route options. Likewise, variability in practice can be introduced within the individual, the task or the environment, with introducing more variability being appropriate as learners gain experience. Variability could be introduced through environmental conditions, the make-up of the bridge team or addressing several scenario goals. The importance of the similarity of training to the goal context and repetition are also emphasised in their framework (Renshaw and Chow, 2019).

6. The applied model for the use of observation

Demonstration of hands-on skills can benefit from applying research in observational learning (Ste-Marie et al., 2012, 2020). The Applied Model for the Use of Observation was developed, in part, to guide practitioners in using observation to improve skill performance and learning (Ste-Marie

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et al., 2012, 2020). Demonstrations of tasks from skilled performers (live or video) benefit novices by allowing them to learn a wide variety of skills. Visual and verbal cues during these demonstrations have produced mixed results and are dependent on factors such as focus of attention and characteristics of both the learner and the task (Ste-Marie et al., 2012, 2020). Similarly, the helpfulness of self-modelling (watching video of one's own performance) has been mixed and dependent upon other instructional features (Ste-Marie et al., 2012, 2020). When providing visual demonstrations (including self-observation) in maritime education and training, elements such as directing students where to focus their attention or giving feedback should be included intentionally and in accordance with research in those areas.

7. Conclusion

More recent theoretical perspectives in motor learning emphasise the importance of individual and environmental contexts, motivation and use of information for performance and learning of psychomotor skills. They have been conceptualised through empirical work, mostly designed with many acquisition trials, few acquisition sessions and relatively simple tasks. Motor learning research has come a long way in including individual and contextual characteristics in predicting instructional strategies and their role in performance and learning.

Distinguishing between performance and learning skills in maritime education and training experimental research designs, as well as applying motor learning concepts to training in maritime education and training, is important. Both the research and teaching contexts require a period of non-practice to accurately assess relatively permanent change in performance of the complex skills required of seafarers. This is particularly important given that how characteristics of the training context such as providing feedback or the order in which skills are practiced are configured can be beneficial for performance but detrimental to learning.

Instructional tools such as providing feedback, instructions, demonstrations and variability in scheduling can be used to optimise training conditions for learning (or transfer or maintenance). They can be used to balance challenge and motivation, adjust functional task difficulty and functional specificity, and as constraints to guide learners' performance.

8. Future directions

Both Hodges and Lohse (2022) and Renshaw and Chow (2019) give outlines of how to begin comprehensively applying current motor learning theory to a structured, applied learning context. Hodges and Lohse's (2022) framework, which considers the goal of a given training session (learning, transfer or maintenance), would be a good place to start applying what is currently known about motor learning in maritime education and training and other learning environments. Renshaw and Chow (2019) walk practitioners through designing training sessions considering useful constraints, similarity of training to real-world performance, variability and the purpose of training. This would also be a useful starting point for application to maritime education and training.

A logical first step in advancing our understanding of motor learning theory's applicability to maritime education and training is to examine whether predictions hold for complex maritime skills, perhaps first in isolation, with an eventual goal of capturing performance and learning in complex contexts and environments. Designing and evaluating theory-based instructional interventions in line with previous motor learning research would be an excellent start. The experimental results from testing these interventions would then provide a richer and more nuanced understanding of the generalisability of current theory and provide direction to new theory development.

Maritime education and training poses an opportunity to address current challenges in motor learning theory as well. The STCW Code contains many complex motor skills with the accompanying competency standards. Many seafarers worldwide must learn these skills, and some require refresher courses after a number of years. Calls for more complex skills, larger sample sizes, and longer and more realistic acquisition and retention intervals have been made in recent motor learning literature (e.g. Anderson et al., 2021), and maritime education and training has potential to be part of a solution.

An exceptional opportunity is presented for cognitive and situated/ socio–cultural research traditions to inform each other's future work in maritime education and training. Future work should consider the overlap in recurring topics, such as instructions, social contexts, assessments and feedback in cognitive and situated/socio–cultural approaches to understand maritime education and training, particularly in the use of simulators (Sellberg et al., 2018; Kim et al., 2021). A better, theory-based understanding of beneficial instructional practices, though cognitive, constraints-based and situated/ socio–cultural approaches would allow for effective and efficient maritime education and training.

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