TRAINING PARADIGM ASSISTED ACCIDENTS: ARE WE SETTING OUR STUDENTS UP FOR FAILURE?

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Abstract. Traditional instructional practices developed around early navigation technologies, or even the more current methodologies conforming to the Standards for Training, Certification, and Watchstanding (STCW), may be unintentionally leading maritime school graduates to make mistakes that cause accidents. Official investigations into marine accidents conclude that even if the watch officer, master or pilot has been assessed as competent in the use of the latest navigational equipment, they may still have failed to understand how to use that technology in the context of bridge team management. The purpose of this paper is to examine, in progression, the results of four studies carried out in the bridge simulators at the California Maritime Academy. Specifically, trends will be identified in student watchstanding performance, in their perceptions of the value of the new navigational technology; in how effective they are in using the equipment, and in how they view the adequacy of existing training regimens. This paper should serve to provide guidance to maritime educators in developing effective teaching techniques that support the recently adopted International Maritime Organization's *e*-Navigation concept.

The data suggest that participants understand the importance of formalized training in modern navigational technologies and overwhelmingly prefer that instruction be accomplished through the use of simulation that is introduced much earlier into their program. This suggests a new training paradigm.

INTRODUCTION

Maritime instructional pedagogies developed around early twentieth century navigation technologies still are being used today. Even the current methods used in the instruction and assessments of STCW competencies are based largely on the traditional teaching paradigm. It is this reluctance to change, for whatever reason, that unintentionally may be leading maritime school graduates to make mistakes that can cause groundings or collisions. In fact, there are alarming indications that the rate of maritime casualties resulting from navigational errors may be increasing in spite of the widespread introduction of advanced systems like ECDIS and AIS [19].

Until very recently it was common to navigate a vessel using only celestial navigation, visual bearings, and unsophisticated radars. Bridge-to-Bridge communications, until the advent of radio, were mainly by whistle signals or flashing light; even VHF communications could be fraught with dangerous misunderstandings. Improvements to those technologies were slow in coming and the changes were introduced only incrementally. Today we are enjoying an exponential increase in both the capabilities and availabilities of new technologies intended for use aboard commercial vessels. Some major innovations include instantaneous, world-wide communications through the use of tele-communication satellites, sophisticated radar units that are capable of superimposing vessel identification signals and chart overlays on the radar screen, and integrated navigation systems using electronic chart technologies.

Coincident with (maybe even as a result of) this technological revolution is the changing nature of the typical maritime university student. The students arriving on campuses today are very comfortable with the latest electronic devices. They have grown up with computers, cell phones, and video games and seem to adapt very easily to the constant technological changes that are taking place around them. Sometimes it appears that they are more comfortable operating in and learning from a virtual world than the real world

[4]. Considering these ongoing, exponential changes in technology and the associated modifications to the skill sets and learning preferences of contemporary maritime students, the authors assert that now is the time to institute a paradigm shift in teaching pedagogy that will maximize the utility of these new technologies for the benefit of our students and the industry in which they will serve.

Given this background, the purpose of this paper is to examine the progression of four recent studies that have considered the efficacy of early introduction of the latest navigational technologies into traditional maritime training programs. Specifically this paper will identify trends in student performances with and without the technology, it will identify their perceptions as to the value of the technology, and it will identify how they are making use the equipment. The last two studies were inspired by the recent (2008) completion of the California Maritime Academy's Simulation Center. The simulators contained therein are state-of-the-art and were instrumental in the development of the salient ideas featured in this study. The authors hope that this paper will serve to provide a sense of direction to maritime educators as they attempt to design more effective training regimens in keeping with the recently adopted International Maritime Organization's e-Navigation concept.

1. LITERATURE

The various studies that are being reviewed in this paper, while they all have some characteristics in common, have each examined different aspects of learning theory. Accordingly, this section will include an overview of the educational literature involved.

1.1. Using simulation as a learning tool

The use of bridge simulations to evaluate human factors in the marine environment is a well established practice [14, 21, 23] and provides many benefits over the real-world environment [22]. According to Hertel and Millis [9], simulation can be an effective pedagogical method to (a) transfer discipline-knowledge, (b) develop skills and (c) apply both knowledge and skills. In fact, researchers have determined that students are more motivated to learn technical material when they see the real-world application of the subject [27]. Student perception of the real-world benefits of course material results in a higher motivation. A higher motivation to learn can lead to an increase in ability in the subject area [16].

1.2. Implicit and Explicit Learning

The requirement for skill mastery for Officer-In-Charge of a Navigational Watch (OICNW) is set by the International Maritime Organization (IMO) Standards of Training, Certification and Watchkeeping (STCW) standards. Although each maritime training facility structures its individual curriculum to fit specific needs, the common pedagogy of a classroom teaching process followed by a practice-based learning experience with a reflection period is normally used. Research suggests that this process improves upon classroom education by making the participants more aware of the differences between their beliefs and their actions [13, 17]. This process takes the student from a purely explicit learning experience to a more implicit learning environment.

Although the distinction between explicit (active) and implicit (passive) learning has been widely acknowledged, the complex interaction between the two has not been widely recognized [25]. Recent research has questioned the basic assumption that the learning of a motor skill must follow the standard practice of moving from explicit to implicit [18]. There is some evidence that both explicit and implicit knowledge are useful in producing a required skill behavior. Specifically, the research by Willingham & Goedert-Eschmann [29] suggests that explicit learning supports and governs behavior until the simultaneously acquired implicit knowledge is sufficient to support the behavior on its own. The results of a study by Taylor & Chi [26] suggest that simulation has the potential to enhance implicit learning. A study by Bird, Osman, Saggerson, and Hayes [1] suggests that observational learning is explicit.

Educators must evaluate how to operationalize the differences between explicit and implicit learning to standard educational models. The specific model that will be considered here is the constructivist model.

1.3. Bridge Team Management and error trapping

Automation changes the task it was meant to support; it creates new error pathways, shifts consequences of error further into the future and delays opportunities for error detection and recovery [12]. Maritime instructors should understand that the logical formalization of the ship's navigational process is of great importance for education in maritime navigation [11]. Therefore, both the technical knowledge of the equipment as well as knowledge of its role in bridge team management and bridge resource management is vital to vessel safety and the safety of the marine environment.

United States Coast Guard data show that maritime accidents, such as groundings and collisions, significantly decreased during a recent five year period [28]. Hetherington, Flin & Mearns [10] have attributed this reduction to enhanced navigation technology. However, these results are not consistent with international findings [19]. Regardless, what is true is that despite the use of technology, maritime accidents still do occur and human factors play an important role.

The maritime community has followed the airline industry in developing a methodology for preventing casualties. This methodology is known as bridge resource management (BRM). According to Swift [24], one function of effective BRM, is the interpretation and assimilation of information obtained by the use of modern electronic systems (e.g., ECDIS). The accuracy and reliability of electronic navigation systems must be "cross-checked" by comparing the positions derived by two independent systems such as GPS and radar. An ambiguity in the positions would indicate that an error chain is developing and the bridge team should react in order to break the developing error chain. The process of identifying errors is commonly known as "error trapping."

Studies by Gonin, Dowd and Alexander [8] suggest that ECDIS provides equivalent or greater navigational safety than paper charts and at the same time reduces the navigation workload. In their studies, cross-track error was the primary measure of navigational accuracy. This study reported that the mean cross-track error for mariners navigating using ECDIS was approximately one third of that for mariners without ECDIS who used paper charts and more traditional navigation methods. Exit interviews in the study revealed that mariners felt that ECDIS contributes to safe navigation. These findings were consistent with those of Donderi et al [7].

2. METHODOLOGY

Recent literature does not contain many examples of specific research that investigated pedagogical approaches to navigational instruction with modern technologies. This may be due to the fact that the greatly expanded capabilities of simulation technologies have only recently been introduced and have yet to be fully exploited.

A total of four studies will be reviewed for this paper. The first study was conducted in California Maritime Academy's original full-mission simulator (dismantled in late 2008). The next three studies utilized one of three full-mission or eight part-task simulators in the new Simulator Center at CMA. Although statistically significant results were few, all four studies showed readily identifiable and consistent trends.

2.1. Human Factors - Performance and Perceptions

The first study, by Buckley and Pecota [3], was carried out during October and November of 2007. Students in the advanced simulation course, DL 420 Watchstanding Simulation, volunteered to participate. Participants in this study, all seniors, consisted of a census of all enrolled cadets at CMA who are taking the bridge simulation course (n = 47). The participants met all prerequisites for the course and had previously taken a 35-hour ECDIS course. This pilot study utilized the last two scenarios of the nine-scenario course. The participants chose the team that they were in for the entire course and that did not change during the study. In total, twelve sections participated in two different scenarios.

The first scenario used was Scenario 8 in which the student team is required to navigate a containership from the San Francisco Main Ship Channel to a specified anchorage position in San Francisco Anchorage No. 8. Approximately half of the teams were randomly selected to have access to ECDIS for Scenario 8. The remainder of the teams did not have access to ECDIS during the scenario.

The second scenario used was Scenario 9 in which the student team is required to navigate a tanker from the Bligh Reef light through the Valdez Narrows in Alaska. Each scenario takes approximately 90 minutes to complete and, once started, is run without interruption. Each team was given the same standing orders and had one week to develop a detailed voyage plan for each transit. For Scenario 9, those teams that did not have access to ECDIS during Scenario 8 were given access and those teams that did have access during Scenario 8 were denied access.

During both scenarios, the course instructor used a data sheet to record measurements at predetermined points during the exercise. These measurements provided the source for the quantitative data which have been reported elsewhere [3]. After each exercise, during the debriefing period, participants were given a survey that elicited responses about the performance of his/her group as well as his/her opinions as to the effects of having, or not having, use of ECDIS during the simulation. The survey instrument consisted of a series of five-point Likert-type perception statements about which the participants were asked to indicate the level to which they agreed or disagreed with that statement (1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree).

The primary research hypothesis (null hypothesis) tested for all survey questions in this study was that there is no difference between the perceptions of participants having access to ECDIS and those without access to ECDIS.

A follow-up to this study was conducted in April 2008 using junior Marine Transportation students enrolled concurrently in the courses DL 320 Introduction to Bridge Simulation and NAU 335 ECDIS. DL 320 Scenario 2 "The Minefield" was selected for use in this part of the study. Navigational performance of fifteen student sections were examined first without the use of ECDIS and then with the use of ECDIS. Performance was based on measurement of cross track error and off-course measurements at certain points throughout the scenario. This study produced the most statistically significant quantitative results of all the study experiments.

2.2. Navigation Study

The second study, carried out Buckley and Pecota [6] during the fall semester of 2008, considered different pedagogical methods for teaching navigation. All volunteer participants (n = 21) were sophomores registered in their first navigation course. The exercises they participated in for this study each took place after they had first covered the material in class with their course instructor. (The navigation instructor was not privy to information about the study other than that it was being conducted. The instructor had no knowledge of which of his students were research participants.) The purpose of this study was to examine the effect, if any, on participant learning and understanding derived from adding simulation, with advanced electronic navigation capability, into a basic navigation class. During this study, participants were divided between three separate treatment groups; traditional navigation lab, non-traditional navigation lab, and navigation lab utilizing full-mission bridge simulators. Each of the treatment groups did the same exercise in the same time period and the participants all completed the pre- and post-test for each study experiment. As part of the post-exercise survey, participants in all experiments completed a qualitative questionnaire designed on a seven-point Likert-type range. The primary research hypothesis (null hypothesis) to be tested for all questions was that there is no difference between the treatment groups. The study also looked at the extent to which implicit and explicit learning took place.

In the first study experiment, participants were asked to plot fixes using visual bearings at 20-minute intervals and then answer relevant questions about those fixes. During this experiment, participants were divided between three separate treatment groups; traditional navigation lab, non-traditional navigation lab, and navigation lab utilizing full-mission bridge simulators. The traditional navigation lab consisted of the standard paper plot that has been the practice in the course. The non-traditional lab consisted of the standard paper plot along with some observational learning in the form of screen-capture shots of both the radar and ECDIS at appropriate time intervals. Finally, the full-mission simulators were used for the experiments. Each of the treatment groups did the same exercise in the same time period and the participants all completed the pre-test, post-test, and survey for each study experiment.

In the second study experiment, participants we asked to plot fixes using various combinations of visual bearings, radar bearings or radar ranges at 12-minute intervals and answer relevant questions about those fixes. During the second experiment, participants were divided between two separate treatments; non-traditional navigation lab and navigation lab utilizing full-mission bridge simulators.

Finally, in the third experiment, participants were asked to plot fixes, using a combination of techniques, and to determine the set and drift of the current. They then calculated the new course to steer to correct for that current. During the third experiment, all participants were utilizing the full-mission bridge simulators.

2.3. Rules Study

The third study, also carried out by Buckley and Pecota [5] during the fall semester of 2008, considered different pedagogical methods for teaching Rules of the Road. All volunteer participants (n = 16) were sophomores registered in the Rules of the Road course NAU 305. This course, which is the only formal course on the International Regulations for Preventing Collisions at Sea in the Marine Transportation curriculum, introduces students to the basics of the responsibilities of ships in maneuvering situations. The population for this experiment was a census of all enrolled cadets at CMA who were taking the Rules course during the fall semester of 2008 (N = 95). All the participants met the prerequisites for the course and some were enrolled concurrently in a radar course.

As with the Navigation study, the research experiments for this study each took place after the participants had first covered the requisite material in class with their course instructor. During this study, participants were divided between three separate treatment groups; traditional lab, and a lab utilizing a full-mission simulator, and a lab using part task simulators. Each of the treatment groups did the same exercise in the same time period and the participants all completed the pre-test and post-test for each study experiment. As part of the post-exercise survey, participants in all experiments completed a qualitative questionnaire designed on a seven-point Likert-type range. The primary research hypothesis (null hypothesis) tested for all questions were that there is no difference between the treatment groups. The study also looked at the extent to which implicit and explicit learning took place.

In all, three separate study experiments were developed. In the first study experiment, participants were asked to make collision avoidance decisions in each of three scenarios involving the steering and sailing rules concerning the meeting, overtaking and crossing situations. During this experiment, participants were divided between three separate treatment groups; traditional rules lecture, full-mission bridge simulator and part task (IBEST) simulators. The traditional rules lecture consisted of a discussion of the practical applications of Rules 13, 14, and 15 using an animated PowerPoint presentation. The full-mission and IBEST simulators were used to allow some participants to maneuver their vessels for collision avoidance by applying Rules 13, 14, and 15 as appropriate. All participants completed the pre- and post-test for each study experiment. As part of the post-exercise survey, participants in all experiments completed a qualitative questionnaire designed on a seven-point Likert-type range.

Participants were asked to indicate the extent to which they either agreed or disagreed with each perceptual statement.

In the second study experiment, participants in the traditional treatment were given a PowerPoint lecture and subsequent discussion on the application of Rule 19, conduct of vessel in restricted visibility. Participants using the simulators were again divided between two separate treatments, full-mission simulator and IBEST simulators. The simulation groups again had three separate scenarios to deal with involving a vessel forward of the beam, abaft the beam and lastly, no detectable vessel at all on the radar. Pre- and post-tests were administered to all participants as well as post-exercise surveys.

In the third experiment, all participants were placed in the either the full-mission simulator or IBEST simulators. In the first scenario, participants' vessels were stationary at night in open waters. No maneuvering was required. Participants were asked to identify the rules situation and identification of various passing vessels by observing their running lights. In the second scenario, also at night, participants were required to navigate their vessels safely past other target vessels in New York harbor from The Battery outbound to the Verrazano Narrows. As in the previous two sessions, pre-tests, post-tests, and post-experiment surveys were administered.

2.4. Error-Trapping Study

The fourth study, by Browne and Buckley [2] was also carried out during the fall semester of 2008, investigated the extent to which bridge teams could successfully identify and trap errors that were introduced into their ECDIS. All volunteer participants (n = 52) were seniors registered in DL 420 Bridge Watchstanding Simulation. During the study, the thirteen sections (4 people per section) participated in four different simulation scenarios. This study utilized the final four scenarios of the nine-scenario course. In the first five scenarios of the course, prior to the commencement of the current study, the watch teams were denied the use of ECDIS and GPS for navigation. Instead, they had to rely on the more traditional navigation techniques of visual and radar piloting to fix their position. For the final four scenarios, the ones examined in this experiment, the students were allowed to use ECDIS and GPS for navigation. Half of the teams had either a gyro or a GPS error introduced into their ECDIS. The primary research hypothesis (null hypothesis) to be tested for all questions is that there is no difference in performance between the teams with no error and those with an error.

Prior to the commencement of the first scenario of the study, the participants were reminded by their instructors that they should not abandon the traditional methods of position fixing because electronic aids to navigation can be subject to failure and errors. The principles of navigation cross-checking were also reviewed. The participants were not told beforehand the purpose of the study. They were not aware that equipment errors were going to be purposely induced for some teams at times previously selected by the researchers.

The first scenario used in the study was Scenario 6 of the course in which the teams were required to navigate a tanker in ballast from a position abeam East Brother Island in the San Francisco Bay to the Golden Gate Bridge, outbound for sea. In Scenario 7, which is also set in San Francisco Bay, the teams were required to navigate a tanker from the Richmond Long Wharf outbound for sea. In Scenario 8 the teams were tasked to navigate a containership from the San Francisco Main Ship Channel to a specified anchorage position in San Francisco Anchorage No. 8. Scenario 9, the final scenario of the course and the study, required the teams to navigate a tanker from the Bligh Reef light through the Valdez Narrows in Alaska.

No equipment errors were imposed during Scenario 6. For the remaining three scenarios approximately half of the teams were randomly selected to receive induced equipment errors while the other half received no errors. Of those teams that received errors at a pre-designated point, approximately half of the teams, randomly selected, received a GPS offset error, in which the accuracy of the GPS position input to the ECDIS was slowly degraded until a position error of 0.3 nm was reached. The remaining teams received a gyrocompass error in which the vessel's heading input was slowly degraded until a heading error of 60 degrees was reached.

Prior to the commencement of the scenarios, the participants entered their pre-computed voyage plan into the bridge simulator Transas ECDIS with a preset cross track error (XTE) limit of 0.1 nm. The teams were instructed to stay as close as possible to the planned track and that if they should depart from the planned XTE limits, they should return within the limits as soon as possible.

For each team, data were collected on the number of times the vessel departed the XTE limits, the distance the XTE was exceeded (in nautical miles) and the length of time the vessel was outside the limits (in minutes). For scenarios 7, 8 and 9, the data were recorded for the 30 minute period prior to the point in the scenario that the error was planned to be introduced to some of the watch teams, and for the 30 minutes following the error. For Scenario 6, because no teams received errors, the data were collected over two consecutive 30 minute blocks of time during the exercise.

3. RESULTS

3.1. Human Factors - Performance and Perceptions

This experiment was an important first step in understanding the complexities of integrating ECDIS into bridge team management. Prior to conducting this study, we expected that the participants with access to ECDIS would have the perception that they had better situational awareness, task prioritization, more confidence, improved vessel handling and better overall team performance than those teams without access to the technology. It was also expected that the participants without access to ECDIS would have the perception that had they had access to ECDIS their performance in those areas would have improved. In general, the data affirmed those expectations with several being statistically significant. These findings were consistent with Donderi et al. [7], Smith et al. [22] and Gonin et al. [8].

In both the original experiment and the follow-on experiment, navigational performance of the groups using ECDIS was generally better than those who were not allowed to use ECDIS. In Scenario 8 of the first experiment, for example, anchoring accuracy was markedly improved (see Fig. 1). In the follow-on experiment, the teams using ECDIS showed significantly reduced cross track errors, fewer groundings and collisions, and generally improved situational awareness (see Fig. 2).

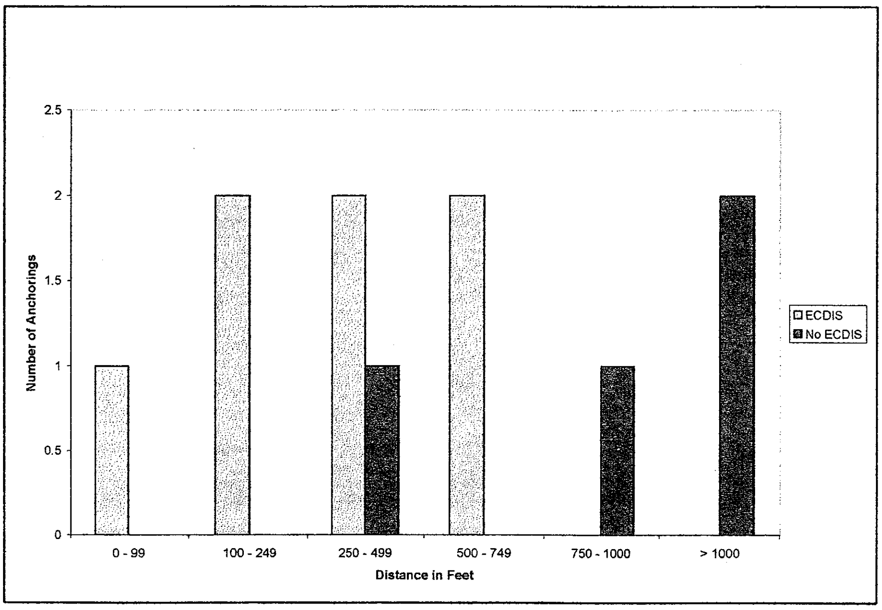

Fig. 1. Scenario 8. Anchoring Accuracy

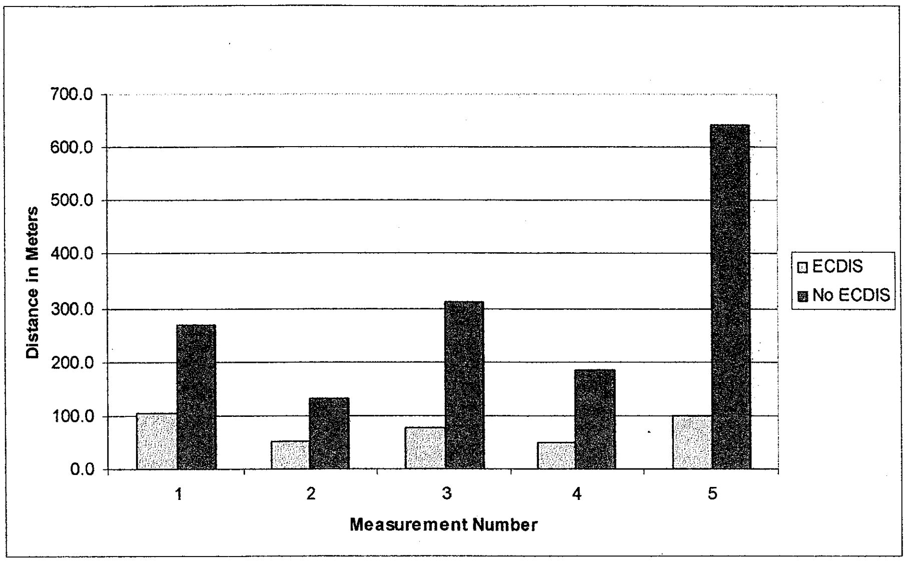

Fig. 2. Cross Track Error from Centerline (Northbound)

The results of the qualitative surveys administered in both the original experiment and the follow-on experiment showed that participant perceptions of their overall performance with ECDIS to be much better than when without ECDIS. The quantitative data, however, did not show such a strong correlation in every case. In essence, the use of ECDIS did not help their performance as much as they thought. One reason for this, and perhaps the most important discovery to come out of these experiments, was that the participants' implementation of ECDIS was uneven at best, detrimental at worst. There seemed to be a uniform lack of protocol or method in the participants' utilization of this relatively new navigational device. This somewhat surprising result led the authors to the conclusion that existing navigational training programs may need to be completely revised to teach maritime students the proper use of these advanced technologies.

3.2. Navigation Study

One of the many objectives of this study was to determine if the participants could learn something about radar and ECDIS implicitly through use of the simulator in basic navigation exercises. As expected, implicit learning did take place, but less implicit learning took place in the traditional lab than in any other treatment. Although the differences were not statistically significant the trend was clear and consistent. The participants in the non-traditional labs did have an increase in implicit learning that may be attributable to the screen-capture shots, but interestingly, their perception was that they did not. Observation learning, as Bird, Osman, Saggerson, & Heyes [1] suggest, may engage the same learning process as physical practice of the observed actions but the findings in the study are inconclusive.

The participants in all of the experiment groups felt that the classroom lessons were easily translated to the simulators. However, each of the three study experiments covered different subjects and there were differences, some statistically significant, in the strength of the participants' feelings depending on the subject. This would suggest that it may not be appropriate to teach all subjects in the simulator. There is evidence to suggest that by using observational learning techniques and bridge simulators in professional courses that traditionally have not used these methods there is an opportunity to take advantage of, and maximize, both explicit and implicit learning. When the quantitative data is combined with participant perceptions and written comments they form a pretty convincing picture.

The most statistically significant information to come out of this study is the very strong opinion by nearly all participants that simulation and the early introduction of ECDIS and radar, in their education are very highly valued. In nearly every case on the post simulation questionnaire, when asked if ECDIS and radar helped participants in their navigation, the overwhelming response was positive.

3.3. Rules Study

As with the parallel navigation study discussed above, this study sought to determine the extent of participants' implicit learning of radar and ECDIS through the use of simulation in a Rules of the Road exercise. The study was also meant to investigate the effectiveness of simulation training in Rules of the Road instruction and those are the study results presented here.

In the first experiment, the participants in the simulation groups were asked to maneuver their vessel in meeting, crossing and overtaking situations based on their knowledge of the Rules. Although all the participants had just covered Rules 13, 14, and 15 in their class and taken an exam on the subject, their ability to translate those rules to the practical situations presented in the simulator was poor. When presented with a Head-on situation on the high seas, more participants chose to turn left (in violation of Rule 14) than turned right. Similarly, when faced with a vessel crossing from starboard to port, some participants chose to speed up or turn left, in violation of Rule 15. When asked later by the researchers if they knew what those rules required in those situations, the participants answered correctly; they simply did not choose the correct action when faced with a realistic situation and limited time to make a decision. This seems to suggest a disconnect between their theoretical learning and the practical application of that knowledge.

In the second experiment involving Rule 19 and restricted visibility, the performance of the participants in the simulator was somewhat better. At least one-half of the participants were taking the radar class concurrently, and most of them were able to apply Rule 19 correctly during an encounter with a single radar contact involving risk of collision. Interestingly though, in the third scenario, the participants were told that the lookout reported hearing a fog signal ahead. There was no actual contact visible on the radar scope in this case. The proper response to this situation was to take all way off but not one of the participants did so. Again, this suggest a disconnect between their theoretical learning and the practical application of that knowledge.

The last experiment was perhaps the most interesting. In the first part, participants were asked to identify the lights of vessels passing close to their vessel which was dead in the water. In addition, participants were asked what their obligation under the Rules would have been if their vessel had been making way. Almost all the participants answered correctly both the light-recognition questions and either the Steering-and-Sailing or Responsibilities-between-Vessels questions. The second part of the last experiment placed each participant on a small tanker at night in New York Harbor. The starting point was abeam The Battery on Lower Manhattan; the end point was the Verrazano Narrows. All eight participants successfully navigated their vessel outbound using radar, ECDIS and visual means. There were no problems during close encounters with several other target vessels. All participants adhered to the Rules and there were no near collisions or groundings.

Examination of the survey questions after each experiment showed an overwhelmingly positive participant appreciation for the use of simulation in Rules of the Road training. Some of the participant's written comments indicated a strong belief that even over the relatively short duration of this study, their knowledge in Rules-of-the-Road application was greatly enhanced.

3.4. Error-Trapping Study

Each of the scenarios in this study differed significantly. As a result, it was not possible to compare performances between the scenarios. Within each scenario it was possible to look at the difference in performance between teams that did not experience errors and those that did. The data concerning the mean number of times outside the XTE limits, the mean maximum distance outside of the XTE limits, and the time outside the XTE limits, suggests that there are no statistical differences in the performance of the teams that experienced a GPS error and those that experienced a gyro compass error in any of the scenarios.

Although the findings were not statistically significant, the trend was quite clear. For Scenarios 7, 8, and 9 there was a noticeable and consistent deterioration in performance for all teams (with and without errors) for the period of time after the error was introduced in some teams. The teams with the introduced errors performed numerically worse than the teams without errors after the introduction of the error, especially in the amount of time outside the XTE limits. In Scenarios 7 and 9 the trend showed that although the teams with the errors did not perform as well as the teams without errors in all categories, the differences were not statistically significant. In Scenario 8, the teams without the errors performed statistically better in all categories. After the errors were introduced, the teams without errors left the lane less often, their maximum distance outside the XTE limit was less, and their time outside the XTE limit was less.

In general, the teams without the errors in their ECDIS performed better than those teams that had an error introduced into their ECDIS. However, the teams with errors were all able to identify the errors and correct for it before the ship was in danger. This suggests that the teams were practicing bridge team management principles and were able to identify the error and trap it early.

4. FINDINGS

Looking at all four studies together a pattern is evolving even though the sample sizes where different and there were differences in the backgrounds of those who participated. We also recognize the difficulties associated with self-reporting surveys and with using traditional course exams as a measure of the effectiveness of simulation. The findings of the studies, when considered together suggest that:

1. The participants in all studies embraced technology and felt strongly that the early introduction of ECDIS and radar in their education are very highly valued.
2. In nearly every case, on the post simulation questionnaire, when asked if ECDIS and radar helped participants in their navigation, the overwhelming response was positive. Although actual performance often did not improve significantly, the participants felt that their situational awareness was better.
3. Participants tended to use the advanced navigation methods differently, sometimes inappropriately. This suggests that the current methods of teaching those technologies, as required by STCW may be inappropriate.
4. With the diversity in response, the data suggests that it may not be appropriate to teach all subjects in the simulator.
5. There is evidence to suggest that by using observational learning techniques and bridge simulators in professional courses that traditionally have not used these methods there is an opportunity to take advantage of, and maximize, both explicit and implicit learning.

5. CONCLUSIONS

Firstly, although the results of this study can be generalized only for the cadets who volunteered to participate in the studies, the data suggest that maritime students understand the importance of formalized training in modern navigational technologies and overwhelmingly prefer new technology instruction to be accomplished through use of computer simulation. They also agreed that simulation training should be introduced much earlier into their program than has ever been attempted previously. This suggests that a new training paradigm is in order. Accordingly, this work has prodigious implications for faculty as well because a paradigm shift as we suggest may change their role from a transmitter of knowledge to a facilitator of learning [17].

Second, it is strongly recommended that equipment manufacturers work more closely with maritime educators as they continue to develop advanced navigation systems. Studies similar to the four described in this paper should be undertaken by equipment developers in collaboration with the faculty of maritime universities equipped with modern bridge simulation technology. Such studies, if conducted properly, could expose equipment deficiencies that may not be detected by traditional research and development methods using only a limited number of professional mariners for equipment evaluation. An added benefit to such collaboration between equipment manufacturers and maritime educators would be to introduce students much earlier to equipment and methods they are most likely to be using upon graduation. If the trend of increasing maritime accidents is to be reversed, maritime education must not continue to lag so far behind industry practices.

Finally, we believe it is vital that through carefully controlled and effective simulation training maritime students develop "bridge-mindedness" to a very high degree well before being turned loose to operate multimillion dollar vessels capable of causing catastrophic environmental disasters after simple navigational errors. Often equipment is added to vessels with little effort to train bridge officers in its use. When this happens, the equipment is frequently underutilized or ignored completely [15]. On many vessels the reduced workload that the technology enables has resulted in reduced manning and an increase in the number and scope of tasks for which a bridge watchstander is responsible [20]. Although technology has the potential to reduce maritime accidents, others have noted that technology alone does not prevent accidents and in some instances actually contributes to them. Human error, misinterpretation of data and poor decision making are still factors despite the presence of reliable technology [10]. Proper training in bridge watchstanding procedures is no longer optional because such errors simply will not be tolerated by the world community in the future.

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