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Evaluating a digital ship design tool prototype: Designers' perceptions of novel ergonomics software

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ABSTRACT

Computer-aided solutions are essential for naval architects to manage and optimize technical complexities when developing a ship's design. Although there are an array of software solutions aimed to optimize the human element in design, practical ergonomics methodologies and technological solutions have struggled to gain widespread application in ship design processes. This paper explores how a new ergonomics technology is perceived by naval architecture students using a mixed-methods framework. Thirteen Naval Architecture and Ocean Engineering Masters students participated in the study. Overall, results found participants perceived the software and its embedded ergonomics tools to benefit their design work, increasing their empathy and ability to understand the work environment and work demands end-users face. However, participant's questioned if ergonomics could be practically and efficiently implemented under real-world project constraints. This revealed underlying social biases and a fundamental lack of understanding in engineering postgraduate students regarding applied ergonomics in naval architecture.

1. Introduction

Ship design and construction is a large-scale, multi-disciplinary project beginning with an initial investment plan which evolves through design concepts into a fully constructed and operable ship (Eyres and Bruce, 2012). Ship design primarily involves technical development, complex calculations and modelling to optimize mission requirements, efficiency (e.g. design, build and operational costs) and overall structural safety. Ship designs are predominately developed through computer-aided design (CAD) tools. Advancements in CAD technology have boosted productivity, reducing product development time (Chryssolouris et al., 2009) and allow for rapid computation and comparison of design parameters (Eyres and Bruce, 2012). Due to increasingly globalized design and manufacturing operations, geographically distributed stakeholders require close collaborations over a project lifecycle. Various computer supported collaborative design tools are utilized to facilitate effective management and knowledge transfer between distributed stakeholders. Examples include digital visualization systems, data exchange and management platforms and social software for mass, Wiki-style collaboration (Shen et al., 2008).

Although specific CAD programs exist which consider ergonomics issues, the integration of the human element through CAD software tools is often difficult and ineffective (Feyen et al., 2000). Designers identify a lack of technical tools, domain knowledge and time as barriers to integration of ergonomic issues (Broberg, 2007). Additionally, the lack of flexibility of these tools can limit its application in early stages of ship design planning (Lundh et al., 2012). The adoption of new technologies is influenced by factors such as perceived usefulness, perceived ease of use, subjective norms, facilitating conditions, self-satisfaction and cost tolerance (Ma et al., 2016; Schepers and Wetzels, 2007). Thus, in order to facilitate the adoption of ergonomics technologies in ship design the methods and tools themselves must be perceived useful, usable, and ultimately add value to the ship design process and final product.

1.1. Facilitating participatory ship design

The shipping industry is an extremely competitive domain, where a fundamental requirement of survival is maximizing the efficiency of operations (Bhattacharya, 2015). Within the shipping industry there is little data on the cost-to-benefit ratio of investing in ergonomics and in general ergonomics is under-researched

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(Österman and Rose, 2015; Österman et al., 2010) and under-applied. This can be attributed to a general lack of knowledge, mandatory regulatory support and practical, value-added methods and tools for naval architects and industry stakeholders (Mallam and Lundh, 2013; Mallam et al., 2015). Ship owners and investors traditionally place higher importance on a ship's cargo carrying capacity, speed and versatility, rather than detailed design factors (Veenstra and Ludema, 2006). However, naval architects are responsible for not only developing a structure optimized from a technical engineering perspective, but also the working and living environment for onboard crew. As ships are large financial investments which stay in operation for several decades after being built (International Maritime Organization, 2010) a well-designed, user-centered onboard working environment can contribute to not only increased safety but also improved productivity and economics (Zare et al., 2015).

End-user considerations are seldom integrated into the planning processes of production projects (Jensen, 2002), and even if included do not guarantee measurable success (Hall-Andersen and Broberg, 2014; Neumann et al., 2009). Designers are not always aware of their influence over the people who will be using their finalized design (Broberg, 1997) and do not have many direct interactions with end-users or a deep understanding of their work demands (Darses and Wolff, 2006). This can lead to designers relying on their own experience to anticipate end-user behaviors (Darses and Wolff, 2006). This is of particular concern for ship design because seafaring is a unique and inherently isolating profession and work environment compared to land-based industries. Naval architects are trained as engineers and may have little understanding of onboard work practices or knowledge of seafaring operations. Gaining access to ships in operation at sea can be difficult for naval architects (both professional and students), as well as for researchers due to the logistics and permissions (e.g. security and safety requirements, granted access from shipping companies, etc.) involved in organizing onboard visits. More common are visits to ships docked in port or being repaired in dry dock, leaving naval architects with little to no exposure to onboard operations, access to seafarers or knowledge of the demands of work and life at sea throughout their education.

Applying participatory design practices to the ship development process is a logical method to fill the knowledge gaps between seafarers, who hold tacit, domain-specific experience of onboard ship operations, and naval architects, who are experts in engineering and design methods, and create the ships and work environments which seafarers work on/in. However, ship design and construction processes are highly interdependent, and involve numerous multi-disciplinary, geographically dispersed stakeholders (Stopford, 2009; Österman et al., 2009). Employee engagement levels within the shipping industry are lower than in shore-based domains (Bhattacharya, 2015). Specifically, in ship development it can be difficult to gather all the required stakeholders together for meetings at the appropriate times throughout the relatively long and variable timelines of ship design and construction (Chauvin et al., 2008). The major challenge for effectively supporting participatory practices in the shipping industry is bridging the geographical, cultural and professional gaps between disciplines involved in ship design and construction. Sanders and Stappers (2008) note this can only be possible if stakeholders have appropriate tools and techniques to facilitate effective knowledge transfer.

1.2. Developing E-SET

The objective of the software prototype, *E-SET* (Ergonomic Ship Evaluation Tool) was to create a digital visualization tool aimed to promote and facilitate the integration of the human element early and continuously throughout conceptual ship design and construction. *E-SET* was designed to facilitate participatory design processes and knowledge transfer particularly between stakeholders involved in the development of ship specifications and general arrangement drawings. As investing in maritime shipping requires significant capital, ship investments are closely tied to financial strategies and economic forecasting. A ship is not only a structure for transportation, but a speculation on future markets (Stopford, 2009). A customer interested in procuring a new ship will define its general purpose and scope based on investment strategies and market predictions. However, after the initial mission requirements and ship purpose are defined, the stakeholders who should be involved during the idea generation phase of design are the employees (onboard crew), ergonomists and designers (naval architects) (Vink et al., 2008).

E-SET was developed to open communication channels between these key stakeholders from differing professional backgrounds in order to facilitate the optimization of crew movement and physical ergonomics issues in ship design. Previous work has followed an iterative human-centered framework, developing from identification of user and context goals and needs to low-fidelity pen-and-paper prototyping to its current state as a first generation digital prototype (see Fig. 1).

Shared “in-the-making” objects such as drafting general arrangement drawings create a common language and understanding between multi-disciplinary stakeholders (Broberg et al., 2011). Tangible mapping of end-user movements and tasks visualized through objects such as physical mock-ups and models (e.g. full-scale 1:1 or scaled 1:8, 1:16, etc.), 2D and 3D CAD drawings and 2D paper drawings and sketching can enhance ergonomics evaluations throughout the design process (Anderson and Broberg, 2015; Aromaa and Väänänen, 2016; Mallam et al., 2015; Österman et al., 2016). This is particularly advantageous during early general arrangement design drafts where basic physical dimensions and areas are developed and crew logistics and space requirements can be optimized early and cheaply in the overall process.

E-SET uses task and link analyses methods to evaluate crew work tasks within ships' work environments as its foundation for facilitating human-centered design in naval architecture design practices (Mallam et al., 2015). Work environment information is important for engineering (Broberg, 2007) and virtual reality can help designers identify flaws in prototype designs before they are implemented in real life (Perez and Neumann, 2015). An online database was developed for *E-SET* which captures and organizes crew work tasks. These tasks are then imported into the 2D and 3D ship models of *E-SET* which visually maps crew movements required for task execution on the general arrangement drawings. The task database was populated from data collected through onboard ship visits, interviewing subject-matter experts and reviewing operational literature and manuals. Initial crew tasks were then prioritized based on duration, intensity and frequency of execution. Fig. 2 displays the graphical user interface (GUI) for *E-SET*, presenting a partial ship model in 3D mode. The left-hand side scrollbar displays the database of crew tasks uploaded which are visualized and analyzed within the ship's 2D and 3D models.

Similar to web mapping services, data are visually mapped in *E-SET* where output metrics including frequency of movement, duration and obstacles encountered are calculated and presented. Combining multiple crew tasks and mapping them together within a single ship model exposes high-traffic areas throughout a structure. The visualization of high traffic areas and logistical bottlenecks reveal critical areas to naval architects where obstructions (e.g. auxiliary equipment, electrics, piping, etc.) should be minimized in order to facilitate safe and efficient crew movement (see

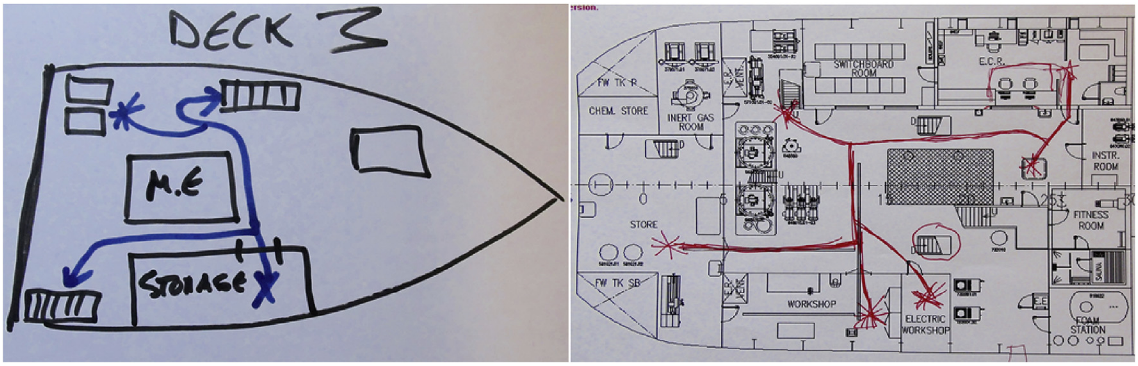

Fig. 1. Crew movement mapped on paper initial layout sketching (left), and general arrangement drawings (right).

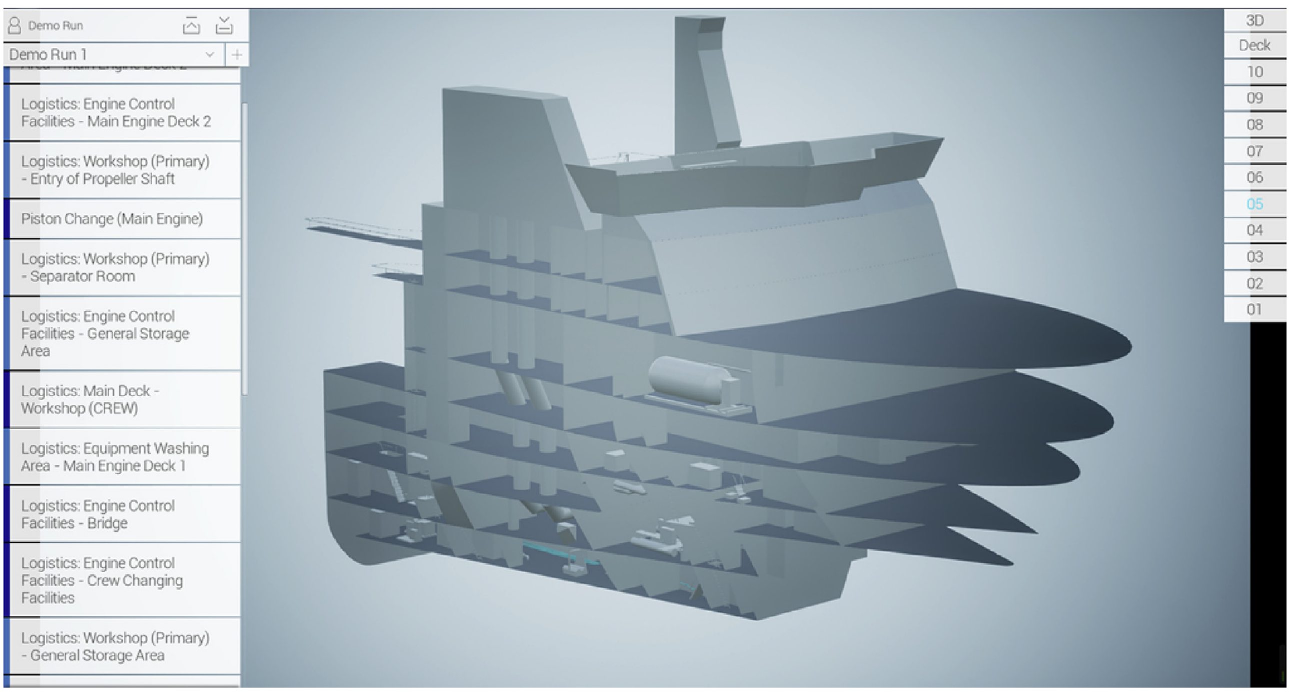

Fig. 2. Graphical user interface of *E-SET* showing a partial ship model in 3D mode.

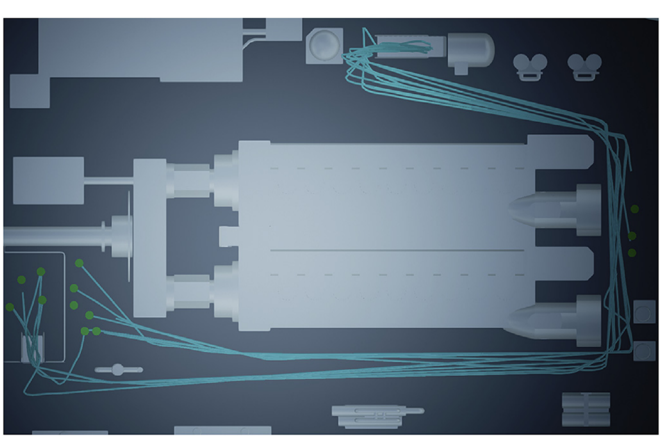

Fig. 3. Screenshot of *E-SET* mapping crew movement of various work tasks around a ship's main engine (center) in 2D.

Fig. 3).

1.3. Usability testing

Usability is the extent with which a product or system can be used by a target audience in a specific context to achieve its desired goals with effectiveness, efficiency and satisfaction (International Organization for Standardization [ISO], 2002). When introducing a new technology, end-users exposed to a novel system or product can encounter usability problems (Hall, 2001). Poor, unusable designs are likely to frustrate people and lead to their underuse, misuse or disuse (Maguire, 2001). Successful software development requires robust, bug free architecture and a GUI design which is aligned with the skill level and knowledge base of the user (Brock et al., 2013). Maximizing the usability and user experience of a product or system is important for adoption by its targeted audience, and has become a key factor for developing computer-based tools (Hassenzahl and Tractinsky, 2006).

There is not a single design strategy that will suit all products, contexts or budgets and it is extremely difficult to construct a unified design strategy to cover all situations (Hall, 2001). Optimally, design methods should be extremely flexible, diverse and dependent on the specific context or product and preferences of individual designers or teams (Bruseberg and McDonagh-Philp, 2001). The "best" methods are generally more expensive and time consuming, while simpler methods stand a much better chance of being implemented in practical design situations (Nielsen, 1994). Excessive user sampling wastes resources, increases costs and development time (Lewis, 1994, 2006; Virzi, 1992). There is no precise sample size number that can be identified for usability testing (Lewis, 2006). However, most usability problems are detected within the first 3–5 subjects, and subsequent testing delivers diminishing returns where additional subjects are unlikely to reveal new information (Virzi, 1992; Nielsen and Landauer, 1993; Lewis, 1994, 2006).

Implementing usability design methods and testing facilitates an overall human-centered design process. This can include data collection directly or indirectly from the users by a variety of diverse methods such as observation, performance-related measurements, critical-incident analyses, questionnaires, interviews, thinking aloud, document analyses, modelling and expert evaluations (ISO, 2002). However, rapid product development cycles threaten rigorous usability testing methods (Wichansky, 2000), thus usability tests often need to be performed over short timelines (Maguire, 2001). Costs for usability testing can be absorbed better by large commercial software ventures, but can be impractical for smaller companies and academic research groups (Brock et al., 2013). However, useful design information and feedback can be elicited from user testing using informal, relatively quick and low cost methods from low fidelity prototypes early and iteratively throughout the design process (Curtis and Nielsen, 1995; Hall, 2001; Nielsen, 1990).

1.4. Purpose

In order for *E-SET* and its embedded ergonomics methods to be accepted and utilized by naval architects and facilitate more human-centered ship designs, the software itself must be usable. This paper explores how new ergonomics technology is perceived by naval architecture students using a mixed-methods framework. It is important to note that this research is intended to be proof of concept testing with the software's intended target audience, not an evaluation of the differing ship layouts and designs the participants analyze with the tool.

2. Methods

2.1. Participants

The participant pool was derived from final year students in the Naval Architecture and Ocean Engineering Master's program. These students are in their final year of study and completing their marine design project. This project is aimed to replicate a real-world, problem-oriented ship design project, from initial problem and customer requests to concept proposals and finalized design. This project intends to expose student design groups to professional engineers, industry professionals and academic faculty of various disciplines. Student learning outcomes are focused on developing project management and communication skills as much as obtaining technical ship development skills. Using a student population had several advantages. It provided a homogenous group of participants close in age, domain-specific education, work experience and industry exposure near the end of their academic education with the skills and knowledge of young professional naval architects. However, as this sample are students with limited real-world experience, their overall competence in ship design and engineering project management is limited.

Thirteen male volunteer participants were recruited (age: 25.3 years ± 2.3 years); 8 from European nations and 5 from Asian nations. As a requirement for admission to the graduate program all had completed previous Bachelor's degrees in various engineering and science disciplines: including, mechanical (7), oceans and marine engineering (2), structural (1), civil (1), science (1) and unspecified (1). The participants did not have previous industry work experience or any formal educational exposure to human factors and ergonomics concepts or methods. This research project was not formally part of the course content or student evaluation. The researchers were invited to the course by its professor; student participation was voluntary and was not connected to, or influenced their academic evaluation.

2.2. Materials

2.2.1. E-SET laboratory configuration

E-SET is designed to run on a personal computer with a standard 64-bit Windows operating system and graphics card. Data collection took place in a laboratory setting where *E-SET* was preloaded onto nine identical personal laptops (44 cm screen, 1920 × 1080 HD resolution, Windows 7 operating system, Intel CORE i7 processors) with internet connectivity and equipped with a standard wired mouse with scroll wheel.

2.2.2. Usability questionnaire

The Post-Study System Usability Questionnaire (PSSUQ) (see Table 1) is an overall satisfaction questionnaire for assessing user satisfaction with system usability (Lewis, 1993). The 19-item version of the instrument utilizes a 7-point Likert scale for each item (1: "strongly agree" to 7: "strongly disagree", as well as "not applicable") aimed to assess users' perceived satisfaction and can be used for different types of products (Lewis, 2002). The PSSUQ measures overall usability, but also three factor subscales: system usefulness, information quality and interface quality with high levels of validity, reliability and sensitivity (Lewis, 1993, 1995; 2002). Additionally, the questionnaire can track changes in usability as a function of the design changes made throughout development for both within a version, as well as across differing versions (Lewis, 2002).

The PSSUQ also provides an opportunity after each item for participants to write open-ended comments to elicit descriptive data (Lewis, 1993, 1995). Additionally, at the end of the questionnaire four open-ended questions were added:

- List the most negative aspect(s) of the system
- List the most positive aspect(s) of the system
- Comment on your overall experiences using this system
- Do you think this could be of value in your work? Why and How?

2.3. Evaluation protocol

The purpose of this experimental design is both proof of concept testing for the prototype and usability testing with the targeted user group. The evaluation protocol was divided into four phases (see Fig. 4).

2.3.1. Ergonomics mini course

Participants attended a 4-h ergonomics mini course given by the researchers that involved traditional classroom lecturing, interactive group work and discussions. The course had been developed over several years as a workshop to introduce and engage naval

Table 1
Post-system usability questionnaire items.

Subscales	Items	
System usefulness	1	Overall, I am satisfied with how easy it is to use this system
	2	It was simple to use this system
	3	I could effectively complete the tasks and scenarios using this system
	4	I was able to complete the tasks and scenarios quickly using this system
	5	I was able to efficiently complete the tasks and scenarios using this system
	6	I felt comfortable using this system
	7	It was easy to learn to use this system
	8	I believe I could become productive quickly using this system
Information quality	9	The system gave error messages that clearly told me how to fix problems
	10	Whenever I made a mistake using the system, I could recover easily and quickly
	11	The information (documentation and instructions) provided with this system was clear
	12	It was easy to find the information I needed
	13	The information provided for the system was easy to understand
	14	The information was effective in helping me complete the tasks and scenarios
	15	The organization of information on the system screens was clear
Interface quality	16	The interface of this system was pleasant
	17	I liked using the interface of this system
	18	This system has all the functions and capabilities I expect it to have
	19	Overall, I am satisfied with this system

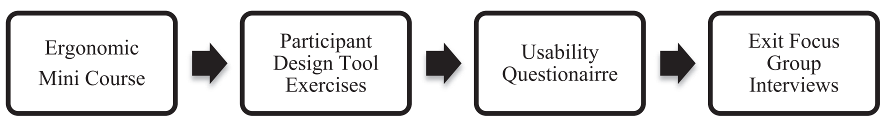

Fig. 4. Evaluation protocol.

architecture students to ergonomics concepts which they can implement in their final year ship design projects. Learning objectives included a general introduction to concepts and purpose of the ergonomics domain, basic methods of physical and cognitive ergonomics and specific coverage of task and link analyses methods. The content focused on how end-user (i.e. ships' crew) knowledge and experience is of value to the design process and how it can be utilized to promote human-centered design in ship development. Participants were also presented with a ship redesign case study involving human-centered design concepts. Participants completed design exercises of a ship's deck layout where they had the possibility to interact with subject-matter experts who were invited to the course as knowledge resources. These included three ergonomics researchers, a maritime safety instructor and seafaring professionals (one master mariner and one marine engineer) who interacted with participant groups by answering questions and providing input during their design exercises.

2.3.2. *Participant exercises & collecting feedback*

Following the mini-course participants were introduced to *E-SET* and the testing protocol they were to complete. Four separate exercises were presented to participants in text format within a paper document (see Table 2). Each exercise was designed to expose and engage participants in differing functions or set of functions of *E-SET* and its GUI. Participants were required to perform a variety of tasks ranging from generic software commands (e.g. opening, uploading and saving files) to more complex navigation of differing 2D and 3D ship models to performing specific ergonomics functions including retrieval of information on crew work tasks, crew movement and obstacle detection. Throughout the exercises participants were encouraged to use the “think aloud” technique, or verbalize their thoughts as they were working with *E-SET*.

Upon completion of the four exercises participants were administered the PSSUQ individually. Participants then engaged in an exit focus group with the researchers consisting of open-ended questions to elaborate upon their questionnaire answers and written comments. The focus group used a semi-structured format utilizing prepared questions to guide and structure the overall discussion (see Table 3). The focus groups and testing sessions were audio recorded for post-hoc verbatim transcription and analysis. Grounded Theory was used to analyze the focus group data (Corbin and Strauss, 2015). Grounded Theory strives to construct explanatory propositions to which the real world corresponds, by allowing themes to emerge from data (Corbin and Strauss, 2015; Patton, 2002). The data were coded and analyzed using qualitative data analysis software (MAXQDA 11, VERBI GmbH, Berlin, Germany) in order to organize emerging themes from focus group discussions.

Table 2
Objectives of the four participant exercises.

Exercise	Objectives
1a	Login/logout, upload, open and save requested files
1b	Explore and identify 8 differing work locations in the 2D and 3D ship model
2	Retrieve route information of a single A-B crew work task
3	Report route and obstacle information for a multi-node work task
4	Interpret high traffic locations for 20 individual crew tasks overlaid together in the ship model

Table 3
An outline of the semi-structured focus group questions.

1	What are your overall impressions of the program?
2	Do you think this could be of value in your work? How? a What advantages do you see? b What disadvantages do you see?
3	Are there functions that could or should be added?
4	Are there functions that could or should be removed?
5	Comment on the following: a Overall purpose b Graphical User Interface c Information quality d Graphics quality e 2D and 3D functions

3. Results

3.1. Usability questionnaire

Overall scale and subscale items report from the thirteen participants reported a generally positive perception of *E-SET's* usability, with results indicating an overall mean score of 2.63 (see Table 4). Lower scores are an indication of higher usability and user satisfaction (Lewis, 1993) on a 7-point Likert scale (1: Strongly Agree, 2: Agree, 3: Somewhat Agree, 4: Neither Agree or Disagree, 5: Somewhat Disagree, 6: Disagree, 7: Strongly Disagree). Relative comparison between the three subscales revealed "interface quality" items having the highest mean score. The highest single item mean scores of the three subscales were all items of the "interface quality" (item 16: $\overline{X} = 2.92$; item 17: $\overline{X} = 3.00$; item 18: $\overline{X} = 4.23$). The "system usability" and "information quality" subscales reported more favorably, with the lowest single item response scores reported from ease of learning and understanding *E-SET* (item 7: $\overline{X} = 1.62$; item 13: $\overline{X} = 2.08$).

3.2. Open-ended questions & focus group discussion

From the Grounded Theory analysis of the transcribed data emerged four reoccurring themes participants focused on: (i) the technical aspects of the software (e.g. functions, GUI, processing times) and specific usability issues, (ii) increasing designer empathy through visualization, (iii) ergonomics in practice, and (iv) social perceptions of ergonomics in engineering and engineering education.

As was revealed in the PSSUQ response scores, the most negative and reoccurring open-ended responses from participants focused on the visual theme and interface of *E-SET.* Participants responded generally positively to the program, its purpose and functioning, but not to its GUI and overall visual presentation. The open-ended feedback focused on the poor interface colors and insufficient labelling of ship technical specifications, equipment and spaces. The ergonomics tools of *E-SET* were reported to be easy to use, interpret and valuable to their design work, however, the technical information about the program's 2D and 3D ship models were not sufficient. Interestingly, the simplicity of the low-fidelity ships' 2D and 3D models, purposefully created in this format, were not viewed as a negative characteristic. Participants found the visual detail of the 2D and 3D models adequate, and did not negatively comment on absence detail in the digital renderings; for example, a piece of machinery being represented as a rudimentary, smooth-faced cubic object. However, participants noted that they wanted technical information included within the models in order to readily identify equipment. This is normally achieved through text labels and reference numbering, which is a straightforward addition to the GUI of *E-SET.*

Table 4
Post-system usability questionnaire overall and subscale results.

	Mean	SD
Overall scale (Item 1–19)	2.63	0.55
System usability (Item 1–8)	2.39	0.36
Information quality (Item 9–15)	2.43	0.21
Interface quality (Item 16–18)	3.38	0.60

In both the open- and close-ended written questions, as well as the focus group discussion sessions participants were asked about their perceptions of *E-SET* and ergonomics in relation to their design work. One participant commented that the task and link analysis functions are directly useful with his work in optimizing work flow and ship layout of the general arrangement his team was currently developing. Participants commented on the value of the 3D model making the conceptualization of the ship drawing "*clearer*", increasing an understanding of the work environment and empathy with the end-user. One participant noted "*you can almost pretend you are walking in the ship and everything becomes clearer*", giving a different perspective to the work spaces and layout. However, they detailed that 3D drawings lacked the simplicity of direct perspective and overview of 2D models necessary for developing large, complex structures. It was noted that they liked *E-SET's* function which allowed instantaneous switching between the 2D and 3D digital models to view the same information but in different formats within one program.

3.2.1. Naval architects' impressions

In general, the participants were more pessimistic with integrating *E-SET* and ergonomics methods into ship design projects. Several pointed out that it was *"not our main focus"*, stating that if they had "*time left over*" at the end of a project a lot of things could be improved (referring not only to end-user issues). Their focus and purpose as naval architects are to work towards the projects pre-established goals as efficiently and effectively as possible. Participants argued that although it is a *"nice thing to do"* they did not see a reason to go above and beyond the established governing requirements and customer requests. The perceived necessary time and money investments added to the fundamental goals and design development of a project. The participants discussed how the acceptance of *E-SET* would be more successful if the ergonomic tools applied to the 2D and 3D models were implemented within technical drawing software naval architects already use and are familiar with. As the ergonomic functions are pre-established and maintained by an outside database, automatically calculated and analyzed, participants found the option as an auxiliary function or application to a preexisting technical design program the most pragmatic strategy for future development and integration into naval architecture work procedures.

4. Discussion

4.1. Perceptions of ergonomics in engineering

The participants reported perceived benefits from using *E-SET* and were generally positive of its purpose, including ergonomics applications in general. Although the ergonomics functions and overall software received favorable scoring on the PSSUQ and throughout focus group questioning, the participants' discussion of practical implementation into their work procedures was overall pessimistic, noting the limitations of resources in projects and their design work. Even as graduate students, with little or no real-world engineering work experience the participants had strong negative opinions regarding the practical implementation of ergonomics into engineering projects, perceiving it as counterintuitive to basic engineering project management goals - adding unnecessary resources, cost and time. These findings revealed a fundamental lack of understanding and knowledge in young engineering students regarding ergonomics and its role within engineering and design.

As perceived usability and ease of use are mediated by attitude (Chen and Huang, 2016) and subjective norms affect attitude (Schepers and Wetzels, 2007) it is the culture of an industry itself that affects the adoption of new technologies and methods. This may be especially true for the shipping industry due to its long history, globalized nature, industry traditions and unique subcultures of naval architecture, shipbuilding and seafaring. However, ergonomics is generally not emphasized in the formal education, standard professional work procedures, methodologies or the rules and regulations that guide naval architecture design work. Designers follow project specifications which are based on customer desires, and developed according to the rules and regulations of an industry (Wulff, Westgaard & Rasmussen, 1999a). Thus, ship design and construction projects focus on optimizing design specifications for a ship's intended purpose (e.g. cargo capacity, operational efficiency, operational environment, build costs, etc.) and meet the minimum construction and safety requirements of various governing bodies. However, the rules and regulations of the shipping industry do not include detailed or mandatory ergonomics support (Mallam and Lundh, 2013).

4.2. Education & knowledge management

Increasing ergonomics knowledge and skills within engineering education curricula is critical for evolving the general perception and utilization of ergonomics by engineering disciplines (Vicente, 2006; Wulff, Westgaard & Rasmussen, 1999b). It was found that engineering students who took an ergonomics course as part of their curriculum were first challenged by the new learning style, but reported increased understanding of the purpose and benefits of developing products and systems for users (Berglund et al., 2015). Similarly, this study had participants report increased empathy for onboard crew by visualizing and exploring the ships physical work environment and crew movement patterns in *E-SET*'s 3D models. These findings suggest that integrating design-specific ergonomics issues and crew work demands through visualization is a valuable addition to naval architecture education and ship design methods, mediating knowledge gap between users, engineers and other project stakeholders.

Engineering design is a social process of negotiation between differing interests and project management should promote the free exchange of ideas and knowledge between different stakeholders (Theberge and Neumann, 2013; Wulff, Westgaard & Rasmussen, 1999b). The failure to integrate ergonomics into system design is not a failure of the technical system as much as it is a failure to accommodate its social sub-systems, (Nadin et al., 2001; Neumann et al., 2009). Knowledge is a systemic, socially constructed, context-specific representation of reality, and thus is not an object to be transferred but a by-product of interactions between individuals within a social system (Parent et al., 2007).

A successful ergonomics program requires strong support from management and financers, particularly in the initial stages of implementation (Vink et al., 2008). Without managerial support, appropriate resource planning and allocation, a new design tool or method will not be accepted or successfully executed. Ergonomics tools must communicate, quantify and document ergonomic aspects of design (Village et al., 2014) while avoiding general recommendations for ergonomics design criteria and increasing documentation (Wulff et al., 2000). This demands specific, pragmatic design-oriented methodologies and tools which can be readily applied by engineers in their work, as ergonomics methods have a tendency to be used by other domains if they appear accessible and originally developed from engineering methods (Stanton and Young, 2003). Similarly, results of this research indicate that further development of *E-SET*, and by extension ergonomics design software solutions in general should focus on integration into pre-existing platforms and methodologies used by naval architects. This will increase the likelihood of their acceptance and use by designers (Gomes de Sá and Zachmann, 1999). However, while complete integration into existing industry and engineering-specific CAD programs could have benefits for direct use by naval architects, it could also alienate those who are not trained and familiar with a particular software platform (e.g. end-users, ergonomists, owners, etc.), further hindering the participatory process and ergonomics utilization in design development.

5. Conclusions

Ultimately, long-term success of ergonomics application in real-world design and construction projects requires increased knowledge mobilization. This not only includes focusing attention on increasing ergonomics skills in traditional engineering disciplines, but also educating project managers, financiers and other stakeholders on the benefits of ergonomics application. This demands that ergonomics become more incentivizing by: (i) providing designers with usable tools and methodologies demonstrating tangible improvements to ship design, and (ii) quantitatively justify the benefits of upfront financial investments and resource allocation to customers.

The scope of this research has been on the former point: developing and testing a practical, usable digital tool for naval architects which aims to add tangible value to their design work. By better understanding technology adoption factors such as perceived satisfaction, usability and usefulness better informed decisions can be made when developing new tools, thus increasing the likelihood of utilization by intended users. The mixed-methods evaluation protocol used in this research provided flexible, context-specific user testing that can be iteratively implemented throughout tight development cycles. This strategy ultimately facilitates increased involvement of the intended target audience which contributes to the development of a more usable and useful system.

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