Influence of Information Layout on Diagnosis Performance

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***Abstract*—Effective diagnosis performance is necessary for the operation of safety-critical industrial systems. Diagnosis depends on the information provided, perceived, interpreted, and integrated by operators. This paper examines the influence of information layout on diagnosis performance. Three layouts were designed to meet the information requirements identified through a work domain analysis and task analysis. One interface depicted the vertical means-end relations in the abstraction hierarchy, a second depicted the horizontal relations between nodes, and a third followed a conventional mimic layout. Because vertical means-end relations present a clear mapping between functional and physical information, it was hypothesized that the vertical interface would facilitate more effective use of functional information and thereby better support diagnosis performance compared with the horizontal and mimic interfaces. No significant influence of information layout on diagnosis accuracy or completion time was found. However, the participants who used the vertical and horizontal interfaces were more confident with their diagnosis conclusions than those using the mimic interface. In addition, the participants using the vertically integrated interface spent significantly less time generating correct hypotheses than the participants using either the horizontal or mimic interfaces. These findings stress the importance of information layout for interfaces of safety-critical systems.**

***Index Terms*—Complex systems, diagnosis performance, ecological interface design (EID), information layout, work domain analysis (WDA).**

I. INTRODUCTION

Diagnosis is a cognitive activity in information processing that is critical for human performance [1]. While the concept is prevalent in both psychology and the medical field, research on diagnosis in safety-critical industries is less common. Morris and Rouse [2] reviewed approximately 80 empirical studies and summarized the effects of visual characteristics, system complexity, time constraints, and individual differences on troubleshooting and problem solving, which are similar to diagnosis [1]. Many of the studies reviewed relied on paper-and-pencil tasks [3] and relatively simple computer-based simulation [4]. The findings from these studies may not scale to contemporary industrial systems and the corresponding increase in diagnosis task complexity confronting operators.

In recent years, trust in automation [5], interface design [6]–[9], system reliability [10], and time constraints [11] have been studied as potential performance shaping factors in industrial process control. However, there is a lack of clear understanding about what factors in digital control systems influence diagnosis performance [12].

A. New Interface Design Philosophies in Complex Systems

In the nuclear power domain, digital visual displays are gradually taking the place of conventional hardwired systems. For interface designers, what information is to be presented, how the information is organized, and the form in which it is presented (i.e., information content, structure, and presentation form, respectively) are suggested to be determined systematically (e.g., [8] and [13]). Andersen [14] summarized three display concepts [task-based displays, ecological displays, and function-oriented displays (FODs)] to facilitate monitoring and control in nuclear power plants.

Task-based displays support tasks defined in procedures. Such displays contain task-relevant information to enhance operator performance on predefined tasks [15].

Ecological interface design (EID) [13], [16] prescribes a work domain analysis (WDA) to determine interface content and structure, and invokes the skills, rules, knowledge taxonomy to determine the information presentation form (e.g., configural form [13], [17], [18]).

FODs are similar to traditional mimic displays, but use color coding (i.e., presentation form) to reflect level of subfunctions [14].

Interface content and form design appear to influence operators' control and diagnosis performance. Ham and Yoon [7], [8] revealed that interfaces with distinct information content from different levels of abstraction hierarchies had significant influence on diagnosis performance. Vicente [16] concluded that functional information from WDA is one of the key reasons that ecological interfaces outperformed mimic interfaces in unfamiliar and unexpected diagnosis tasks. However, the influence of information content and form on diagnosis performance have received more research interest (e.g., [6], [17]–[19]) than information structure [7]. The concept of information structure can be applied to either the structure of various process views or as the structure of information in one specific process view (i.e., information layout [7]). This study focuses on information layout while seeking to keep information content and form constant.

B. Current Methods to Derive Interface Content

Two approaches to content specification dominate the literature. The task-based approach obtains information from the analysis of specific tasks, adopting methods such as hierarchical task analysis [20] and goals, operators, methods, selection rules [21]. The system-based approach is based upon analysis of constraints in the environment or systems (namely, WDA), including but not limited to frameworks such as abstraction hierarchy (AH) [22] and multilevel flow modeling [23].

Both approaches have their merits and limitations. Miller and Vicente [19] compared the approaches, concluding that they are complementary. Jamieson *et al.* [24] integrated task analysis information into

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Manuscript received December 27, 2016; revised April 17, 2017 and August 1, 2017; accepted September 15, 2017. Date of publication November 10, 2017; date of current version May 15, 2018. This work was supported by the National Natural Science Foundation of China under Project 71371104. This paper was recommended by Associate Editor C. M. Burns. *(Corresponding author: Zhizhong Li.)*

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Digital Object Identifier 10.1109/THMS.2017.2767284

a traditional ecological interface and compared three interfaces with different information content: one with primarily physical information (P interface), a second with both physical and functional information (P + F interface), and a third with physical, functional, and task information (P + F + T interface). An experiment in a full-scope petrochemical plant simulator revealed that both P + F and P + F + T interfaces were superior to the P interface in terms of supporting fault diagnosis and action performance [25].

The AH is one WDA framework [26]. AH provides a framework to decompose the work domain functionally with means-end structures between adjacent levels. Although the number, types, and labels of levels of an abstraction framework have evolved [27], the five levels of abstraction have been widely used for the WDA of process facilities: functional purpose (FP), abstract function (AF), generalized function (GF), physical function (PFn), and physical form (e.g., [6], [16]–[18]).

C. Information Layout Based on Interface Design Philosophy

Different interface design philosophies have varying implications for information layout.

In ecological interfaces, there is no explicit interface design guideline for information layout. However, because the information contents of ecological interfaces are derived from WDA, most EID interfaces organize information based on the hierarchies. Pieces of information relevant to mass balance, energy balance, and other laws or criteria (AF level) are primarily organized together; information about crucial functions that support these laws or criteria are typically grouped, and information about physical components that support the crucial functions are similarly colocated. Following this logic, parameters related to energy and mass are therefore usually in separate displays (e.g., [6], [17], [18], [25]). Such organization, as well as its combination with configural forms, makes direct perception (a defining characteristic of ecological interfaces) possible, and supporting knowledge workers coping with unanticipated and unfamiliar situations [16]. Therefore, organizing information in accordance with information in abstraction hierarchies is a potential information layout. This layout is based on content from SYStem-based analysis and Vertical means-end mappings in AH, so it is labeled here as the SysV layout. One caveat to note is that there is no implicit layout guidance in EID, so it cannot be concluded that EID uses the SysV layout exclusively.

The second layout is based on one of the troubleshooting strategies documented by Rasmussen and Jensen [28]. They summarized three typical diagnostic patterns used by experienced electronics repairmen: topographic search, function search, and search by fault evaluation. Search by fault evaluation requires professional experience with similar accidents, whereas both topological search and function search require understanding of work principles and physical structure. Therefore, novices confronted with unfamiliar and unexpected accidents would be expected to adopt topological or function searches. Additionally, the search of physical structures and system functions is natural for workers in complex systems. Pedersen and Lind [29] noted the importance of stressing the distinctions and relations between different types of functions in the systems as well. Therefore, organizing information according to functions can be categorized as a distinct type of information layout. In AH, the GF level presents necessary functions (means) that support the AF level (ends); therefore, organizing information according to function stresses the horizontal relations between means (e.g., functions) in the GF level. This layout is based on content from SYStem-based analysis primarily and organizes information according to their horizontal interrelations among nodes (i.e., functions) in the GF level, so it is labeled here as the SysH layout.

The third layout is based on widely used mimic displays. Traditional mimic displays show a stripped-down piping-and-instrumentation diagram (P&ID) annotated with process parameters. Such a layout, labeled as the PID layout in this study, presents the process flow of the target system, making it easy for trained operators to understand how the system operates [14]. In AH, PFn resembles P&ID [6].

The three layouts stress information from, respectively, the AF, GF, and PFn levels in AH. The lower the level, the more nodes in that level, and the more interrelations. Because the SysV layout maps high-level (AF level) information to low-level information (GF and PFn level), interfaces based on the SysV layout may better support operators in the use of high-level information, resulting in better diagnosis performance. In contrast, neither the SysH layout nor the PID layout stresses the mapping between different levels of AH. The GF level that the SysH layout corresponds to includes fewer nodes and simpler interrelations among these elements than the PFn level that the PID layout corresponds to. Therefore, interfaces based on the SysH layout may help operators understand the system with less information, showing some superiority in diagnosis performance to those using PID interfaces.

The objective of this study is to investigate the influence of information layout on diagnosis performance. The remainder of this paper is organized as follows. Section II describes the process of deriving information content by WDA and task analysis and the process of designing interfaces with different layouts. Section III illustrates the experiment design. Sections IV and V present the results and discuss contributions and insights gained.

II. INTERFACE DESIGN PROCESS

Three interfaces based on the three layouts were designed. Because the information layout was of exclusive interest, the content and form of the three interfaces were held constant. Both WDA and task analysis were used to identify work domain constraints and identify task-specific content. Bar graphs were adopted for information presentation form, borrowing from previous research [7], [8].

A. Hypothetical Nuclear Power Plant: Physical Description

A hypothetical nuclear power plant served as the work domain (see Fig. 1). The physical structure and working principles of the simulated power plant were highly simplified so that student participants could understand the operation and complete the diagnosis tasks.

A heat generator generates heat through a nuclear reaction. The heat is transferred to the coolant flowing circularly in the heat generator. The heated coolant is then pumped into two steam generators through two hot leg tubes. A pressurizer is connected to the hot leg tubes and the cold leg tubes to stabilize the pressure of the coolant. Charging flows from the chemical and volume control system are activated when the pressurizer cannot stabilize the coolant pressure due to a coolant leak. The high-temperature coolant flows through the U-shaped tube in the steam generators and exchanges heat with the low-temperature cooling water outside the U-shaped tube. The heat exchange in the steam generators reduces the temperature of the coolant that next flows back to the heat generator through the two cold leg tubes and pumps, and the heat exchange evaporates the cooling water pumped from a feedwater heater, and the vapor then flows into a steam turbine. The vapor drives the turbine, generating electrical power. After that, the condenser condenses the vapor into liquid water (cooling water). The cooling water flows into the heater, where it exchanges heat with steam from the side steam valve, and is then pumped into two steam generators. After passing the heat to the cooling water in the heater, the steam is liquefied, flowing into the drain tank, and then flowing back to the condenser. A containment vessel prevents the radiation in the coolant

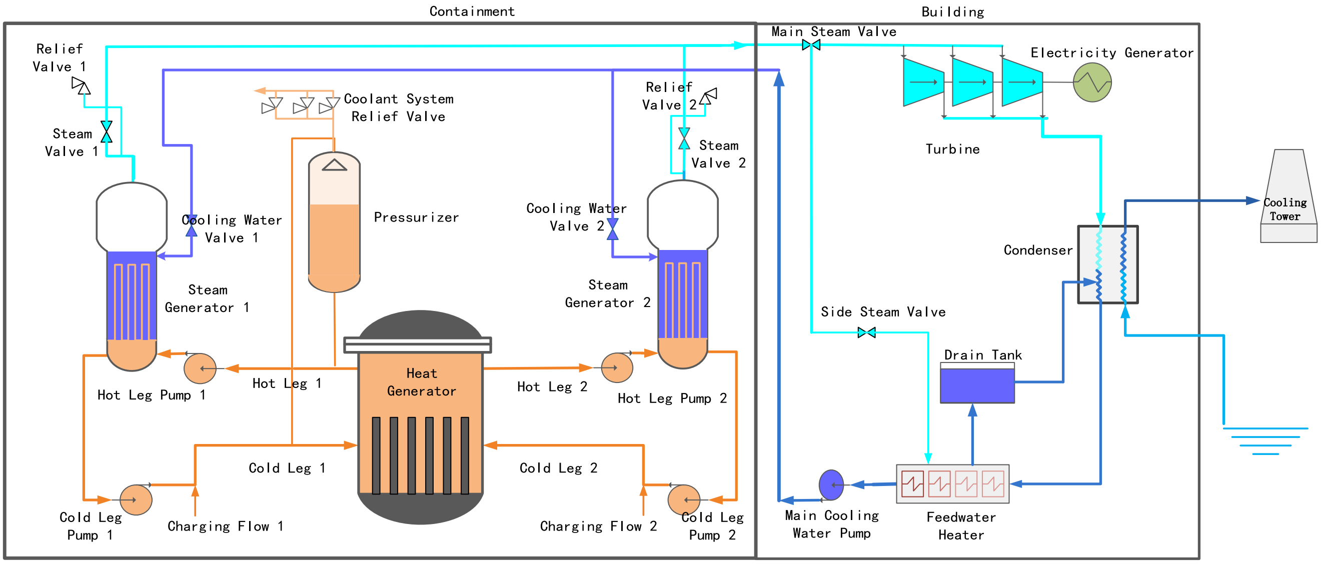

Fig. 1. Physical structure of the hypothetical plan.

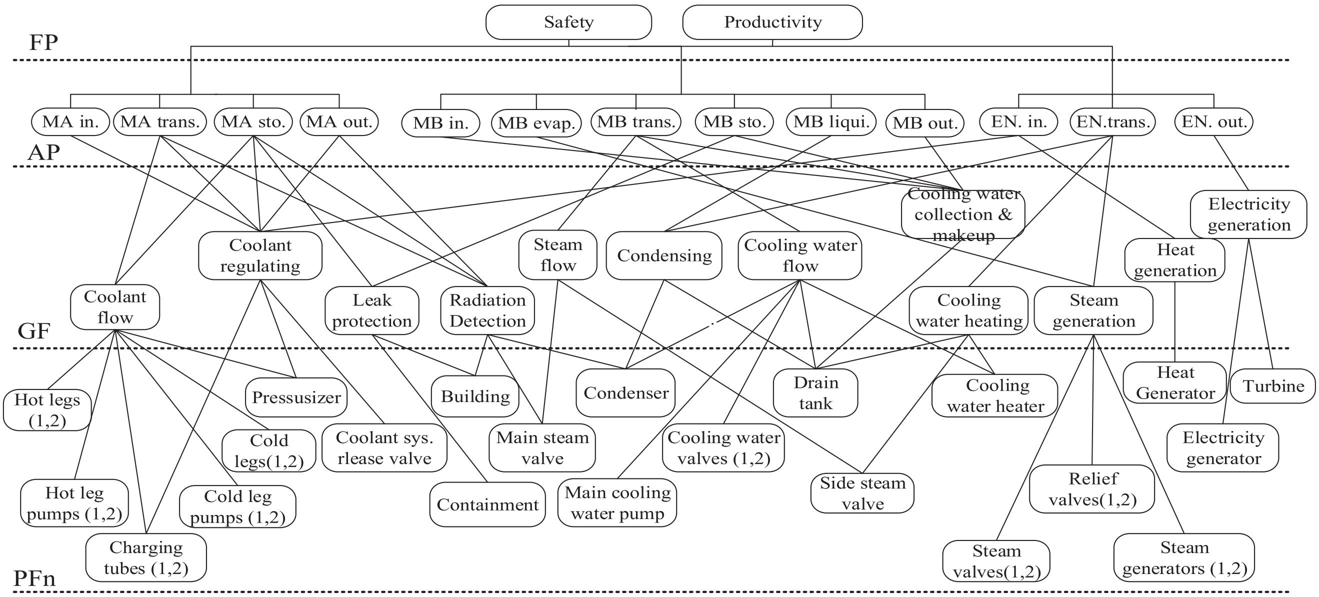

Fig. 2. Mapping between levels of AH of the work domain.

system from leaking to the environment. A building is built to help maintain devices in the second loop.

B. Derivation of Information Content: WDA and Task Analysis

WDA was conducted to decompose the complex system into the functions necessary to support safe operation. Fig. 2 shows the vertical mapping between adjacent levels of an AH. This analysis process identified two types of information: functional information and physical information. Functional information refers specifically and exclusively to the eight equations that denoted mass or energy conservation of subsystems, whereas other process parameters were regarded as physical information.

Because all accident scenarios were simplified, information requirements were different from those in real plants. To guarantee all task-relevant information was presented, parameters required for the diagnosis of the various accident scenarios were identified through task analysis. Information from both WDA and task analysis were combined for presentation in the interfaces.

C. Information Organization in the Interfaces

The three information layouts are SysV, which focuses on the vertical means-end relations, SysH, which focuses on the horizontal relations between nodes in the AH, and PID, which inherits the conventional P&ID interface layout.

1) SysV Interface: The SysV interface can be divided into seven modules, as shown in Fig. 3. Information related to energy conservation, including temperature parameters, power parameters, and energy conservation equations, was grouped in Module 3. Modules 4 and 5 present information related to coolant conservation and cooling water conservation. Because the containment and building were not connected to the system physically, parameters related to them were grouped in Module 6. All pumps and valves information was presented

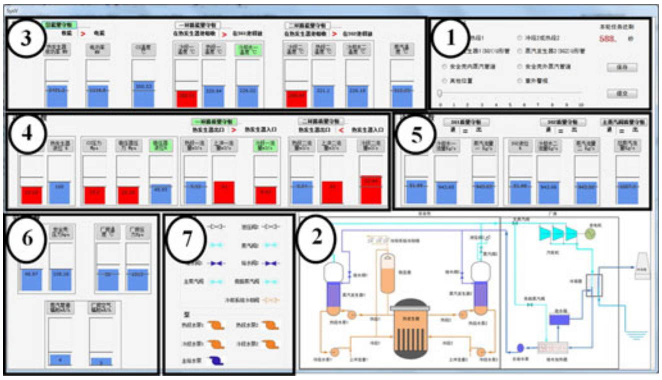

Fig. 3. Illustration of SysV interface.

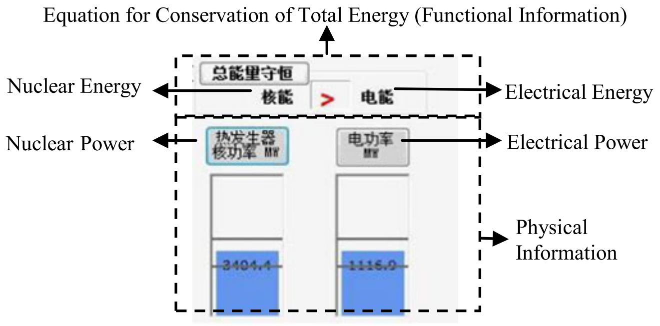

Fig. 4. Example of how SysV interface stresses vertical means-end relations.

in Module 7. Module 2 showed an illustration of the physical structure of the hypothetical system, and Module 1 was the diagnosis panel. One caveat to note: Module 1 is a data collection/response entry interface and consistent with the SysH and PID interfaces. This module contains eight options as possible leak locations, a scale to estimate probability, two buttons (one to save, the other to submit), and remaining time for current trial.

To address the vertical means-end relations in AH, functional information (equations) was presented above corresponding physical information. For instance, in Module 1 (energy conservation), an equation indicating general energy conservation (nuclear power versus electricity) was presented (see Fig. 4), underneath which were two bar graphs representing nuclear power and electricity output, respectively. When the value of each indicator does not exceed a threshold or a reasonable interval, the bar would be blue, otherwise the bar turns red. Such a layout is expected to facilitate the mapping between higher level and lower level information.

2) SysH Interface: The SysH interface is divided into ten modules, as shown in Fig. 5. All parameters were grouped in accordance with the functions at the GF level of AH. Modules 4–10 represent seven functions: coolant regulation, coolant flow, heat generation, steam generation, steam flow, electricity generation, and leak protection. Among the seven functions, the coolant flow function (Module 5) can be further divided into two subfunctions: the first circuit [circuit on the left side of the heat generator, connecting to the left steam generator (SG1)] and the second circuit [circuit on the right side of the heat generator, connecting to the right steam generator (SG2)]. The steam generation (Module 7) can be further divided into two subfunctions as well: the SG1-related function and the SG2-related function.

In this interface, relations between functions are addressed, whereas higher level information and its mapping to lower level information are not shown explicitly. The higher level information, i.e., eight equations that represent mass and energy conservation, should not be presented.

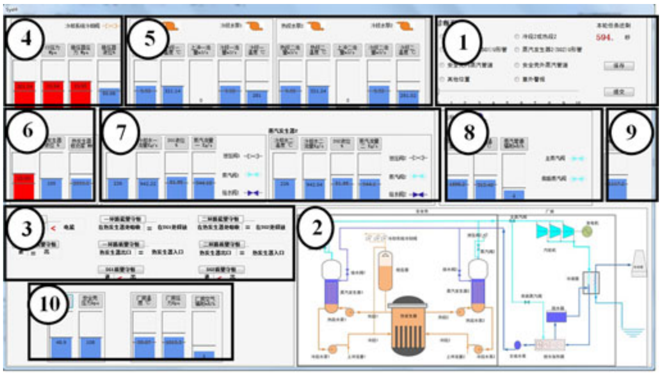

Fig. 5. Illustration of SysH interface.

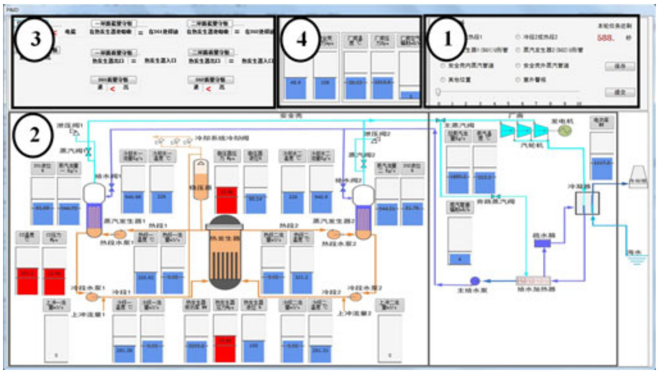

Fig. 6. Illustration of PID interface.

To include the same information content, however, Module 3 is divided to present this type of information. Module 2 shows the illustration of the physical structure of the hypothetical system as the same as Module 2 in the SysV interface, and Module 1 is the diagnosis panel and the same as in the two other interfaces.

3) PID Interface: The PID interface (see Fig. 6) differs in two ways from what is typically observed in operational plants. First, higher level information is added in Modules 3 and 4 to include the same information content. Second, information is presented in bar graphs to keep information presentation form constant. The illustration of the physical structure is stretched in Module 2 so that parameters are presented close to their corresponding devices and instruments. Module 1 is the same diagnosis panel as included in the SysV and SysH interfaces.

D. Subjectivity in the Design Process

There is inevitable subjectivity during the interface design process, including the following.

1) The work domain is simplified, so no actual operational data could be referred to. The system and accident scenarios were tailored to ensure that student participants could understand the system and complete the tasks. This is also why task analysis was used to ensure all task-relevant parameters were presented.
2) When it comes to locating various modules in interfaces, subjectivity is inevitable as well. For example, in the SysV interface (see Fig. 3), Module 3 can be located where Module 4 or Module 5 was located. The display size, module size, and relations of different modules were all taken into consideration, which is subjective.
3) Some functions (radiation detection, condensing, and cooling water flow, collection and heating) were not presented in the

interfaces, either because the physical functions that supported these general functions have been simplified or because the physical functions that support multiple general functions have been classified into other presented functions. For instance, the condenser, drain tank, and cooling water heater are simplified in the system; thus, the general functions they support, such as condensing, cooling water flow, and cooling water collection and make up, are not presented in the current interface.

III. METHOD

A. Participants

In total, 74 male science and engineering students aged 18–23 ($\text{mean} = 20$, $\text{SD} = 1.3$) were recruited as participants. Two participants did not finish the experiment. All participants had learned physics for an average of nine semesters from high school and had an average of four years of computer experience. They were informed about the details of the experiment protocol and voluntarily signed the informed consent form before the experiment proceeded. The experiment took approximately 2.5 h to complete, and all participants were compensated with 60 RMB per hour.

B. Independent Variables

Information layout was the sole independent variable and was manipulated between subjects. It had three levels: SysV, SysH, and PID. Participants were randomly assigned to the three layout groups.

C. Dependent Variables

Four dependent variables were measured in each trial: completion time, diagnosis accuracy, time to generate a correct hypothesis, and estimated probability of the hypothesis generated. Completion time was defined as the time for a participant to complete a trial. Diagnosis accuracy was calculated as the proportion of correct diagnosis trials. The participants were required to estimate an occurrence probability for every hypothesis they selected. We used the last hypothesis generated (and then submitted) to score diagnosis accuracy. Time to generate a correct hypothesis was defined as the time from the beginning of a trial to the generation of the first correct hypothesis. If the last hypothesis was the first correct one, then the time to generate a correct hypothesis would be equal to completion time. Otherwise, the former should be less than the latter. Time to generate a correct hypothesis was only calculated for trials with a correct final hypothesis.

In addition, the participants were required to mark information (both functional information and physical information) that was important for their diagnosis by clicking the name of a specific piece of information. Once clicked, the name of the information (a button) turned from gray to green. In Modules 3 and 4 of Fig. 3, the participants marked those green buttons as important information. If the participants thought the marked information was not important, they could click the information again, and its name would turn from green to gray. Only information that was marked as green when the participant submitted the diagnosis result would be recorded as important information. This type of information was recorded to further examine results, if needed. The number of important parameters (both physical and functional information) and the numbers of equations (functional information), therefore, are introduced as another two dependent variables.

D. Experiment Tasks and Scenarios

Participants engaged in diagnosis tasks where they were required to find leak locations in the simulated plant. Eight possible leak locations were listed on the upper right side of the general status interface. The participants were required to monitor various parameters, choose one location diagnosis and assess the possibility that the diagnosis was correct. For each trial, only one accident occurred. However, the participants could record as many diagnoses as they generated, such that they might switch from a correct to an incorrect hypothesis. They submitted their conclusions until they thought their diagnosis was mostly correct. After submission, they could begin another trial.

Four accident scenarios resulting in low coolant system pressure were generated, and operators applied the same diagnosis procedure before responding to any one of them [30]. The four accident scenarios were small break losses of coolant accidents, steam generator tube ruptures, steam line breaks inside containment, and steam line breaks outside containment. The four scenarios were simplified so that the undergraduate participants were able to understand. All simplifications in the experiment followed fundamental physical laws. A pilot study was conducted to test the difficulty of each simplified scenario, and none stood out as being more difficult than the others.

Each participant completed eight trials (i.e., each of the four scenarios twice). The same leak locations were used in the three interface conditions. The first four trials and the last four trials were, respectively, made up of the four different scenarios. The orders of the four scenarios in the first half and the second half of the eight trials were different to avoid the participants completing the tasks by rote.

E. Procedure

The experiment started with a practice session. An experimenter explained how the simulated plant works and how to use the experiment platform. The participant then completed an 18-question quiz about how the plant works. The one participant who scored lower than 80% was removed from the experiment. Next, the participant completed two practice sessions to familiarize himself with the working principles and physical structures of the plant and the experiment simulation platform. The first practice was completed in isolation with a long time constraint (600 s). In the second practice, the experimenter explained the principles of a trial accident scenario and presented again the use of the experiment platform. The accident scenarios used in the practice trials employed different leak locations from the four accident scenarios used in experiment.

After the practice session, the participants had a 5-min rest before they began the formal test. In the formal test part, all participants were asked to figure out the leak location by observing one of the three interfaces. Each trial began with an alarm for the low coolant system pressure. In each trial, a participant could save as many diagnoses as desired, but was instructed not to submit until he thought the final one was correct. They were released after completing eight trials.

F. Data Analysis

One participant halted the experiment after the formal test began, therefore all his data were eliminated. Another student failed the quiz. Data from 72 participants were finally analyzed.

IV. RESULTS

The means and standard deviations for all measured variables are presented in Table I.

Analysis of variance (ANOVA) and post hoc pairwise comparison of means using least significant difference were conducted for data analysis at $\alpha = 0.05$ (See Table II for a summary of p-values and Table III for pairwise test results).

TABLE I
MEAN VALUES (STANDARD DEVIATION) OF PERFORMANCE MEASURES

Dependent variables	N	Information layout		
		SysV	SysH	PID
Completion time (s)	72	184 (67.5)	185 (68.1)	191 (67.0)
Diagnosis accuracy	72	0.57 (0.30)	0.62 (0.28)	0.55 (0.256)
Time to generate correct hypothesis (s)	66*	107 (53.5)	137 (58.8)	147 (66.5)
Estimated probability	72	0.83 (0.11)	0.84 (0.12)	0.75 (0.144)
No. of important parameters	72	46 (26.6)	50 (26.7)	38 (26.6)
No. of equations	72	18 (10.2)	18 (9.7)	11 (9.6)

*Six participants did not get correct hypothesis.

TABLE II
ANOVA RESULTS OF INFORMATION LAYOUT EFFECTS

Dependent variables	d.f.	F	p
Completion time	2	0.13	0.878
Diagnosis accuracy	2	0.57	0.569
Time to generate correct hypothesis	2	4.57	0.014*
Estimated probability	2	4.34	0.017*
No. of important parameters	2	1.36	0.263
No. of equations	2	3.84	0.026*

*Significant at $\alpha = 0.05$.

TABLE III
POST HOC PAIRWISE RESULTS (p-VALUE)

	Information layout*					
	1		2		3	
	2	3	1	3	1	2
Completion time	0.957	0.642	0.957	0.681	0.642	0.681
Diagnosis accuracy	0.501	0.708	0.501	0.296	0.708	0.296
Time to generate correct hypothesis	0.039*	0.005*	0.039*	0.410	0.005*	0.410
Estimated probability	0.778	0.019*	0.778	0.009*	0.019*	0.009*
Number of important parameters	0.575	0.292	0.575	0.109	0.292	0.109
Number of equations	0.895	0.023*	0.895	0.016*	0.023*	0.016*

*Significant at $\alpha = 0.05$.

Completion time: No significant effect of information layout on the completion time was observed ($p > 0.05$).

Diagnosis accuracy: The diagnosis accuracy of each trial was coded as 0 (the diagnosis submitted was wrong) or 1 (the diagnosis submitted was correct). No significant effect of information layout on the diagnosis accuracy was observed ($p > 0.05$).

Time to generate correct hypothesis: Information layout had a significant influence on the time to generate a correct hypothesis, $F_{(2,63)} = 4.57$, $p = 0.014$ ($M_{\mathrm{SysV\ interface}} = 107\,\mathrm{s}$, $M_{\mathrm{SysH\ interface}} = 137\,\mathrm{s}$, $M_{\mathrm{PID\ interface}} = 147\,\mathrm{s}$). Post hoc tests suggested that, at the SysV interface level, the participants generated the correct hypothesis faster than those at the SysH interface level, $p = 0.039$, and at the PID interface level, $p = 0.005$. The time to generate a correct hypothesis at the SysH interface level was not significantly different from that at the PID interface level.

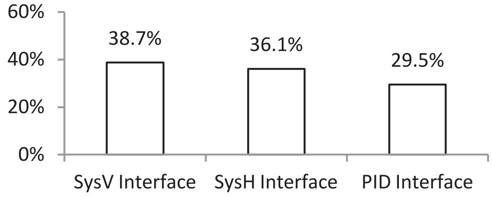

Fig. 7. Percentage of functional information marked important by participants out of all information marked important.

Estimated probability: Information layout was found to have a significant influence on estimated probability, $F_{(2,69)} = 4.34, p = 0.017$ ($M_{\mathrm{SysV\ interface}} = 0.83$, $M_{\mathrm{SysH\ interface}} = 0.84$, $M_{\mathrm{PID\ interface}} = 0.75$). The estimated probabilities at the PID interface level were less than those at both SysV interface ($p = 0.019$) and SysH interface ($p = 0.009$) levels. There were no differences between the estimated probabilities at the SysV interface level and SysH interface level.

Number of important information: No significant influence was found for information layout on the number of important information ($p > 0.05$).

Number of equations: Information layout was found to have a significant influence on number of equations, $F_{(2,69)} = 3.84$, $p = 0.026$ ($M_{\mathrm{SysV\ interface}} = 18$, $M_{\mathrm{SysH\ interface}} = 18$, $M_{\mathrm{PID\ interface}} = 11$). Post hoc tests suggested that participants in the SysV interface condition marked more functional information than those in the PID condition, ($p = 0.023$) and participants in the SysH condition marked more functional information than those in the PID condition ($p = 0.016$). However, the number of equations marked at the SysV interface level was not significantly different from that at the SysH interface level.

Fig. 7 shows the percentage of functional information in the total amount of information marked important by the participants. In all, 38.7% of information marked important by the participants at the SysV level, and 36.1% of that at the SysH level, was functional information. In contrast, only 29.5% of the information marked important by the participants at the PID interface level was functional information.

V. DISCUSSION

The study explored the influence of information layout on fault diagnosis performance in a simulated power plant. Results revealed that the independent variable did influence aspects of diagnosis performance.

Some previous studies have compared the influence of EID versus PID interfaces on performance in main control rooms, whereas others compared the influence of a function-based interface versus a PID. However, the three information layouts based on different design philosophies have not been compared in one study. Moreover, in contrast to information content and presentation form, information layout has not been isolated as a controlled variable.

The results in the current study did not show a significant influence of information layout on diagnostic *product*, (i.e., completion time and accuracy), but did have a significant effect on diagnosis *process* (i.e., time to generate a correct hypothesis, estimated probability, and information consulted).

The failure to observe an influence on product variables may be explained by the intrusion of how the diagnosis hypothesis was recorded. The participants were required to record their hypothesis once they had one, such that they had to pause to fill out their hypothesis before they continued their diagnosis, which may have compromised their diagnosis results. It is possible that a less intrusive measure of diagnosis outcome may yield different results.

The participants using the interface emphasizing means-end relations (SysV) generated a correct hypothesis significantly faster than participants at the other two levels (SysH and PID), whereas the participants using either an interface emphasizing causal relations (SysH) or the topological process relationships level (PID) showed no significant difference in time to generate a correct hypothesis. Moreover, the participants using either the means-end or causal interfaces (SysV and SysH) estimated the hypothesis with a significantly higher probability of occurrence than the participants using the conventional PID interface. This implies that the participants whose diagnoses emphasize means-ends or causal information may feel more confident in their diagnosis, even though their diagnosis accuracy was not found to be superior.

The significant effect of information layout on diagnosis process results suggests that information layout influences how the participants use functional information. Vicente [16] demonstrated that functional information in ecological interfaces is the key to improve operator performance. In the current study, information content (both physical information and functional information) in the three interfaces is the same, while different information layouts may influence the frequency of using functional information. In the interface emphasizing means-ends relations, functional information and corresponding physical information were grouped together so that the participants could quickly link means to ends. In contrast, functional and physical information in the PID interface were grouped separately. However, the layout in the interface emphasizing causal relations also facilitated the participants to relate functional information to corresponding physical information, despite being separately grouped as well. The frequencies of using functional information also appeared to differ across information structure types. Operators using information displays structured according to either means-ends or causal relations accessed more functional information than those using the PID structure.

In addition to the frequencies of using functional information, information layout may influence how the participants navigated to information. In the SysV interface, mapping from functional information to related physical information is vivid, and the participants could directly locate related physical information exactly underneath the functional information. In the SysH interface, the participants could not use functional information unless they understood the relation among various subfunctions. The participants using the PID interface had to search for information on individual instruments and their roles in the system if they needed to use the functional information. Information needed in each interface, from the SysV interface to the SysH interface and to the PID interface, separately corresponds to three levels in AH top-down, from AF to GF and to PFn. The lower the level, the more elements in that level, and the more complicated the interrelations. This may explain why the participants at the SysV interface level generated correct hypotheses fastest. This explanation needs to be verified via further tests, such as using eye trackers to record saccade path and fixation locations of the participants, or analyzing verbal reports. Both methods, eye tracking and verbal reports, however, are intrusive to some extent, leading to potential negative influence on experiment results.

These results demonstrate the important role of information layout in interface design. Interfaces with the same information content and presentation forms still may have different effects on diagnosis performance if they have different information layouts. Because information requirements and characteristics vary in different industries, subsequent research could further investigate specific information layouts that support certain industries based on system differences. Results in the current research show that, under unfamiliar and unexpected accident circumstances in nuclear power plants, organizing information according to AH top-down could facilitate diagnosis performance, while the advantages and disadvantages of different interfaces under other circumstances need further examination.

The experiment employed a highly simplified nuclear power plant simulation. Although efforts were made to design fault scenarios and select student participants such that the experimental tasks were similar to diagnosis tasks performed by licensed operators, these limitations inevitably constrain the generalizability of the results from the study.

VI. CONCLUSION

The current study adds to the literature on diagnosis regarding the effects of information layout on diagnosis performance. Two important results related to information layout were found. The participants who used an interface that explicitly links physical and functional information generated correct hypotheses faster than those who used interface layouts lacking these links. In addition, the participants using an information layout that is enigmatic of contemporary process interfaces were less confident in their diagnoses. These results stress the importance of information layout in safety-critical systems.

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