

# **AN INFORMATION SYSTEMS DESIGN THEORY FOR AN EXPERT SYSTEM FOR TRAINING**

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## **1. INTRODUCTION**

This paper reports the results of a study that used information systems design theory (ISDT) to develop an expert systems-based training environment to teach statistical process control. Technology has added new options to deliver training (Buch 2002). In addition, information technology (IT) helps to build new tools and methods that could help to share knowledge and learning easily (Kekäle 2002). For example, production managers can use such tools for training the workforce before the production actually occurs, and consequently, make savings and reduce the time used in training. Marold (2002) believes that “the learning model of the 21<sup>st</sup> century uses the computer as the conduit of teaching and learning” (p. 114). Kekäle et al. (2002) argue that IT continues to produce new ways to help people to learn.

Expert Systems (ES) provide the means to create tools that are widely used for helping people. ES use artificial intelligence (AI) and are defined as computerized advisory programs that attempt to imitate the reasoning process of experts in solving problems (Turban 1995; Turban 2001). Training represents one of the areas with the most significant payoff in using AI (Herrod 1989). ES “help us focus on our instructional development efforts on knowledge rather than procedures and to develop solutions to increasingly complex problems” (Grabinger 1990), p.13). Chang et al. (1993) mention that an ES is one of the best tools to train people in quality systems (e.g., ISO 9000).

The purpose of this study is to understand the role that an ES developed through an ISDT can play in training the workforce in quality assurance for industrial processes. At the time this research was conducted, an ES with training capabilities did not exist in the market. Thus, the research focused on developing and evaluating an ES training tool for a complex task by using a design research approach. Complex tasks are not easy to learn or to teach, especially when trainees do not have the adequate education level for such a training program. Statistical Process Control was chosen as the task domain because it deals with statistics and mathematics concepts, but is applied by workers who do not know these concepts.

## **2. RESEARCH PROCESS**

The proposed research is based on the ISDT framework from Walls et al. (1992) and aims to develop a system design that can be used as the base to build an ES for training through the construction and evaluation of prototypes. Such an ES will serve to test the ISDT and then construct the ES for training.

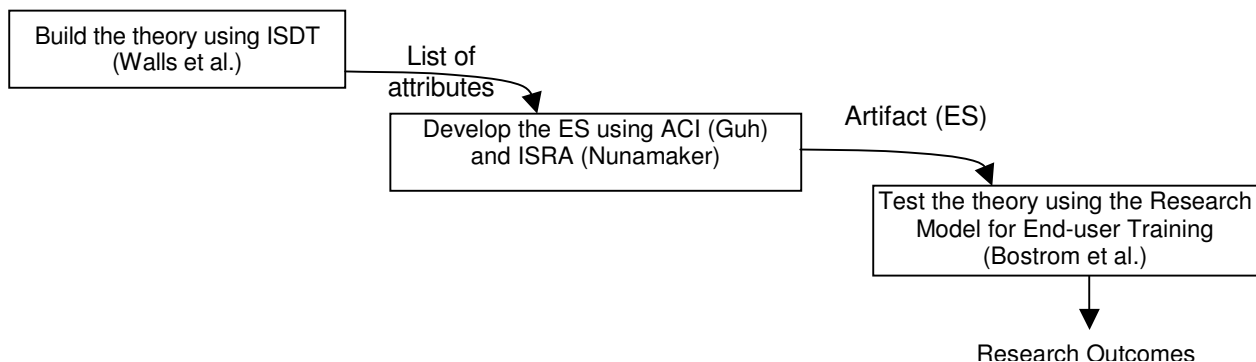
A design theory is prescriptive and not explanatory or predictive in nature. Walls et al. (1992) believe that the purpose of a design theory is to support the achievement of goals. Thus, a design theory describes how to achieve a goal and not what the goal should be. For the study, the design theory specifies the design of a prototype for an ES as a training tool that helps in the delivery of training in complex tasks using rich training methods.

The study is based on a three-step process. It requires an interrelation between the steps. Thus, the overall process is composed of a waterfall-like model. Each step of the proposed study is described further in the following sections. The conceptual model is shown in Figure 1 and has the following process:

- 1 Build the theory using the ISDT framework from Walls et al. (1992). This part of the research allows the creation a design theory to identify the most important attributes for an ES for training. Such an artifact can be developed through any approach. However,

since ISDT allows the utilization of previous theories that are at the core of the new design, then by using the approach ISDT the researchers were able to identify which attributes are absolutely necessary so that the artifact can be used successfully.

- 2 The system is the artifact used in the training process to test whether it delivers better outcomes than a reduced version and a traditional approach.
- 3 Build the artifact using the Assignable Cause Interpreter (ACI) framework from Guh (2003), the Information Systems Research Approach (ISRA) from Nunamaker (1992), as well as using all the attributes from the previous step. When an organization has need for very specific software, in general, the market does not have it. Thus, it is necessary to develop such new software that address the needs these special needs. This software can be referred as “purposely-developed”. The second step intends to develop a purposely-developed software: a training system. This purposely-developed artifact is a new class of information systems that will be used for a very specific purpose: to train people that are working – or wanted to work – in the manufacturing industry, especially in processes that require quality control using Statistical Process Control. In addition, this artifact is intended for people with a low education level so that the purposely-developed artifact would help them to learn while they are practicing with it. The second step must be performed using a prototyping approach.
- 4 Test the artifact using a training quasi-experiment based on the Research Model for End-User Training from Bostrom et al. (1990). This is the final step of the project, which helps to draw the conclusions from the proposed research.



**Figure 1 Training research process model**

**3. AN INFORMATION SYSTEMS DESIGN THEORY FOR AN EXPERT SYSTEM FOR TRAINING DEVELOPMENT**

This section presents the first step of the research process: the development of the Information Systems Design Theory for an Expert System for Training (ISDTEST<sup>1</sup>). This theory serves as the main source for the development of the training tools used in the present research. It is from this theory that the components for the development of the Expert System for Training (EST) and the, Information System for Training (IST) are taken.

**3.1 Information System Design Theory (ISDT)**

Walls et al. (1992) suggest a two-tier structure that lays out the components of an ISDT. Such a structure is composed of two main elements: the Design Product component and the Design Process component. Table 1 lists ISDT components.

**Table 1 Components of ISDT (Walls, Widmeyer et al. 1992)**

<i>Design Product</i>	
1. Meta-requirements	Describes the class of goals to which the theory applies
2. Meta-Design	Describes a class of artifacts hypothesized to meet the meta-requirements
3. Kernel theories	Theories from natural or social sciences governing design requirements
4. Testable design product hypotheses	Used to test whether the meta-design satisfies the meta-requirements
<i>Design Process</i>	
1. Design method	A description of procedure(s) for artifact construction
2. Kernel theories	Theories from natural or social sciences governing design process itself
3. Testable design process hypotheses	Used to verify whether the design method results in an artifact which is consistent with the meta-design

**3.2 Information Systems Design Theory for an EST**

Walls et al. (1992) believe that one of the concerns for researchers in the Information Systems area is the design of systems and the development of system design theories that address the question of how to establish relationships between components of a system to achieve a specific goal (Hilton 2003). One goal of ISDT is the creation of artifacts. Artifact

<sup>1</sup> Please pronounce ISDTEST as: "I-S-D-TEST".

creation relies on existing kernel theories that are applied, tested, modified, and extended through experience, creativity, intuition, and problem solving capabilities of the researcher (Walls 1992; Markus 2002; Hevner 2004).

Design science creates and evaluates IT artifacts intended to solve recognized problems in organizations (Hevner 2004). In addition, “the process of constructing and exercising innovative” IT “artifacts enable design-science researchers to understand organizational phenomena in context” (Hevner 2004, p. 77). The ISDT is proposed as a means to develop an ES to train people in the interpretation of  $\bar{X}$ -R charts (EST). A second (and reduced) version (IST) has to be created so that a comparison between both versions can be performed in order to assess EST outcomes. Table 2 lists the components of the ISDT for the present study.

**Table 2 Components of ISDT applied to Expert System for Training**

<i>Design Product</i>	
1. Meta-requirements	<ol style="list-style-type: none"> <li>1. Provide a framework of training</li> <li>2. Write algorithms for the most common five anomalies in the manufacturing industry in Aguascalientes, Mexico using “if-then” rules</li> <li>3. Increase the number of examples that can be solved during training sessions</li> <li>4. Interpret <math>\bar{X}</math>-R charts</li> <li>5. Identify and illustrate where the anomalies (if any) are located and provide a description of the corresponding corrective action</li> </ol>
2. Meta-Design	<p><i>An expert system for training that consists of:</i></p> <ol style="list-style-type: none"> <li>1. Process-specific knowledge base</li> <li>2. Inference engine</li> <li>3. A Graphical User Interface to retrieve and build examples</li> <li>4. Set of examples</li> <li>5. Pattern recognition/corrective action feature</li> </ol>
3. Kernel theories	<ol style="list-style-type: none"> <li>1. Statistical Process Control (Shewhart 1986)</li> <li>2. Architecture of an Assignable Cause Interpreter (Guh 2003)</li> <li>3. Framework for Research on End-User Training (Bostrom 1990)</li> </ol>
4. Testable design product hypotheses	<p>H1: <i>Training outcomes are equal or better with purposely-developed tools than using traditional means.</i></p> <p>H2: <i>Assuming H1 is true, using EST versus IST to train members of the workforce increases training effectiveness.</i></p>
<i>Design Process</i>	
1. Design method	<ol style="list-style-type: none"> <li>1. Object oriented techniques can link the design theory to an instance. Then, an object-oriented design methodology is the best suitable approach. Therefore, Unified Modeling Language (UML) will be used to identify all the potential elements of the expert system for training.</li> <li>2. Because a series of prototypes must be constructed, thus incremental prototyping is the approach to be used.</li> </ol>
2. Kernel theories	<ol style="list-style-type: none"> <li>1. Usability testing theory (Dumas 1999)</li> <li>2. Information Systems Research Approach (Nunamaker 1992)</li> <li>3. Unified Modified Language (UML) (Kobryn 1999)</li> </ol>
3. Testable design	<p>H3: <i>An EST that is developed through prototyping is more successful than a</i></p>

#### 4. DEVELOPMENT OF AN EXPERT SYSTEM FOR TRAINING BASED ON AN INFORMATION SYSTEMS

##### DESIGN THEORY

This section presents the second step of the research process: the development of the EST, and its reduced version the IST, based on the ISDTEST.

##### 4.1 Requirements Gathering for the EST

This section shows how the requirements for the EST were gathered based on the meta-requirements defined in the ISDT (see Table 3).

Past research on training identified a set of issues that have to be addressed. Among those issues are: scarcity of training materials (Hsu and Turoff 2002; Huang 2002), learning by doing is very important for trainees (Oldfield and Rose 2004), training costs (Bowman, Group et al. 1995; Irish 1995), trainees forget what they learn during training (Bucik and Muthu 1997), inadequate education (Mason and Antony 2000; Cheng, Ng et al. 2002), time constraints (Desai, Richards et al. 1999; Mazier 2002), and expertise availability (Nelson, Armstrong et al. 2002). These issues can be addressed by creating a 24x7 tool that is combined with a training strategy. Thus, a training tool that includes a set of attributes that addresses these issues stands a good chance of being successful. Taking into account these issues, Table 3 lists the identified issues and which attributes of the EST address them.

**Table 3 Requirements identified from the framework of training**

Issue	Attribute
Scarcity of training materials	<ul style="list-style-type: none"> <li>• Include the notes for the training course in electronic format</li> <li>• Allow trainees to create as many examples as they want</li> </ul>
Learning by doing	<ul style="list-style-type: none"> <li>• An easy to use interface that allows trainees to explore as many scenarios as they want, with a data sample</li> <li>• An interface that shows how the distribution changes as a data sample is manipulated</li> </ul>
Training costs	<ul style="list-style-type: none"> <li>• There are no fees to pay to experts since the system will be always available</li> <li>• Do not restrict the number of persons that can be trained with the system</li> </ul>

<sup>2</sup> A hypothesis for the design process phase was not tested because the artifact was created using a prototyping approach only.

Trainees forget what have been taught	<ul style="list-style-type: none"> <li>• Allow trainees to store their own examples</li> <li>• Trainees can reinforce their knowledge as many times as they want by reviewing their examples</li> </ul>
Time constraints	<ul style="list-style-type: none"> <li>• System must be developed in a platform most likely to exist in any training place and/or home so that the system always will be available to be used</li> </ul>
Expertise availability	<ul style="list-style-type: none"> <li>• Include a knowledge base that identifies unwanted patterns in data samples</li> <li>• Include an inference engine that searches data samples for unwanted patterns</li> <li>• Include help about how to use the system in electronic format</li> </ul>

#### 4.1.2 Build algorithms of a set of anomalies using “if-then” rules

The manufacturing industry identifies several unwanted patterns for quality control purposes. These patterns should be analyzed when products are being manufactured. A successful EST cannot be developed without the algorithms to detect these patterns. Such algorithms represent the knowledge base that should be included in the EST, and they are responsible for analyzing a set of data and for providing results to trainees.

#### 4.1.3 Increase the number of examples that can be solved during the training sessions

It is very important to connect theory to practice (van Delft 2001). In the case of training, this connection is through the solution of potential cases or scenarios. A training software tool should allow trainees to create their own examples, not only review an established pool of exercises. Although the pool of exercises can be big, still it has the characteristic of being limited. Taking this into account, the following attributes were identified as critical for the EST.

- Allow the creation of examples by interacting with the system through a GUI.
- Give the option of storing examples into the pool of exercises.
- Allow the modification of an example so that trainees explore different options with the same data sample.

#### 4.1.4 Interpret $\bar{X}$ -R Charts

An EST should be able to uncover unwanted patterns in a data sample. This is the main goal of analyzing  $\bar{X}$ -R charts. It is very important that the EST not only analyzes data but also to make an inference about what is happening in this data. This is a critical attribute for the EST: after analyzing data, the system must make an interpretation of a data sample in order to inform

trainees.

#### **4.1.5 Identify and illustrate where the anomalies (if any) are located**

After analyzing data it is extremely important to inform trainees about the actual state of a data sample. Such feedback allows trainees to visually identify what is happening and associate this chart with its corresponding description. For example, if a particular data set has an anomaly, the anomaly has to be identified by the system. Then, the system must show graphically which points in the sample are contributing to the anomaly. Also, the system must inform trainees what type of anomaly is present. This leads to the following critical attributes:

- Create a plot of the data sample before it has been analyzed
- If an anomaly is present, modify the plot so that the points that are contributing to a particular anomaly are perfectly distinguishable from the rest
- Inform the trainee about the result of the analysis in textual form
- Show graphically the distribution that a particular data set has
- Each time that any point is modified, modify the plot of the distribution.

#### **4.2 Subjects testing the prototype of the EST**

The methodology used in this study implemented ISDT as described by Walls et al. (1992). The EST was developed using the guidelines for Phase I from Walls et al. (1992), Table 5, p. 46) and the prototyping approach as suggested by Nunamaker (1992). In addition, versions of the EST were developed through incremental prototyping. Four persons tested the different prototypes developed by the researchers. These evaluators have been working in developing information systems for about three years on average. In addition, they have experience in maintaining software, and have knowledge of three different systems analysis and design approaches (object oriented, structured and rapid application development) and two operating systems (Windows and Unix). Evaluators had the same demographic characteristics as the subjects who were recruited for the test portion of this research. Testing was conducted in an

unstructured approach, that is, requirements were collected through informal individual interviews; records were not kept. New requirements and observations made by evaluators of a current prototype were addressed in a new prototype, which, in turn, was evaluated by the same testers.

After several prototypes had been constructed, a usability test and a pilot test were conducted with different evaluators in order to create the final prototype. These two tests led to the development of the final version of the EST and IST as well.

#### **4.3 Software elements for the research**

The research aims to test the effectiveness of training using an EST and an IST in a complex task: Interpretation of  $\bar{X}$ -R charts (part of SPC) for industrial processes. The task is more complex than learning how to use Microsoft Word, Microsoft Excel, or email, which were used in previous studies (Bowman 1995; Desai 2000). SPC deals with some statistical and mathematical concepts, pattern recognition and the corresponding corrective action. Such functionality can be incorporated into an EST. The EST's knowledge base includes the rules of the statistics and mathematics needed and the heuristics for pattern recognition. The EST's interface can plot the  $\bar{X}$ -R charts and how a data sample is distributed. In the case that the sample has anomalies, the EST can highlight them in the plots. In addition, as the EST applies the rules and identifies  $\bar{X}$ -R anomalies (patterns) present in the sample, it can help to learn how to identify such a problem. An ES that performs pattern recognition and identifies where in the sample the anomaly is present (in a visual way using a GUI) was developed for the present study.

It is extremely important that the EST must be easy-to-use. A well-designed interface can give the trainee a much clearer overall picture of the system's view (Vokurka 1996; Hayes 1999). A GUI can be tailored so that trainees only point-and-click and drag-and-drop while using the EST. Further, using GUIs minimizes the dialogue between the EST and trainees, and can

reduce the need to train the trainees in the use of the EST.

The IST is an abbreviated version of the EST. The IST does not include ES techniques so that it cannot make sensitive data analysis. Thus, trainees using this version cannot benefit from using this feature.

#### **4.4 Usability Test**

A usability test was conducted in order to assess whether trainees would be able to use the EST and the IST easily. The usability test was conducted after the final prototype was completed based on evaluations made by four evaluators. The usability test was conducted in a structured approach. Subjects were asked to use the full version of the training system (EST) for three hours (the full version, in effect, includes the reduced version: IST). They completed a pre-test and a posttest questionnaire. The questionnaire had two sections. Section 1 was applied before the test, and section 2 after subjects made use of the system. Questionnaires were developed using suggestions from current literature (Dumas 1999) as well as some items from an usability test previously conducted<sup>3</sup>. Open-ended questions were added to collect evaluators' recommendations of new features and improvements for the artifact.

Potential participants were invited based on two criteria: first, they are working in software development-related jobs; and second, they have some knowledge of SPC. Twenty-seven students in the ninth semester of the Computer Science bachelor program<sup>4</sup> in the Autonomous University of Aguascalientes (UAA) in Mexico were invited to participate as usability testers. They were invited because, in a previous statistics course, they were taught SPC and they held a software development-related job. Nineteen of them participated in the test, which represents a 70.37% response ratio.

The tests were conducted with all participants at the same time in the same computer

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<sup>3</sup> The usability test was conducted at the University of Washington for its UW Libraries' Information Gateway. The test was conducted through an online survey. University of Washington, U. o. (2004). Usability test for the University of Washington Librraies' Information Gateway, University of Washington. 2005.

<sup>4</sup> The Computer Science bachelor program at the UAA is composed of ten semesters of course work.

laboratory. All computers had exactly the same technological characteristics in order to eliminate any problems related with hardware specifications.

Testers detected seven problems. Those problems were addressed and resolved after the first usability evaluation. Results obtained through open-ended questions and comments made for closed-ended questions were grouped together into two major categories: suggestions and errors found. The usability testers made nine suggestions for enhancements.

Suggestions were qualified as: “definite”, “possible”, and “discard”. Suggestions qualified as “definite” were resolved (number 1, 2, and 8) because those would increase usability, minimize problems operating the EST and IST, and would increase both systems’ quality. Only one suggestion was qualified as “possible” (number 6, *Allow to capture sample manually*). It was considered but discarded because target users are more likely not to be proficient in using computers. This issue would require pre-training users in the use of the keyboard, especially function keys, num lock, tab, caps lock, enter, space bar, and the numeric keyboard. In addition, users would need to define a range for the data set. Thus, adding the use of a computer keyboard would reduce the system’s usability. Suggestions qualified as “discard” are numbers 3, 4 5, 7 and 9. Those were ignored because they were not relevant or do not add value to both systems. Table 4 shows a list of the suggestions.

**Table 4 Suggestions made during first usability evaluation**

Suggestions	Times Mentioned
1. Standardize font	6
2. Include specific help by topic, not general help	1
3. Include a number to each point based on order	1
4. Add hypothesis tests	1
5. Change graphics to 3D	2
6. Allow to capture sample manually	3
7. Add more colors to graphics	2
8. Add a message that displays how to use <i>Create own examples</i> GUI	1
9. Allow window controls (maximize, minimize, close)	2

A second usability evaluation was conducted to determine if the issues detected were

resolved. Testers were those of the first usability evaluation, which increased system evaluation reliability and helped to strengthen results. In the second round of evaluation, only the posttest questionnaire was applied because there was no mortality of testers. Results from the second usability evaluation showed changes compared with the first evaluation. The results show less dispersion. In all cases, a reduction in the means as well as the standard deviations can be observed.

In addition, regarding the question “Would you recommend this system to other persons?”, eighteen of testers said “Yes” (compared to sixteen in the first evaluation), zero said “No” (same number as first evaluation), and one said “Do not know” (compared with three in the first evaluation). Thus, the subjects were more likely to recommend the system after the second evaluation. From both usability evaluations, results show that the system is very likely to have high usability for trainees. Thus, after completely addressing the issues and suggestions made by usability testers, the final version of the EST and IST were ready to be used.

## **5. TEST THE DESIGN THEORY USING THE ARTIFACT**

This section presents the third step of the study: an evaluation of how the two different systems behaved using the same training approach. Evaluations of the artifact were made based on learning outcomes. Testing the artifact was conducted following the guidelines for Phase II, from Walls et al. (1992, see Table 6, p. 47).

### **5.1 Information Requirements Pooled from Phase I Testing**

EST requirements were gathered and tested as described above. After conducting these tests, the final EST was ready for testing. Once the EST was developed, it was necessary to make some changes to develop the IST.

### **5.2 Building the Two Training Systems: EST and IST**

After the EST was developed, modifications were made to it resulting in the IST. The following list mentions what changes were made to EST in order to develop the IST:

1. Eliminate the GUI that allows creation and storage of self-created examples. This procedure was performed by deleting the source code and the button that calls this interface from the main EST's GUI.
2. Eliminate the ES data analyses techniques from the training system. The source code that includes the expertise in identifying  $\bar{X}$ -R charts was removed from the EST.
3. Compiling the IST. After the first two steps were performed, the resultant source code was compiled so that the object code for IST was created.

### **5.3 Developing Test Cases**

The first author created a total of eighty cases for training purposes. A pool of thirty cases was included as text files into both versions of the developed artifacts – EST and IST. In addition, a pool of fifty more cases was prepared for use during training sessions. Five sets of ten of the cases were used in each of the training sessions. Some cases included one or more anomalies, and some cases were anomaly-free. All anomalies that the systems analyze were present in the set of designed cases.

### **5.4 Test Procedures**

In total, the final step was conducted using three groups. Two groups tested the two versions of the system – one tested the EST and the other tested the IST. In addition, a third group was added for control purposes. This new group did not make use of any system, but only made use of traditional training means. Each group had twenty-five testers. The size of the class was limited to 25 because this is the number of computers available in the computer laboratory where training was conducted for the two groups using a system.

Testers were free to enroll in any section; they were not assigned to groups by the researcher. Two persons who were not associated with the study conducted the enrollment process. Participants did not know which course would use which version of the system, or if any course would use a system at all. Participants appeared to have made their selection based on

the available dates in which the course was offered. The type of training was randomly assigned to each section after the enrollment process was finished.

## 5.5 Research Design

In order to have a better understanding of the effect of training outcomes in the workforce, it was decided to conduct a quasi-experiment using the population most likely to require SPC at their workplace: adults that have not been previously trained to use SPC. These individuals may be employed or looking for work in manufacturing companies. The study only included people who were required by their employers or who wanted to learn the interpretation of  $\bar{X}$ -R charts.

Several companies in Aguascalientes, Mexico manufacture products such as: microchips, frozen produce, rotational modeling polyethylene containers, and auto parts. All of these companies have quality control techniques in place. Several were invited to participate in the study through four organizations that have relations with them. These organizations are: Consejo de Ciencia y Tecnología del Estado de Aguascalientes<sup>5</sup>, Servicio Estatal de Empleo<sup>6</sup>, Instituto de Capacitación para el Trabajador del Estado de Aguascalientes<sup>7</sup> and the UAA. An invitation that included the description of the course and necessary characteristics of participants was sent to these four organizations so that they invited only those businesses that could offer participants that met the criteria. Participants included only adult individuals with similar levels of education and work experience. An invitation that included a description of the purpose, contents, and objectives of the courses was sent to local organizations. Additional information was provided through telephone and face-to-face discussions in order to answer questions and explain issues related to training courses. Each organization invited only persons that most likely would need SPC in their future jobs.

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<sup>5</sup> The Science and Technology Council of the State of Aguascalientes.

<sup>6</sup> The State Employment Service.

<sup>7</sup> The Training Institute for the Worker in the State of Aguascalientes.

The quasi-experiment was designed to test the feasibility of the ISDT as prescribed by Walls et al.; external validity and generalization were not intended. To the extent possible, a controlled environment was created to minimize the effects of these extraneous factors on the quasi-experiment results.

Each group had five training sessions about SPC using different training tools. Only one instructor was used for the study in order to control the effects of teaching styles and to avoid compensatory coaching for any group. The three groups received the same printed notes for the course. In addition, one group (ESTG) used the Expert System for Training, while the second group (ISTG) used the Information System for Training; the third group (NOSG) was trained using traditional means – a blackboard, markers, etc. Sessions were organized into three parts. In the first part, trainees in the ESTG and ISTG groups were told to review instructions provided online and on paper, while the NOSG group were given a lecture. In the second part, cases were solved and presented, and in the final part trainees were asked to explore their own data sets, which were collected on paper (ISTG and NOSG) or in text files (ESTG) by the instructor (who is the first author). At the end of the day, the researcher examined the trainees' solved examples to assess their motivation to learn. In all three groups trainees' results demonstrated a high level of motivation. Results in performance of the three experimental groups were compared in order to assess which group had the best learning. Table 5 shows the similarities and differences between training courses.

The study measured the effectiveness of training (the dependent variable) by applying an exam at the end of the training course. The three training courses were conducted as follows, on a daily basis, for a set of five consecutive days:

- The ESTG group made use of the EST, which is the complete version of the developed training tool using the ISDTEST. The EST allows trainees to review stored examples, create their own examples, analyze examples (either stored or created), review electronic notes of the course, and store created examples. In addition, EST uses ES techniques to detect

when an anomaly is present in a data. The ESTG group received a package with the notes for the course. During the first session, participants first received a 15-minute demonstration about how to use the system. Subsequent sessions began with a brief introduction to the topic of the day. Then, participants read that part of the material but did not receive a lecture. In the next activity, the group (conducted by the researcher) solved a set of ten examples previously prepared by the researcher and some examples proposed by participants. After that, trainees were allowed to create and solve their own examples. Examples were plotted and saved as text files using the EST. Each participant was required to plot and save at least ten examples. Every day the researcher retrieved and reviewed all text files to verify whether participants were engaged in building their own examples. For this group, the instructor functioned as a consultant: only answering questions but not lecturing at all.

- The ISTG group made use of the IST, which is the reduced version of the developed training tool using ISDTEST. The IST allows trainees to review stored examples, create their own examples, perform data analysis, and review the electronic notes for the course. This version does not have ES techniques to detect anomalies in data samples, but only makes a straightforward analysis of a data set. This version of the training system only identifies when an anomaly is present. The ISTG group received a package with the notes for the course. During the first session, participants first received a 15-minute demonstration about how to use the system. Subsequent sessions began with a brief introduction to the topic of the day. Then, participants read that part of the material but did not receive a lecture. In the next activity, the group (conducted by the researcher) solved a set of ten examples previously prepared by the researcher and some examples proposed by participants. After that, trainees were allowed to create and solve their own examples. Examples were plotted and solved in the system. Subjects determined if a chart was normal or abnormal; subjects identified anomalies that may have been present and which points contributed to the anomaly. They transcribed these analyses on paper sheets previously prepared by the

researcher. Each participant was required to plot and save at least ten examples. Every day the researcher reviewed all paper sheets to verify whether participants were engaged in building their own examples. For this group, the instructor functioned as a consultant: only answering questions but not lecturing.

- The NOSG group was given traditional training. That is, they did not use any type of training system. The NOSG group received a package with the notes for the course. During each session participants were lectured on the topic of the day. In the next activity, the group (conducted by the researcher) solved a set of ten examples previously prepared by the researcher and some examples proposed by participants. After that, trainees were allowed to create and solve their own examples. Examples were plotted and solved by hand. Subjects determined if a chart was normal or abnormal; subjects identified anomalies that may have been present and which points contributed to the anomaly. They transcribed these analyses on paper sheets previously prepared by the researcher. Each participant was required to plot and write at least ten examples. Every day the researcher reviewed all paper sheets to verify whether participants were engaged in building their own examples. For this group, the instructor functioned in the traditional role as lecturer.

**Table 5 Summary of differences and similarities in training courses**

<b>Feature</b> <b>Course</b>	<b>Tool(s) used</b>	<b>Topics were studied by</b>	<b>Materials given to trainees</b>	<b>Self-created examples</b>	<b>How trainees progress was assessed</b>
<b>ESTG</b>	EST	Self-study	Course notes	Collected in text files	Through reviewing text files created through the EST
<b>ISTG</b>	IST	Self-study	Course notes	Collected on paper	Through reviewing examples written on paper
<b>NOSG</b>	Blackboard and markers	Lecture	Course notes	Collected on paper	Through reviewing examples written on paper

Each course was offered during the same time frame (mornings on weekdays) over three consecutive weeks. ISTG was offered the first week, ESTG was offered the second week, and NOSG the third week. Participants were free to enroll in any of the three courses. Enrollment

was conducted on a first come first served basis. After enrollment was completed, the type of training (EST, IST, traditional) was randomly assigned to each course.

The EST and IST courses were offered in the same computer laboratory at the Autonomous University of Aguascalientes (UAA) so that any issues related with technology differences were removed. The traditional training course was offered in a classroom at the same University's facilities. The researcher taught all three courses.

Each subject was asked to sign a letter of consent stating that his/her participation in the study is voluntary. Subjects could drop out of the study at any time they wished. Demographic data about each participant was collected at the beginning of the quasi-experiment.

In order to assess whether participants were engaged in the learning process, the researcher reviewed participants' self-created examples. Based on the examples created by participants, it was very clear that all of them wanted to learn. No single participant failed to deliver his/her set of ten examples every day. Thus, it can be said that they were engaged in the training process. In addition, self-created examples were increasing in complexity. That is, the first examples were very simple and most of them only included a single anomaly. However, as participants advanced through the training sessions, they created examples in which two or more anomalies were plotted.

At the end of the fifth session for each group, an exam was administrated to participants to measure learning in the training sessions. The exam consisted of a set of fifteen exercises. Some exercises contained anomalies and some did not. Each exercise was graded in two parts depending on the type of exercise. Correct anomaly identification is composed of two actions: first, identify an anomaly correctly; second, identify which points are contributing to the anomaly. Based on that, an exercise with anomalies was graded as follows: a point was awarded when a participant correctly identified a particular anomaly (part one) and a point was awarded when a participant correctly marked the points that contributed to the anomaly identified. An exercise without anomalies was graded as follows: a point was awarded when a participant correctly

identified the chart as anomaly-free (part one). Only one point was awarded because if participants were guessing, then they were failing in the two required actions mentioned before. Thus, they were losing two points, not gaining one.

At the end of the quasi-experiment, a questionnaire was given to participants in order to measure the outcomes of the training program.

### **5.6 Comparison of Performance Among the Groups**

The skills trained were the interpretation of  $\bar{X}$ -R charts for SPC in industrial processes. The course contents were SPC basic concepts, description of the different anomalies that  $\bar{X}$ -R charts identify, and practicing with a set of exercises (some stored into the EST database and some created by trainees). However, the EST is a training tool that allows the creation of examples. Manipulation of data was available only for ESTG group.

No participants dropped the courses. Hence all of them completed all five sessions and wrote the final exam. Table 6 shows the descriptive statistics regarding final exam scores for the three groups. The distribution for the ESTG was not normal with 11 of 25 subjects scoring a perfect 10. It was negatively skewed. Following the suggestion made by Tabachnik and Fidell (1996), ESTG skewness (-1.328) is beyond two times SES ( $\pm 0.968$ ), which means that sample is not normally distributed.

In addition, the distribution for ISTG group was not normal with 12 of 25 subjects scoring either a 9 or a 9.5. It was negatively skewed but not as skewed as the first group (ESTG). ISTG skewness (-1.050) is beyond two times SES ( $\pm 0.968$ ), which means that sample is not normally distributed.

Contrary to ESTG and ISTG groups, data for NOSG was not skewed. NPSG skewness (-0.546) is between two times SES ( $\pm 0.968$ ), which means that sample is normally distributed.

**Table 6 Descriptive statistics for the final exam results**

	<b>ESTG</b>	<b>ISTG</b>	<b>NOSG</b>
<b>Mean</b>	9.29	8.29	5.69
<b>Mode</b>	10	9.00, 9.50	5.75, 6.75
<b>Std. Deviation</b>	0.89	1.07	1.90

<b>Range</b>	3.25	4.0	6.25
<b>Minimum</b>	6.75	5.50	2
<b>Maximum</b>	10.0	9.50	8.25
<b>Skewness</b>	-1.328	-1.050	-0.546
<b>Std Error of Skewness</b>	0.464	0.464	0.464

Time required for completing the exam was recorded for each subject as minutes required. Descriptive statistics for time required for the three groups are shown in Table 7. The average time was just below 22 minutes. There was no significant correlation ( $r=-0.152$ ,  $p=0.469$ ) between time taken and score. For the ISTG the average time was just above 22 minutes. There was no significant correlation ( $r=0.100$ ,  $p=0.635$ ) between time taken and score. The average time was just above 34 minutes for the NOSG. There was no significant correlation ( $r=0.317$ ,  $p=0.123$ ) between time taken and score.

**Table 7 Descriptive statistics: time required for answering the exam**

	<b>ESTG</b>	<b>ISTG</b>	<b>NOSG</b>
<b>N</b>	25	25	25
<b>Range</b>	16	16	19
<b>Minimum</b>	15	15	22
<b>Maximum</b>	31	31	41
<b>Mean</b>	21.84	22.40	34.08
<b>St. Deviation</b>	3.90	5.00	6.18

Participants answered a demographic survey. Except for minor differences the three groups were similar based on age, gender, level of studies, current employment status, and whether participants had previous knowledge/experience on SPC.

Data analysis shows that the three groups performed differently. By comparing overall grade means and time required for answering the final exam means, overall, ESTG subjects performed best. The ESTG group mean (9.29) is one full point higher than the ISTG group mean (8.29), and 3.7 points higher than the NOSG group mean.

In addition, ESTG subjects, on average, required less time to complete the final exam. Thus, overall, subjects in the ESTG had the best performance and required less time for answering the same exam.

Subjects' mean grades were tested using ANOVA. The test shows that the means of the three groups are different. Table 8 shows descriptive statistics.

**Table 8 Summary of descriptive statistics**

Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	25	9.29	.8859	.1772	8.9243	9.6557	6.75	10.00
2	25	8.29	1.0721	.2144	7.8475	8.7325	5.50	9.50
3	25	5.69	1.8961	.3792	4.9073	6.4727	2.00	8.25
Total	75	7.756	2.0314	.2346	7.2893	8.2241	2.00	10.00

A test of homogeneity of variances (Levene's Statistic) shows that the three groups' variances are not equal ( $p < 0.001$ ). While this violates an assumption of ANOVA, failing to meet this "assumption of homogeneity of variances is not fatal to ANOVA, which is relatively robust, particularly when groups are of equal sample size", which is the case of the study (Garson 1998). Table 9 shows that the training method makes a difference in performance ( $p < 0.001$ ). Hence, the training method is important and depending on the type of training, training outcomes are different. It is important to control the overall alpha error rate while testing each of the pairwise differences for statistical significance. In order to do that a Tukey HSD and Ryan-Einot-Gabriel-Welsch Range (REGWQ) post hoc analysis was conducted. Post hoc analysis shows that all pairwise differences were statistically significant: The ESTG group had better performance than any other training approaches, and the ISTG group's performance was better than the NOSG group.

**Table 9 ANOVA table for comparison of training groups**

	Sum of squares	df1	Mean Square	F	Significance
Between Groups	172.667	2	86.333	46.841	.000
Within Groups	132.705	72	1.843		
Total	305.372	74			

As a backup, nonparametric tests, Kruskal-Wallis, Median, and Dunn-Sidak paired t-test were also performed and results are highly significant. The ESTG group had better outcomes than the ISTG group ( $p < 0.004$ ) and the NOSG group ( $p < 0.001$ ). The ISTG group had better outcomes than the NOSG group ( $p < 0.001$ ).

## 6. CONCLUSIONS

The present study was conducted in a three-step research process. Each step

intends to address a different aspect of the overall study. The following sections present the conclusions for each step in the study.

### **6.1 BUILD THE THEORY USING ISDT**

“Designing in IS involves designing products, work practices, information, and technology” (Walls et al. 2004, p. 50). In addition, many of the elements of information systems are artifacts that have to be designed (Walls et al. 2004).

Walls et al. (2004) define four levels of usage for ISDTs. Such levels are: 1) ISDT is used as a cloak of theoretical legitimacy, 2) ISDT is used as a common language and framework, 3) ISDT is used as a way of generating new insights about the characteristics of a new class of information systems, and 3) the richness of ISDT itself is enhanced. Thus, ISDT theories allow the developing of a new class of artifacts –such as the EST.

Taking into account such categorization of ISDTs, the ISDTEST is located at level three, which “is the desirable level of ISDT usage that will advance the development of endogenous IS theories” (p. 56). The ISDTEST presents a new class of artifacts, in this case, the EST. The EST is a training tool developed to train people that have a low education level currently working –or wanting to work– in manufacturing organizations. This type of persons requires tools different than those intended for educated people.

ISDTs are also very useful when the artifact to be developed is of a new type. Software systems traditionally are developed using feedback obtained from users. However, when knowledgeable users are not available, previous research is a very useful source of information so that the critical requirements can be identified. It was

very important to identify theories related to this study. Theories that allowed the identification of the most important features that the EST should have. Thus, using the design research approach for developing software systems has a big impact in the outcomes.

Before conducting this study, the lead researcher developed several information systems. All these systems were developed using a traditional approach based on users' needs and researcher's experience, but were not developed using previous research. It was really hard to match what users had in mind with what users really need and with what this researcher thought was what users required. Comparing the previous approach with the design research approach, it is very clear that since the first prototype the main issues were identified and addressed. Using the design research approach requires less time, less resources, and decreases the cost for developing an information system. Thus, the design research approach is more comprehensive for developing information systems than a traditional approach.

Sometimes, systems developers tend to ignore features or architectures that might work perfectly for a new system. However, by using a design research approach, systems analysts can develop more robust information systems that might require less effort, time and resources. By creating an ISDT system analysts can show an initial model to users so that both, analysts and users, can communicate easily about issues regarding the new system. Such information systems would be more maintainable, which would decrease systems costs and would increase the chance of users' acceptance. By using existing kernel theories, the final prototype would include all the features that the users would require so that minor changes would be added in order to have a system that complies with all users' requirements. Hence, ISDT helps to

minimize the probability of overlooking important issues for a new particular software system.

## **6.2 DEVELOP AN EXPERT SYSTEM USING ACI AND ISRA**

A major contribution of the present study was the development of a prototype of the Expert System for Training. Such type of system does not exist currently. The EST is intended to train people with low education in a specific quality control technique used in manufacturing. Based on theory, the artifact was developed using a prototyping approach. Several prototypes were constructed and evaluated using pre-solved examples and pre-designed errors. It was very useful to develop the artifact by prototyping because each version was tested so that errors and improvements were identified and addressed. This approach also helped in developing a system that was up to what users would require. After having a prototype with full functionality, further prototypes were tested by four persons. This process helped to improve and enhance the EST. This is a very important lesson learned because a prototype can be evaluated by users and developers at the same time so that both developers can understand what users want and users can understand what developers want to achieve. Hence, the system will evolve until it becomes the final software product. Product that users feel they contribute to develop so that this would increase the chances of users' acceptance.

When it was decided that the final version was completed, a usability test was conducted. After the usability test was completed and issues discovered and suggested by users were addressed, the final version of the EST was ready. Then, based on the EST the IST was created. This procedure delivered the two systems used to test the artifact for this research.

This step of the study brings an opportunity for developers that are trying to develop software training systems. This step delivers an initial model than can be used for developing the first prototype. Hence, this is an initial requirements gathering process. Then, further prototypes can be developed and evaluated until the final training system is completed. However, it is important to inform that the algorithms created for the EST are a solution for a particular training case. Thus, new algorithms should be created in order to develop a new training tool based on the ISDTEST.

By comparing how participants performed, we found persuasive evidence that the EST helps trainees learn better and faster than those trained with traditional means. In addition, this artifact has special characteristics that previous SPC systems do not have. First, it allows direct data manipulation so that trainees can learn by creating different scenarios based on the same data. Second, since the artifact works in real time, it allows trainees to identify whether a data sample is behaving within required manufacturing parameters. And third, this artifact motivates learning during training sessions. It was observed that participants using the EST were more eager to participate than their counterparts in the other two groups; they always showed up on time and created more than the number of required exercises.

### **6.3 TEST THE THEORY USING THE RESEARCH MODEL FOR END-USER TRAINING**

The third step was to test both versions of the training system plus a traditional training approach to assess which approach delivers better training outcomes.

Given that most of participants in both ESTG and ISTG groups held a high school diploma (96%) and they did not have enough statistical skills, it is very clear that they performed extremely well. For example, ESTG group grades are negatively skewed.

Eleven out of twenty five scored a perfect 10 and twenty-three out twenty-five scored an 8 at least. Scores for the ISTG group are also negatively skewed, not as ESTG group. No participant in the ISTG group scored a perfect 10. However, eighteen out twenty-five scored an 8 at least. Comparing these results with the grades from the control group (NOSG) indicates that both artifacts created with a design research approach really make a difference in learning outcomes. For example, the mode in ESTG group was 10, for the ISTG group were 9 and 9.5 (each one appeared four times), and for the NOSG were 5.75 and 6.75 (both appeared three times). These results show clearly that participants in ESTG and ISTG outperformed participants in NOSG.

#### **6.4 IMPORTANCE FOR PRACTICE**

“Both academics and practitioners accept the gap between theory and practice” (Martin 2004). However, it is argued that both should accept that practice and theory complement each other (Martin 2004) rather than competing. “Design theories do not only emerge from practice and practical knowledge. They emerge also from general theories of explanatory character and from ideas of good design “(Goldkuhl 2004). Thus, design research offers an excellent approach for addressing practitioners’ needs.

ISDT is a means to produce relevant research because ISDT is capable of developing information systems that are applicable to specific practice needs. By addressing such needs, ISDT helps organizations to be more competitive, innovative, and to respond quickly to changes in their environment. The ISDTEST created for the present research not only provided a training tool for industrial organizations that want or have in place SPC for quality control purposes, but also it provides a new set of characteristics that should be included in systems with the same purpose.

In addition, the present document can be used as guidelines for developing new type of systems that address very specific issues for practice. However, the ISDTEST cannot be used as a general guideline for any type of systems, even if they would require ES techniques.

Another contribution to practice is a general process for developing especial systems. The three-step process presented in section 3.1 might be useful for developing information systems that are based on theory not only on users' requirements. This process can serve as a guideline for systems analysts and software project leaders as well.

#### **6.5 LIMITATIONS OF THE STUDY**

There are some limitations of this study. The researcher is not really an expert in using ISDT as research approach, which means that he could have ignored important kernel theories for the design theory and/or overlooked attributes that might need to be included in the system. In addition, new research has been published in the IS field. Thus, a second study making a new literature review of theories could have different outcomes.

Experts in training in SPC that also have the knowledge in developing information systems were not available. Hence, testers could have ignored important issues during evaluations and were not addressed. Training systems (EST and IST) might can be enhanced and improved by using a different programming language (e.g. an AI language), or a different AI approach (e.g. fuzzy logic) which could increase usability and quality. In addition, using non-prototyping systems development approach might result in a different training system.

Since a quasiexperimental design was used in the third step, findings cannot be generalized. Even though statistical power is strong and hypothesis testing outcomes were very good, sample groups are not representative of the population and external validity is not strong. Sample may represent part of the population, but not the population itself. Hence, results might be different if a representative sample is used. In addition, results might be different if a bigger sample is used in the third step of the study. Only one instructor was used for the three groups in order to control for teaching differences. However, there is a chance that the instructor was more hands-on involved with one group and this might be reflected in the outcomes.

In addition there might be another issues not identified in the study that might affect the outcomes.

#### **6.6 AREAS FOR ADDITIONAL RESEARCH**

The same study can be conducted with a representative sample of the intended population in order to strengthen external validity. In addition, a longitudinal study can be conducted so that several evaluations of participants can be performed. This is especially the case for evaluations in a real setting so that subjects' learning can be analyzed. Such a study could evaluate not only whether participants learn during training courses but also how much they retain after training, and what is their real on-the-job performance.

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