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Effectiveness of Experiment Design Guidelines for Virtual Laboratories in the SDVIcE tool

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Abstract: Laboratory work is an integral part of science and engineering education. The nature and practices of laboratories have been changed by two new technology-intensive automations: simulated labs and remote labs as alternatives for conventional hands-on labs. Instructors play a critical role in leading effective laboratory experiences. The effectiveness of the laboratory work depends on the quality of the learning designs. The engineering instructors are not trained in designing effective virtual laboratory experiments. In order to facilitate the engineering instructors process of scientific experiment designs we have designed and developed guidelines and made them available online in the form of the SDVIcE tool. These guidelines cover all the major aspects of the scientific experiment design process such as decision regarding the broad goal of the experiment, formulation of learning objectives, selection of instructional strategy aligned to the goal of the experiment, designing tasks and assessment aligned to the instructional strategy and the learning objectives. We adopted the S-D-I-V-E (Scoping-Development-Internal Review-Validation-External Use) methodology synthesized from the existing methods followed by international bodies for developing each of the guidelines. In this paper we discuss the evaluation of the effectiveness of these guidelines by assessing the quality of the experiment designs by means of a rubric. As part of the evaluation we carried out field-testing with ten engineering instructors who designed four experiments each initially without using the guidelines and later using the guidelines. The scores of the experiment designs as per the rubric before and after the use of guidelines are analysed to arrive at the results regarding the effectiveness of the guidelines. The difference in the scores indicates that there is overall 80% improvement in the quality of the experiment designs after the engineering instructors used the guidelines. The instructors formulated learning objectives at higher cognitive levels such as analysis, evaluation and creation and also incorporated active learning strategies during the various phases of the experiment process after using the guidelines that was missing before the use of guidelines.

Keywords: Virtual laboratories, Experiment design guidelines, Effectiveness

1. Introduction

The effectiveness of the laboratory work depends on the quality of the learning designs. The engineering instructors are not trained in designing effective virtual laboratory experiments. There are frameworks, guidelines and tools that the instructors can use for learning designs. The limitations of these are that they are not comprehensive and are not specific for the virtual laboratory experiment designs. Due to this the instructors do not find the existing guidelines useful in designing effective virtual laboratory experiments. In order to address the gap we designed and developed nine sets of guidelines through the S-D-I-V-E (**S**coping-**D**evelopment-**I**nternal Review-**V**alidation-**E**xternal Use) methodology derived from literature. In order to make these guidelines accessible they are made available in the form of the online SDVIcE (**S**cientific **D**esign of **Vi**rtual lab **E**xperiments) tool available at the URL - http://vlabs.iitb.ac.in/vlab_tool_alpha/. This tool takes the instructors step-by-step through the experiment design process providing help and examples at each step. In order to evaluate the effectiveness of the guidelines we carried out field-testing with ten engineering instructors. Each instructor designed four experiments initially without using the guidelines and later using the guidelines. The quality of the experiment designs before and after was assessed by means of a rubric developed for the same. The research question of our study is: What is the effectiveness of the experiment design guidelines in improving the quality of the design of experiments and lab manual for using existing virtual labs? The results of the comparison of the rubric scores before and after using the guidelines indicate an average 90% improvement in the quality of the experiment designs. Hence we can claim that the guidelines are effective in improving the quality of the experiment designs.

2. Related Work

2.1 Theoretical Basis of our work

The Engineering laboratory instruction has reached a crisis level due to inadequate instructional resources. There is a lack of challenge and initiative provided to the students in performing experiments. (Susan R. Singer et al., 2006, Bryce, T. G.K.Robertson, I. J., 2008,N. Cagiltay et al., 2011) Instructors play a critical role in leading effective laboratory experiences. Improving instructors' capacity to lead laboratory experiences effectively is critical to advancing the educational goals of these experiences. This can be achieved by developing more comprehensive systems of support for Instructors. (Mishra & Koehler, 2006; Angeli & Valanides, 2009; Tsai & Chai, 2014) the Instructors can achieve their laboratory goals if they design Student centered effective experiments, based on scientifically proven instructional strategies exploiting the features of virtual labs. (Kathleen Scalise et al., 2011) through a literature review of 79 studies provide a research-based evidence about best practices in instructional design for virtual laboratories and science-simulation software. From the literature synthesis five categories emerged as a Design Principles Framework for Simulations and Virtual Laboratories, based on the grades 6–12 research literature, which may be used to design and develop science-simulation and virtual-lab products, as well as make decisions about whether and which Simulations and Virtual Laboratories. (Nuri Balta, 2015) have proposed the science laboratory instructional design (SLID) model as shown in the figure. They expect that SLID will enhance the process of teaching and learning science in laboratory setting. (Thomas W. Shiland, 1999) suggest specific ways laboratory activities might be modified (instead of completely changed) to increase understanding in science with constructivism as the basis for the change. (NACOL Committee on Online Science Kemi Jona & John Adsit with Allison Powell, 2008) have proposed quality guidelines for developing and evaluating student scientific investigations and surrounding course content. The four curriculum standards identified as principles of effective laboratory experiences by the National Research Council in America's Lab Report (NRC, 2006) are 1. Clearly Communicated Purposes 2. Sequenced into the Flow of Instruction 3. Integrated Learning of Science Concepts and Processes and 4. Ongoing Discussion and Reflection.

2.2 Our Solution

The literature review on the existing frameworks, models and guidelines indicates the following: All the existing frameworks and models are for learning designs for either classroom learning material or traditional science laboratories. The SLID framework specifies the components of the laboratory experiment instructional design but not for the virtual learning environment and for the engineering context. The guidelines are not specific so teachers may not find these very useful in implementation of their day-to-day teaching. The guidelines should be such that the instructors can come up with the learning material to be given to the students with minimum time and resource demands. Also when implemented the learning material administered should lead to effective laboratory work.
We designed and developed the virtual laboratory experiment design guidelines for the engineering instructors and made them available online in the form of the SDVIcE tool to address the problems with the existing solutions.

3. Methodology

3.1 Design and development of guidelines (S-D-I-V-E)

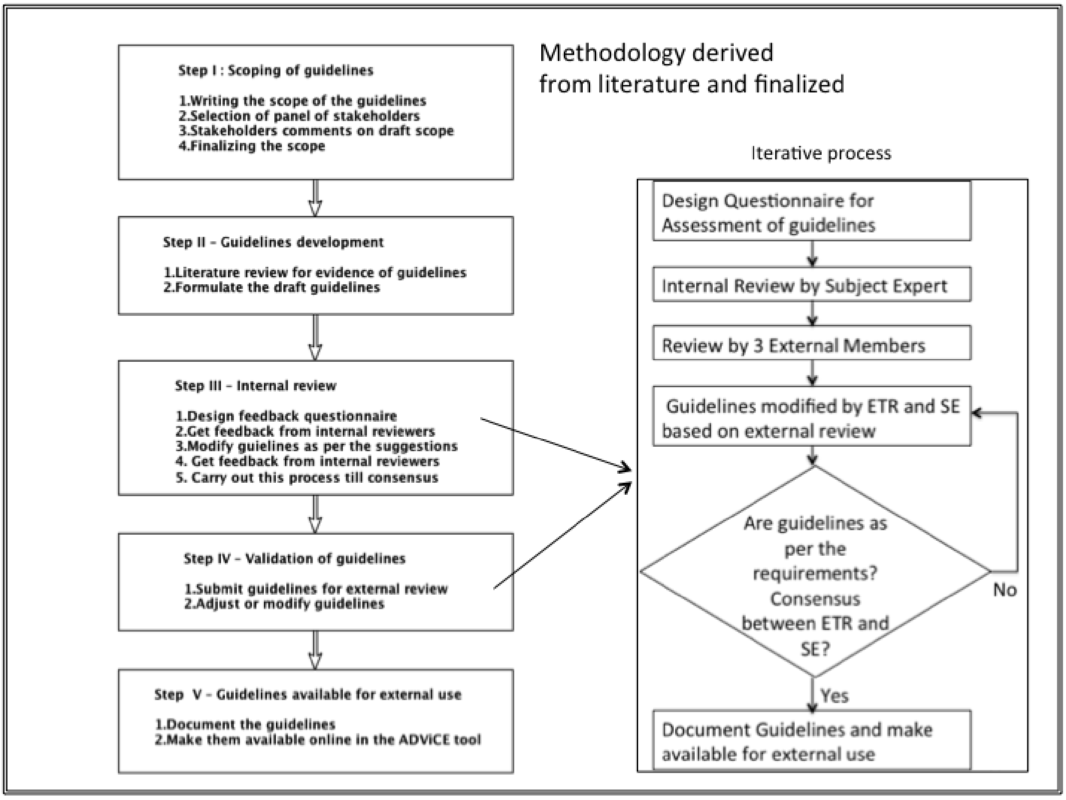

Figure 1. S-D-I-V-E Methodology for design and development of EDG.

The above figure 1 illustrates the S-D-I-V-E methodology adopted for the design and development of the experiment design guidelines.

Step I – Scoping: The following sub steps were carried out as part of this step

1. Writing the scope of the guidelines: This was carried out as per the LoTaAs framework derived from literature review and the four studies with engineering instructors. The decisions regarding the various aspects of guidelines such as which guidelines to be formulated, what criteria to be used for assessing the guidelines and how these guidelines would be reviewed; were taken at this stage.
2. Selection of panel of stakeholders: It was decided that the panel for internal review would consist of two members – one the researcher (ET expert) and the other a subject matter expert (SME). The panel consisting of three members for external review would consist of the engineering instructors who will be using the guidelines, subject experts and industry experts.
3. Stakeholders' comments on draft scope: The internal panel would review the scope and arrive at consensus for validity and practicality of the scope of the guidelines.
4. Finalizing the scope: Once the consensus is arrived at; the scope of the guidelines was finalized. The guidelines would be developed as nine sets for virtual laboratories for the course Basic and Advanced Electronics. These nine sets would be as follows: Guidelines for
   - Set I: Selection of experiment broad goal
   - Set II: Formulation of learning objectives at various cognitive levels and skills
   - Set III: Expository experiment designs at various difficulty levels
   - Set IV: Expository experiment designs incorporating active learning methods
   - Set V: Designing tasks aligned to the learning objectives for Discovery Instructional Strategy

- Set VI: Designing tasks aligned to the learning objectives for Well Structured Problem Solving Instructional Strategy
- Set VII: Designing tasks aligned to the learning objectives for Problem Based Instructional Strategy
- Set VIII: Design of authentic assessment mechanisms
- Set IX: Selection of virtual laboratory depending on the features

Step II – Guidelines development: The following sub steps were carried out as part of this step

1. Literature review for evidence of guidelines: In order to formulate the various sets of guidelines a thorough literature review was carried out. The methodology used for sampling the literature is given in figure--. Initially the existing guidelines were listed down and reviewed based on the criteria decided for the guidelines in the previous step. It was observed that the existing guidelines had certain limitations such as they were very broad and not specific also not in the context of virtual laboratories and hence were not suitable in the context of our research. There was a need of refinement of these existing guidelines for the context of virtual laboratories and the course Basic and Advanced Electronics and hence they were refined.
2. Formulate the draft guidelines: Once the existing guidelines were obtained and need for refinement was established the refined draft of the guidelines for all the six sets were designed and developed.

Step III – Internal review

1. Design feedback questionnaire: The draft guidelines were initially reviewed internally and hence the feedback questionnaire was designed. The questions were written based on the selected criteria for the guidelines. The subject expert validated the questions after being framed by the researcher (ET expert).
2. Get feedback from internal reviewers: The panel reviewed the draft guidelines internally and arrived at the consensus regarding all the guidelines. The review was carried out based on the designed questionnaire.

Step IV – Validation: The following sub steps were carried out as part of this step

1. Submit guidelines for external review: The draft guidelines were given for review to the external stakeholders. Each set of guidelines would be given to a panel of three members. They too were given the questionnaire to assess the validity and suitability of the guidelines for the context of our research.
2. Adjust or modify guidelines: After the external review depending on the feedback the guidelines were modified. The modified guidelines were again reviewed internally and the modification carried out till a consensus was arrived amongst the researcher and internal reviewer.

Iterative Process of Guideline refinement

Step V - Make the guidelines available for external use

1. Document the guidelines: Once the guidelines were finalized after the double review process they were systematically written as a document which can be sent to the engineering instructors for the initial pilot testing and later use in the experiment designs.
2. Make them available online in the SDVIcE tool: The last step was to convert these paper-based guidelines into the online version in the form of the SDVIcE tool for increasing the accessibility.

3.2 Research Method

The evaluation of the effectiveness of the Experiment design guidelines was carried out after it was established that the engineering faculties find it usable and useful for designing laboratory experiments aligned to their learning objectives. The Experiment design guidelines can be considered effective if the quality of the experiments designed after using the guidelines is better than the quality of experiments without using the guidelines. In order to find out this effectiveness we carried out a field test study with 10 engineering instructors.

The leading research question for this study was:

> **RQ6c: What is the effectiveness of the experiment design guidelines in improving the quality of the design of experiments and lab manual for using existing virtual labs?**

3.3 Implementation

The following steps specify the implementation of the research study

1. Identify dimensions of quality of experiment designs.
2. Developing a rubric for assessment of the design of experiments.
3. Field-testing with ten engineering instructors.
4. Scoring the designed experiments as per the rubric
5. Analyzing the rubric scores
6. Arriving at the results of the field testing

1. Identify dimensions of quality of experiment designs.

The experiment design guidelines were designed and developed after an iterative process and hence if they are followed and implemented by the engineering instructors it should lead to high quality experiment designs. So we take the basis of the guidelines in order to come up with the dimensions of quality of the designs. The quality of experiment designs depends on a variety of parameters or dimensions that are as follows:

a. The experiment design follows a scientific design process
b. The experiment design incorporates the various phases in the scientific design process
c. The experiment design incorporates various instructional strategies
d. The experiment design for the various instructional strategies are as per the templates
e. If the Expository instructional strategy is used then the tasks are designed with constructivist approach
f. The experiments are designed at different difficulty levels
g. The broad goal/s of the experiment is clearly specified
h. The broad goal/s is aligned to the content type of the topic
i. The learning objectives are valid and clearly defined
j. The experiment design has learning objectives at various cognitive levels as per Revised Bloom's taxonomy
k. The virtual laboratory tasks are aligned to the learning objectives of the experiment.
l. The virtual laboratory tasks provide opportunities to the students to work in the two domains of objects and concepts
m. The virtual laboratory tasks are different for the different instructional strategies
n. The assessment questions are aligned to the learning objectives
o. The assessment questions in the design of learning are correct
p. The assessment questions in the design for learning truly help the students in their learning
q. The assessment measures the students' knowledge as per the content type
r. The assessment measures the target skills developed by the students
s. The virtual laboratory selected has affordances that allow students to perform the tasks designed in the experiment

2. Developing a rubric for assessment of the design of experiments.

After identifying the dimensions for quality of the experiment designs we developed a rubric so that the experiment designs could be assessed for their quality. We present rubric below

3. Field-testing with ten engineering instructors.

The next step in the study was the field-testing in which ten engineering instructors volunteered to participate in the process. Each instructor was requested to design minimum four experiments for their course and topic before referring to the guidelines. Then they used the guidelines available online in the ADVIcE tool and designed the same experiments again. Thus total 40 experiment designs before and after the usage of the guidelines formed the data of the study. These artifacts were then analysed for their quality. The experiments were designed for the courses Mobile communication, Power Electronics, Advanced Electronics, Digital Electronics, Introduction to php, Printing –Pre-press and Optical communication. These courses belong to the domains of Electrical engineering, Information technology, Computer engineering and Electronics and Telecommunication. The quality of the designed experiments was evaluated based on the developed rubric.

4. Scoring the designed experiments as per the rubric

In order to score the experiments the designs were given to two subject experts. The scores were found to be reliable and the reliability was measured by Cronbach's alpha. The value was found to be **0.78.**

3.4 Analysis of the scores

After scoring the various experiments and checking for the reliability of the scores we carried out the analysis of the scores of the designs before and after the usage of guidelines per instructor. The following table 1 give the results of the analysis.

Table 1

Analysis of the scores as per the rubric

Total Experiment Designs	High	Medium	Low
Before	6	8	26
After	24	3	3

As can be observed from the table the engineering instructors designed 40 experiments in total before and after using the guidelines. The number of experiments with high quality increased from 6 to 24 after using the guidelines, the number of experiments with medium quality decreased from 8 to 3 and the number of experiments with low quality reduced from 26 to only 3. So after using the guidelines there was a improvement in the quality of majority of the experiment designs.

The table 2 illustrates the instructor-wise analysis of the rubric score data.

Table 2

Instructor wise scores as per rubric

	Quality of experiment design as per rubric							
Faculty	Before using EDG				After using EDG			
	High	Medium	Low	Total	High	Medium	Low	Total
1	1	1	2	4	2	2	0	4
2	0	1	3	4	2	1	1	4
3	1	1	2	4	2	1	1	4
4	0	1	3	4	3	1	0	4

5	1	0	3	4	3	1	0	4
6	1	0	3	4	2	2	0	4
7	1	1	2	4	3	1	0	4
8	0	1	3	4	2	2	0	4
9	1	1	2	4	3	1	0	4
10	0	1	3	4	2	0	2	4
10	6	8	26	40	24	12	4	40

Table 3

Transition in the experiment design quality for each instructor

	Quality of experiment design as per rubric					
Instructor	Before	After	Before	After	Before	After
	High		Medium		Low	
Instructor 1	1	2	1	2	2	0
	High		Medium		Low	
Instructor 2	0	2	1	1	3	1
	High		Medium		Low	
Instructor 3	1	2	1	1	2	1
	High		Medium		Low	
Instructor 4	0	3	1	1	3	0
	High		Medium		Low	
Instructor 5	1	3	0	1	3	0
	High		Medium		Low	
Instructor 6	1	2	0	2	3	0
	High		Medium		Low	
Instructor 7	1	3	1	1	2	0
	High		Medium		Low	
Instructor 8	0	2	1	2	3	0
	High		Medium		Low	
Instructor 9	1	3	1	1	2	0
	High		Medium		Low	
Instructor 10	0	2	1	0	3	2

4. Conclusion and Discussion

The following can be inferred from the results graph

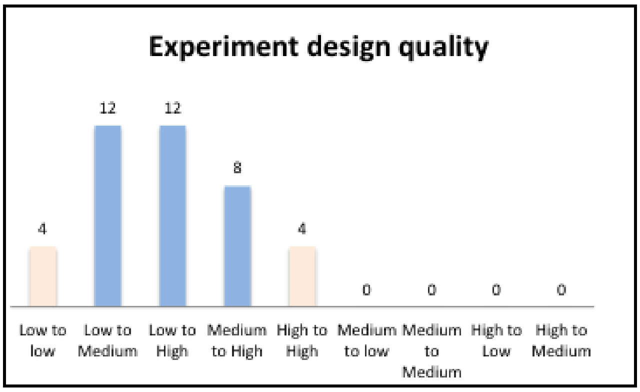

Figure 2. Improvement in the experiment design quality.

i. The quality of 4 experiment designs (10%) remained at low level
ii. The quality of 12 experiment designs (30%) improved from low level to medium level
iii. The quality of 12 experiment designs (30%) improved from low level to high level
iv. The quality of 8 experiment designs (20%) improved from medium level to high level
v. There was no change in the quality of 4 (10%) experiment designs. They remained at high level.
vi. There was no negative effect of using the guidelines that is none of the experiment design quality was lowered from either high to medium or medium to low or high to medium.

The analysis of the scores of the experiment designs before and after using the guidelines indicate that there is an overall improvement in the quality of the designs. 60% of the designs had a high quality and 30% medium quality. Only 10% designs had low quality.
We can conclude from the results that the experiment design guidelines are effective in improving the quality of the experiment designs.

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