SEMINAR REPORT
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# Table of Contents

Abstract ................................................................................................................................. 1

1. Framework for TELoTS and TELE-EDesC .................................................................. 2
   1.1 Teaching Learning of Thinking Skills ..................................................................... 2
   1.2 TEL of Thinking Skills ......................................................................................... 4
   1.3 TELE-EDesC as a TEL environment ..................................................................... 7
   1.4 TELoTS Framework ............................................................................................. 9

2. Application of SOP to Computer Networks ................................................................. 11
   2.1 Types of Engineering Design Problems ................................................................ 11
   2.2 Examples in Wireless Network Domain ................................................................. 13
   2.3 EDIV Template ..................................................................................................... 15
   2.4 Problems that EDIV successfully applies ............................................................. 16
      2.4.1 Examples of problems ..................................................................................... 16
      2.4.2 Characteristics of problems .......................................................................... 17
   2.5 Problems that EDIV fails to apply ........................................................................ 18
      2.5.1 Examples of problems ..................................................................................... 18
      2.5.2 Characteristics of problems .......................................................................... 18
      2.5.3 Likely reasons .................................................................................................. 19

3. Extension of Seminar to Ph.D. ..................................................................................... 20
   3.1 Choice of TS .......................................................................................................... 20
      3.1.1 Example ......................................................................................................... 21
   3.2 Literature Review .................................................................................................. 22
   3.3 Future Work ........................................................................................................... 23

4. References ....................................................................................................................... 24
List of Table

Table 1.1.1 List of Curricula aimed towards teaching of thinking skills.......................................................... 3
Table 1.2.2 TEL Environment for Thinking Skills .............................................................................................. 5
Table 1.3.3 Mapping learning dialogs to instructional strategy, metacognitive process and SOP sub-competency .......................................................................................................................... 8
Table 2.1.4 Classification of Engineering Design Problems .................................................................................. 13
Table 2.2.5 Examples of design problems in Wireless Network ......................................................................... 15
Table 2.4.1 6 Innovative Problems in design of wireless network that meet TELoTS SOP framework 16

List of Figures

Figure 1.4.1 Mapping Meta Cognitive processes to Instruction Strategies......................................................... 10
Figure 3. 2 Extension of Seminar Work to Ph.D Thesis...................................................................................... 20
Figure 3.1.1.3 Structuring Open Problem by Problem Decomposition............................................................. 21
Abstract

Engineering design is an essential skill for today’s 21st century engineers. The real world problems are complex and hence design solutions for them becomes even more intricate. The first step towards solving a complex problem is to structure it such that the goal, nature of the problem is identified and a problem space creates a context which leads to the solution process. This skill is known as Structuring Open Problem (SOP) and it is categorized as a Thinking Skill. This report deals with the thinking skill SOP in two domains analog electronics and wireless network.

The first section of the report does an extensive literature survey of thinking skills, its teaching learning and technology enhanced learning (TEL) system for thinking skills. The first section also reviews the TELoTS pedagogy framework and its application in SOP for the domain of analog electronics. By doing so process of creating and developing pedagogically linked technology features have been internalized.

The second section of the report tries to implement one of the components of TELoTS framework EDIV (Engineering Design Interactive Visualization) template in the topic of design of wireless networks. This section reports a different dimension towards SOP, which is problem decomposition.

The last section contains work in progress which is application of TELoTS framework to the TS – Problem decomposition.
1. Framework for TELoTS and TELE-EDesC

Thinking is a cognitive process which results in knowledge attainment. But often the knowledge content is directly imparted to the learners without providing explicit opportunities for the learners to go through the cognitive processes. Development of such cognitive processes in the 21st century learners are found to be vital for their success in the current workplace (NAS, 2014). There are various definitions available for ‘thinking skills’ (TS). Some of them are listed below:

- "The mental derivation of mental elements (thoughts) from perceptions and the mental manipulation/combination of these thoughts" (Cohen 1971, p. 5).
- "The mental manipulation of sensory input to formulate thoughts, reason about, or judge" (Beyer 1984a).
- "The extension of evidence in accord with that evidence so as to fill up gaps in the evidence: and this is done by moving through a succession of interconnected steps which may be stated at the time, or left till later to be stated" (Bartlett 1958, p. 75).
- Thinking skills are cognitive process that human being apply for sense making, reasoning and problem-solving (Beyer, 1988; Lipman, 2003).

One of the most important aspect of these thinking skills is that they are found to be pan-domain in nature. Irrespective of the field, stream and discipline, development of ‘thinking skills’ in learners is imperative. There are several pan-domain thinking skills in the field of engineering and science such as system design, problem-posing, estimation, algorithmic thinking, data representation, data analysis etc. (Felder, 1988). Given the significance of the thinking skills the challenge lies in their teaching. The teaching for thinking skills needs to be explicit as the learners cannot acquire these skills while learning domain content.

1.1 Teaching Learning of Thinking Skills

The efforts towards the teaching of thinking skills was done in two ways. There were aims towards integrating the thinking skills in curriculum (White & Frederiksen, 1998) and on the other side specific pedagogic strategies were developed. In addition to this ‘Teaching for Critical Thinking’ has also been included in teacher education (Costa, 1985). Scientific inquiry is a thinking skill in which the learner follows a process of developing an explanation of a question in the natural world (or universe) by testing, investigating and collecting data that will either support or refute the learner’s original idea. MARS (Raghavan & Glaser, 1995), ISLE (Etkina & Van Heuvelen, 2007), ThinkerTools (White & Frederiksen, 1998), Inquiry learning
and Teaching (Minstrell & Van Zee, 2000) are the instances of incorporating scientific inquiry, a thinking skill, in the curriculum. The following Table 1.1.1 captures their important facets:

**Table 1.1.1 List of Curricula aimed towards teaching of thinking skills**

<table>
<thead>
<tr>
<th>Sno</th>
<th>Curriculum Name</th>
<th>Topic</th>
<th>Thinking Skills</th>
<th>Features</th>
</tr>
</thead>
</table>
| 1   | MARS (Model Assisted Reasoning in Science)           | Balance of forces – floating and sinking | Model–based reasoning skills           | • Conceptual understanding  
• Reasoning about scientific phenomena                                     |
| 2   | ISLE (Investigative Science Learning Environment)     | Physics                | • Experiment design  
• Model building  
• Use of multiple-representations  
• Evaluation               | • Comprehensive Learning system  
• Physics course from elementary to graduate school  
• Concept construction  
• New approach to assessment                                               |
| 3   | ThinkerTools                                         | Middle School Science Curriculum | Scientific Inquiry                    | • Instructional approach that develops students’ metacognitive knowledge  
• Reflective Assessment                                                      |
| 4   | Inquiry learning and Teaching                        | K-12 Science Curriculum | Scientific Inquiry                    | • Eliciting prior knowledge  
• Prediction, Engagement with a phenomenon, Group work  
• Higher order thinking  
• Student-centered classes                                                   |

There are several recognized pedagogic strategies for teaching of thinking skills (Beyer, 1985; Costa, 1985). Some of them are:

- Promoting interaction by learning in a group setting
- On-time help
- Ill structured and open –ended problems
- Sufficient time for reflection on questions posed and answers
• Application of acquired skill in another domain – transfer

The pedagogic strategies give an insight to the key features that need to exist in a learning environment such as scaffolding, formative assessment and metacognitive support (Murthy, Iyer & Mavinkurve, 2015).

So far the thinking skill that is predominantly reviewed is scientific inquiry. In engineering education, design thinking is widely accepted as the purpose of its education. Engineering design thinking is an iterative decision making process (Sheppard et al., 1997) which is based on fundamental concepts of science, mathematics and engineering (ABET, 2000). But unfortunately graduate engineers are unable to demonstrate the design skills. The most preferred pedagogical strategy for teaching design is Problem Based learning (PBL). PBL in the classroom consists of problems that are routine in nature and well-defined. The real world problems are ill-structured and hence when engineering graduates encounter such problems they are unable to design solutions. The emphasis while using PBL is to give real world problem solving experience to students (Wood, et al., 2001; Dutson, et al., 1997; Dally & Zhang, 1993). Engineering design thinking is a combination of complex cognitive processes such as ill-structured problem solving, inquiring learning and systematic decision making (Dym et al., 2005). There have been several efforts in engineering design thinking skill education such as

• Senior capstone courses
• Design contests
• Project Based Learning
• Reverse Engineering
• Integration of design across curriculum

Even with the above efforts there are challenges reported in the teaching of engineering design thinking skill. With the use of widely available technology and communication tools complex learning environments can be created to facilitate teaching. The pedagogic strategies listed above are also integrated in technology. Numerous technology enhanced learning (TEL) environments are developed for the purpose of teaching thinking skills.

1.2 TEL of Thinking Skills

Information and Communication Technologies (ICT) have affordances which have been utilized to develop learning environments and associated tools to support. PC and mobile phones have become ubiquitous and their usage has brought about a new generation of
learners who are well versed with technology tools. Some of the affordances of ICT are listed below (Conole & Dyke, 2004)

- Accessibility
- Diversity
- Communication and Collaboration
- Reflection
- Multi-modal and non-linear
- Immediacy

These affordances of ICT have led to a development of Smart Learning Environments (SLE) for various thinking skills. The Table 1.2.2 shows the list of TEL environment for developed for teaching of Thinking Skills

<table>
<thead>
<tr>
<th>Sno</th>
<th>Name</th>
<th>Domain</th>
<th>Thinking Skill</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Model-it</td>
<td>High School and Middle school Science</td>
<td>Model building</td>
<td>• Building dynamic models of scientific phenomena</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Running simulations with their models to verify and analyse the results</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Offering supports for learners in the design process</td>
</tr>
<tr>
<td>2</td>
<td>WISE (Web-based Inquiry Science Environment)</td>
<td>Science School Education</td>
<td>Scientific Inquiry</td>
<td>• Sustainable classroom inquiry instruction across the varied contexts where learning takes place</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 25 English language projects as well as projects in Norwegian, German, and Dutch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Scaling research-based curriculum</td>
</tr>
<tr>
<td>3</td>
<td>Co-Lab</td>
<td>Natural science in upper secondary level and the first years in university</td>
<td>Collaboration, inquiry, and modeling</td>
<td>• Groups of students examine scientific phenomena and express their shared understanding in a</td>
</tr>
<tr>
<td></td>
<td>Belvedere</td>
<td>10th grade Science</td>
<td>Scientific argumentation skills</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------</td>
<td>---------------------</td>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>rannable computer model</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Learners thus engage in three analytically distinct processes, namely inquiry, modeling and collaboration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Main goal of system is to stimulate critical discussion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Provides graphical environment with advice on demand</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• An automated advisor that gives advice on demand concerning ways in which an argument can be extended or revised.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>gIBIS (Graphical Issue Based Information System)</th>
<th>Industry Design</th>
<th>Design Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>Captive of design history: the decisions, rejected options, and trade-off analysis-in short, the rationale behind the design decisions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Computer mediated teamwork</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Support large information base to support navigation</td>
</tr>
</tbody>
</table>

Two other TEL environments such as WiMVT (Web Based Inquirer with Modeling and Visulation Technology) and Apple Tree exist. WiMVT is targeted towards the thinking skills reasoning and reflection whereas Apple Tree towards collaborative argumentation skill. Technology can support various pedagogic strategies for teaching of thinking skills, hence TEL environment are built by large targeting specific TS. The next section is about a TEL environment for a specific TS known as ‘Structuring Open Problem’ (SOP).
1.3 TELE-EDesC as a TEL environment

Before describing about SOP and TELE-EDesC, from Table 1.2, I have tried to capture some of the common features of TEL for scientific inquiry:

- Interactivity
- Collaboration
- Simulations with variable manipulation
- Graphical tools
- Modeling tools

Interactivity with content and other learners is afforded by the use of technology. It is said that interactivity assists in deep cognitive processing of the learners (Moreno & Mayer, 2007). There are five commons types of interactivity possible: dialoguing, controlling, manipulating, searching and navigation. But care needs to be taken while placing such interactive features in the TEL environment as they could lead to cognitive overload in the learners. Moreno & Mayer while highlighting the role of interactivity have also suggested principles that reduce cognitive overload and keep the learner motivated. They are guided activity, reflection, feedback, pacing, and pre-training (Moreno & Mayer, 2007). In addition to the above features ‘feedback’ feature in the TEL environment is also highly desired. Succinct feedback that explains the rationale behind the answer is found to be more effective than mere display of correct/wrong answer. Thus the universal features in any TEL system are (i) Accessibility, (ii) Attractiveness, (iii) Effectiveness and (iv) Efficiency (AAEE).

TELE-EDesC (Technology Environment to Develop engineering design competencies) was developed to teach ‘Structure Open Problem’ (SOP) thinking skill in the domain of analog electronics domain. SOP is the first step in design process as it requires to constructing and restructuring an open ended problem ill-structured problem to a more manageable and organized problem. The design of TELE-EDeSc is based on a pedagogical framework known as TELoTS (Technology Enhanced Learning of Thinking skills) which is described in detail in the section 1.4. The TELoTS pedagogical framework was followed to decide on the features of TELE-EDesC. Initially the in the sub-competencies of the TS SOP were categorized. The following are the sub-competencies of SOP (Mavinakurve, 2015):

- SOP 1. Identification of specifications
- SOP 2. Use of specifications
- SOP 3. Implement sequence of design steps
- SOP 4. Write structured problem statement
Meta cognitive processes that trigger the sub-competencies were also identified subsequently. The learning activities in TELE-EDesC trigger the metacognitive processes by integrating appropriate instructional strategy. Based on extensive review of multimedia principles and interactivity design principles the learning activities in TELE-EDesC were implemented as 'learning dialogs'. The following Table 1.3.3 identifies the 'learning dialogs' implemented in TELE-EDesC, their corresponding instructional strategy, meta cognitive process aimed at and then the sub-competency of SOP (Mavinkurve, 2015).

*Table 1.3.3 Mapping learning dialogs to instructional strategy, metacognitive process and SOP sub-competency*

<table>
<thead>
<tr>
<th>S.No</th>
<th>TELE-EDesC Learning Dialog</th>
<th>Metacognitive Process</th>
<th>Instructional Strategy</th>
<th>Sub-Competency in SOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Decision Making Task Question (DMTQ)</td>
<td>Decision Making</td>
<td>Formative Assessment</td>
<td>SOP 1, SOP 2, SOP 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Feedback</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Simulative Manipulation (SM)</td>
<td>Concept Integration</td>
<td>Experimental design and feedback</td>
<td>SOP 1, SOP 2, SOP 3</td>
</tr>
<tr>
<td>3</td>
<td>Self-Controlled Animation</td>
<td></td>
<td>Interpret multiple representations</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Concept Clarification Question (CCQ)</td>
<td>Synthesis</td>
<td>Question Prompts</td>
<td>SOP 4</td>
</tr>
<tr>
<td>5</td>
<td>Capsule Recommendation</td>
<td></td>
<td>Summary Statements</td>
<td></td>
</tr>
</tbody>
</table>

From the above review of TELE-EDesC we see that there is a strong pedagogical approach in deciding the features of the TEL environment. There exists numerous other design approaches for development of SLE, but they all seem to be very specific to the learning goal in the SLE and are difficult to incorporate for other learning goals. Some broad frameworks (Murthy, Iyer & Mavinkurve, 2015) such as knowledge integration and scaffolding design exists for science inquiry. Pedagogical approach was developed to place the learning goal, which is teaching of TS, at the centre of design of SLE. SLE developers get carried away by the affordances that the technology offers and develop tools/environment rich in features as well as interactivity. This design approach may not be favourable for the learning goal.
1.4 TELoTS Framework

SLE focus on technology and having pedagogical aspect as additional feature defeats the learning goal. TELoTS focus is on the learning goal – Thinking Skill. It is achieved by the following process:

i. Characterizing the Thinking Skill by Competencies – Thinking Skill is a complex task and competencies are used to represent the steps/facets involved. The competencies can also be used as an assessment mechanism as they form the learning outcomes or the learning goal. The Thinking skill when broken down into competencies becomes more malleable and the teaching learning can be directed towards the achievement of the same. For the TS SOP, we saw the sub competencies in section 1.3. After identifying the sub-competencies the topic through which the TS will be developed needs to be picked. In case of TELE-EDesC it was analog electronics. The learning objectives in the chosen topic for the TS sub competencies will be created at the same time the assessment strategy for the learning objectives will be developed.

ii. Design Learning activities – After step (i) we would have the sub-competencies. The next step is to identify the metacognitive processes that trigger the sub-competencies. Metacognition is the experience one has when one is having an inner dialogue inside the brain and evaluating one’s decision making/problem solving process. Metacognition is the ability to know what one knows or doesn’t (Costa, 1985). Metacognitive consists of two main dimensions: Monitoring task performance and problem solving strategy. The Figure 1.4.1 shows how these dimensions help in selecting the appropriate instructional strategies. Then the role of technology comes into play. The technological feature that implements the instructional strategy is selected for the TEL environment. Once all such strategies and technological features are identified sequencing them into a meaningful learning activity is done.

iii. Smart Learning Environment development – The sequence of learning activities in hand at the same time the technological features for the instructional strategies identified, the development of SLE has a strong pedagogical approach.

The above processes described is the TELoTS framework as prescribed by Sahana et.al 2015. TELE-EDesC is the result of the application of TELoTS framework in SOP. There is an attempt to use the TELoTS framework developed for SOP in analog electronics to SOP in
computer networks domain. The section 2 contains details of such implementation and the problem that arises thereof.

Figure 1.4.1 Mapping Meta Cognitive processes to Instruction Strategies
2. Application of SOP to Computer Networks

Engineering graduates are expected to design solutions to solve real world problems. Undergraduate engineering education looks at design as, “Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements” (Dym, 2005). As the first step in TELoTs framework is to characterize the TS. From extensive literature review the TS Engineering Design consists of the following sub-competencies (Mavinkurve, 2015):

i. Structure Open Problem (SOP)
ii. Multiple Representation (MR)
iii. Information Gathering (IG)
iv. Divergent Thinking (DIV)
v. Convergent Thinking (CONV)

In the previous section we saw how the TELoTs framework was applied to SOP in the context of analog electronics as a result of which the TEL environment TELE-EDesC was created. TELE-EDesC is used to teach SOP in analog electronics. Empirical studies show that learners attain the competency SOP in analog electronics but are unable to transfer the same to any other topic from the domain (Mavinkurve & Murthy, 2015). In this section our attempt is to realise whether the TELoTS framework created for SOP in analog electronics can be applied to any other topic from any domain. The domain that we have chosen for this study is ‘Computer Networks’ and the topic is ‘design of wireless networks’.

2.1 Types of Engineering Design Problems

One of the fundamental activity of engineering is design (Simon, 1996). Engineering graduates should be able to design effective solutions to meet societal needs. But unfortunately they are unable to do so, as the real world problems are

- Open-ended : can have multiple possible solutions
- Ill-Structured : no known solutions
- Vague Objectives : unspecified goals and specifications
- Confounding Constraints : unclear constraints

Engineering Design needs to be addressed separately as a thinking skill and taught during the engineering undergraduate program. It is found that solving real world problems requires components such as content knowledge, structural knowledge, domain specific strategy and
general strategy as well as factors which are beyond purely cognitive such as value/belief/attitude, evaluation/monitoring/planning and justification skills (Sinnot, 1989). Hong (Hong, 1998) proposed a solving processes of ill-structured problems based on the studies of Sinnott (1989) and Voss & Post (1988). It states that real world problem solving consists of three processes:

i. Representation problems
ii. Solution Process
iii. Monitor and Evaluation

The first step in solving a real world problem which is problem representation consists of defining (a) if there exists a problem?, (b) nature of the problem, (c) construct problem space by selecting and searching from memory, (d) create a context (Hong, 1998). The TS SOP is the thinking skill required to represent the problem.

Paraphrasing from the literature, the TS SOP is: the ability to identify the problem, determine its nature, construct problem space and create a context which leads to the solution process

To deal with real world design problems, engineering graduates have to be taught with such problems. Problem Based Learning (PBL) as the name suggests revolves around problems. Various descriptions of PBL can be grouped into three types (Schmidt et al., 2009) as follows:

i. Type I – helps learners to “make sense of the world by constructing mental models” (Schmidt et al., 2009)
ii. Type II – helps learners learn diagnostic reasoning and mimic the thought process of experts
iii. Type III – helps learners “how to learn”

Although there are different descriptions of PBL some of the common elements are (a) use of problems to initiate learning, (b) collaboration, (c) flexible scaffolding, (d) self-directed learning, (e) flexible pacing for self-study (Sockalingam, 2010).

Among the above elements as first is the use of problems, let us know look at the different types of problems in engineering design. The classification of design problems is based on the difficulty of the sub-tasks in the design process namely: problem decomposition and design plan (Brown & Chandrasekaran, 1989). The Table 2.1.4 compares the three classes of design problems. The types of design problem are:

1. Class I: They are also known as ‘Creative Problems’. There are no information available about the effective problem decompositions and the design plan for sub-problems
2. Class II: They are known as ‘Innovative Problems’. In these type of problems there exist known problem decompositions but the design plan needs some innovative construction/modification.

3. Class III: They are known as ‘Routine Problems’, where both the problem decomposition as well as the design plans are known.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Class of Design Problem</th>
<th>Problem Decomposition</th>
<th>Design Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Class I (Creative)</td>
<td>Not Known</td>
<td>Not Known</td>
</tr>
<tr>
<td>2</td>
<td>Class II (Innovative)</td>
<td>Known</td>
<td>Not Known</td>
</tr>
<tr>
<td>3</td>
<td>Class III (Routine)</td>
<td>Known</td>
<td>Known</td>
</tr>
</tbody>
</table>

In TELE-EDesC the design problems in the domain analog electronics are of the type ‘Innovative’ (Mavinkurve, 2015). The learning goal in TELE-EDesC is to re-build the innovative problem into type routine. In the next section we try to formulate design problems of all the types but in the topic ‘wireless computer networks’.

### 2.2 Examples in Wireless Network Domain

There are number of sub-processes in design. They are grouped into processes that propose design choices and auxiliary processes (Brown & Chandrasekaran, 1989). The details about the two process groups is below:

a. Processes that propose design choices: This process group consists of design activities that contributes to the “generate” aspect of the design. The sub processes are as follows:

   i. Decomposition – “Knowledge of the form D -> {D1, D2, ... Dn}, where D is a given design problem, and Di's are "smaller" sub problems (i.e., associated with smaller search spaces than D) is often available in many domains” (Brown & Chandrasekaran, 1989). Decomposition is often the first step in analysis of open-ended problems. In case of alternate decompositions there will be a need for backtracking on the choices made. In domains that are well-defined there exists design hierarchies, so decomposition would involve smaller search spaces. E.g.) automobile design. The search space after decomposition would result in a graph with AND/OR relations. This would tell us which sub-problems
need to be compulsorily solved and others are alternatives. The information needed for decomposition are: goals, constraints and synthesis of the solutions of sub-problems.

ii. Design Plans – “A design plan, specifies a sequence of design actions to take for producing a piece of abstract or concrete design” (Brown & Chandrasekaran, 1989). Design plan is a precompiled partial design solution. Each individual sub-problem will have the design plan and the solution of the collection of sub-problems once integrated into a complete design will be the design plan for the original design problem.

iii. Reusing existing Correct Design – Many domains have a collection of successful and iconic design plans. The existing design plans are matched to the constraints and goals of the problem and the closest match is chosen. The closest design plan is then modified/reused as is for the current design problem.

iv. Constraints based design – Relaxation Procedures (Mackworth, 1977) are those when the constraints are applied incrementally to finally converge on a solution set that satisfies all constraints. There exists one more method of implementing constraint based design where the constraints are relaxed so that a hard design problem is converted to an easy one. But caution is placed on this process as using this might involve creation of multiple problem space that might not converge and a whole lot of effort would be spent in searching the solution space.

b. Auxiliary Processes: These are processes that aid in the processes that propose the design choices. These processes are provide some information to the above set of processes. They are:

i. Goal and constraint identification of sub-problems

ii. Recomposition – Integration of solutions of sub-problems to form the final solution of the original problem.

iii. Design Evaluation – Analysis of failure and performance

iv. Design Verification – Making a system prototype and testing the same.

The design problem categorization in section 2.2 is based on the above discussed two processes decomposition and design plan. Applying this classification in the topic of ‘design of wireless network’ resulted in the Table 2.2.5.
Table 2.2.5 Examples of design problems in Wireless Network

<table>
<thead>
<tr>
<th>Creative Problem</th>
<th>Innovative Problem</th>
<th>Routine Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design a Wireless network for Mumbai city</td>
<td>Design a Wireless Network of 80.11 (g/n) standard to support 300 users sprawled across 8 floors (or) Design a Wireless Network for a hostel in IIT-B</td>
<td>Design a Wireless Network of 802.11 (g/n) with downstream 1.2Mb/s capacity and upstream of 15kb/s capacity.</td>
</tr>
</tbody>
</table>

2.3 EDIV Template

One of the most important feature of TELE-EDesC as discussed in section 1.3 and Table 1.3.3 is that of use of visualizations. EDIV (Engineering Design Interactive Visualizations) is based on an open design problem in electronics that students can use for self-learning (Mavinkurve & Murthy, 2012). EDIVs are self-contained in the sense that it contains all the conceptual knowledge to solve the design problem as well as learner activities that leads to the development of competency in the learner. In this case the solution of the open design problem is a structured problem statement of an innovative design problem. Studies have shown that learners using EDIV are able to perform better SOP than learners who do not use EDIV (Mavinkurve & Murthy, 2012).

To enable the EDIV writers to generate instructional material an EDIV writing template was also generated. The EDIV writers are the SME (Subject Matter Expert) in any domain and want to incorporate teaching of the TS SOP in their chosen subject. The EDIV writing template contains two sections – prior work before writing template and writing EDIV. Before writing the EDIV the SME needs to (i) select an open design problem, (ii) write complete step by step solution, (iii) identify steps that learners need to perform SOP. The last step in which the SME needs to identify steps to perform SOP related to the sub-competencies of SOP which was discussed in section 1.3. Writing the EDIV consists of the following steps:

Step 1. Preparation of modules to extract visible and hidden specifications, its related concepts and the instructional content. The modules need to contain facts (visible/hidden), principles and sequence of design steps.

Step 2. Writing Learning Objectives for the topic and the design problem.
Step 3. Writing Instructional Activities for the learning objectives. The EDIV template consists of guidelines for instructional activities such as Concept Clarification Question (CCQ), Decision Making Task Question (DMTQ), Animation, Information box (concept capsules), Variable Manipulation, Conceptual Design support (important design steps).

The output from the learner is a structured version of the open ended problem. The Step 1 is identical to the sub-competencies of SOP in section 1.3. We will apply the EDIV template Step 1 to problems from the topic ‘design of wireless network’ and examine in the next section.

2.4 Problems that EDIV successfully applies

The design problems are classified into (i) creative, (ii) innovative and (iii) routine. For the design problems in creative category the Step 1 in section 2.3 will be futile since the specifications are totally unknown at this stage. The EDIV authors (Mavinkurve & Murthy, 2012) have stated that the template can be used for innovative design problems. So we examine innovative problems in the topic of ‘design of wireless network’.

2.4.1 Examples of problems

The Table 2.4.1.6 shows two examples of problems and the corresponding sub-competencies of SOP that can be derived/arrived at from the problem:

<table>
<thead>
<tr>
<th>Innovative Problem</th>
<th>SOP 1</th>
<th>SOP 2</th>
<th>SOP 3</th>
<th>SOP 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design an 802.11 WLAN operating at 54Mbps having several stations supporting a max of 70 VoIP calls per minute. Each STA runs a voice over IP (VoIP) application which generates a 240 byte VoIP packet, every 20 milliseconds.</td>
<td>VOIP packet components: DIFS, PHY, MAC, SIFS, FCS, ACK Size</td>
<td>Compute minimum overhead in DCF/PCF</td>
<td>• Decide network topology (ad-hoc or infrastructure) based on min overhead</td>
<td>Design an 802.11 WLAN in DCF/PCF mode......</td>
</tr>
</tbody>
</table>
Design a WLAN with throughput of 100 Mb/s. The WLAN is to be employed in a hostel where the majority of applications are web-transactions with the average data rate at $10^4$ bytes.

- Type of WLAN Standards 802.11 a/b/g/n
- Frequency, Bandwidth, Modulation
- Calculate System spectral efficiency by dividing throughput by the analog bandwidth
- Choose the type of wireless network
- AP selection based on the radio channel range
- Placement of AP to minimize the problem with system coverage area as it interferes with the throughput
- Type of wireless network (PTP/PTMP)

A structured statement radio channel range, AP placement and wireless network type.

2.4.2 Characteristics of problems

The above two problems contain some common characteristics which are listed below:

- functional specifications are some kind of 'numerical' data in nature
- functional specs form the basis for the decomposition of the problem
- decomposition using data the appropriate computation tasks are introduced
- this results in a smaller problem search space

Some concepts that relate to the above scenario:

1. Notes on Decomposition – Problems for which decomposition works in one step are called (block) separable or trivially parallelizable (Boyd et. al, 2007). As a general example of such a problem, suppose the variable $x$ can be partitioned into sub vectors $x_1,\ldots,x_k$, the objective is a sum of functions of $x_i$, and each constraint involves only variables from one of the sub vectors $x_i$. Then evidently we can solve each problem involving $x_i$ separately (and in parallel), and then re-assemble the solution $x$. A more interesting situation occurs when there is some coupling or interaction between the sub vectors, so the problems cannot be solved independently. For these cases there are techniques that solve the overall problem by iteratively solving a sequence of smaller problems. Some of the types of such problems are solved using techniques categorized under Primal decomposition, Dual Decomposition and Decomposition Structures with constraints (Boyd et. al, 2007)

2. Decomposition techniques in Parallel computing – There are four decomposition techniques in parallel computing namely- Recursive, Data, Exploratory Decomposition
and Speculative (Grama, Gupta & Karypis, 1994). The above problems mainly use the data decomposition methods as numerical data about some functional specifications is specified. Data decomposition limits the problem search space and the tasks are targeted towards the computation of data provided and it’s relating functional parameters.

2.5 Problems that EDIV fails to apply

In the category of innovative design problems from the Table 2.2.5 in section 2.2, we see that under the category of innovative problems in design of wireless networks there are examples of two problems. One in which the functions, parameters, goals and constraints are numerically represented and the other in which all these are discretely mentioned. Innovative problems of the second kind are the ones in which the EDIV fails to apply. The next section provides some examples of such problems.

2.5.1 Examples of problems

Eg 1. Design a Wireless Network for a hostel in IIT-B

Eg 2. Jones Hospital requires a cost effective Wireless network solution for their hospital network. The hospital employs over 800 employees, working in a building composed of seven buildings in an urban area.

2.5.2 Characteristics of problems

- The first step in EDIV is to extract specifications both visible and hidden. When the functions, parameters, goals and constraints are discretely mentioned, before extracting the specifications, the problem space needs to be constructed.
- The problem space needs to be represented as a graph with all the variables involved. The variables in the graphs are shown as nodes and they are connected with AND/OR relations. The constraints (e.g. cost effective) presented in the problem also affect the relations between the variables.
- The decomposition in both the examples is well-known but the problem search space is huge and involves the designer to traverse the problem space frequently to structure the open-ended problem.
2.5.3 Likely reasons

From section 2.4.2 there are some related concepts in problem decomposition that have arrived from literature review. They are again presented here in context to the section 2.5.

1. Notes on Decomposition – The above problems are not block separable or trivially parallelizable. The problem of optimally designing a network in order to meet a given set of specifications (such as prescribed traffic requirements, reliability, respecting delay) is complex. The network design problems include several classical OR (Operation Research) problems (Ferreira & Galvao, 1994). These problems look very similar to the OR problems. Additionally these problems involve construction of Decomposition Structures with constraints (Boyd et. al, 2007)

2. Decomposition techniques in Parallel computing – The problems in section 2.4.1 used the data decomposition methods which limited their problem space. The example problems provided in this section do not contain explicit data but are discretely mentioned and it is up to the designer to extract them. A combination of recursive, exploratory and speculative decomposition strategy (Grama, Gupta & Karypis, 1994) would be employed for decomposition of such innovative problems. This would result in a big problem space and would require traversal across the problem space in order to structure.

3. Literature mentions that the computer network design problems include several OR problems (Ferreira & Galvao, 1994). To structure OR problems there exists a set of methods known as Problem Structuring Methods (PSM). PSM were developed pragmatically, i.e, grew by and large by practice and solving OR problems. PSMs were first developed for ‘well-structured problems’ but then PSMs for ‘ill-structured problems’ also evolved. A PSM for a OR problem needs to (Mingers & Rosenhead, 2004):
   a. enable several perspectives to be brought into conjunction
   b. operate iteratively
   c. permit partial or local improvements to be identified rather than merging of various interests

This suggests that the while a learner performs SOP, the output needs to contain the picture of several ways of solving the problem, ability to move back and forth between the alternatives and keeping the sub-problem view separate rather than synthesizing it as a problem statement again.
3. Extension of Seminar to Ph.D.

The figure 3.2 represents the plan to extend the work done in seminar to Ph.D. thesis. The thinking skill chosen is ‘Problem Decomposition’ in the context of design of wireless network. The unique nature of the design problems in computer networks has prompted the choice of the TS.

![Diagram](image)

**Figure 3.2 Extension of Seminar Work to Ph.D Thesis**

3.1 Choice of TS

Engineering design is a fundamental skill for engineers. There is a need to engineering graduates to design effective solutions for real world problems. The engineering graduates are unable to demonstrate this skill on job as the problems they have dealt with are of lesser complexity. The engineering education lacks in effectively imparting design skills necessary for the 21st century workforce. The section 2 mentions the competencies in the engineering design TS. Among them first comes SOP, which is the first step in any problem solving
process. TELoTS framework for SOP TS has been developed and implemented as a TEL system TELE-EDesC.

While applying the one of the components, EDIV, of the TELoTS SOP framework, it was found that the problems which are not block separable need an additional design strategy – ‘problem decomposition’. The use of design strategies plays a significant role in engineering design, and a commonly used strategy is problem decomposition/recomposition (Song & Becker, 2014). Problem decomposition/recomposition is frequently used by experienced engineers, for solving complex engineering problems (Arvanitis et al., 2001).

3.1.1 Example

![Figure 3.1.1.3 Structuring Open Problem by Problem Decomposition](image-url)
3.2 Literature Review

The process of problem decomposition involves in breaking down the problem into sub-problems. While structuring the open problem, instead of a merged problem statement, if the sub-problems and their relations are presented it becomes easier for the designer to approach the solution. Literature states that the use of problem decomposition is developed by experience and that there exists a gap between novices and experts in problem decomposition skill in engineering design (Ho, 2001; Dym et. al, 2005).

Past studies identified that there are two ways to perform problem decomposition: breadth-first and depth-first approach. The breadth first decomposition focuses on exploring various solutions of each sub-problem and avoids deep exploration to any specific solution in the early stage. Depth-first decomposition tends to explore a specific sub-problem in detail before other sub-problems are investigated. Process of problem decomposition is related to the interdependencies in the problem (Marengo, 1989). If the subparts of a problem have strong interdependencies then the problem cannot be decomposed.

One of the major findings in studying engineering design is that novices are prone to using depth-first decomposition in problem solving (Jeffries et. al, 1981) while experts are more inclined to use breadth-first decomposition to break the problem into “manageable chunk sizes” (Ormerod & Ridgway, 1999).

Based on a meta-analysis (Mehalik & Schunn, 2007) of what constitutes a good design, the authors reviewed a large section of literature on design processes. They constructed framework of design processes and tried to code the literature based on this framework. By doing so, the authors have identified elements of design processes that have been associated with good design. The elements of design processes with high to moderate reporting frequency are:

1. problem representation
2. functional decomposition
3. interactive/iterative design methodology
4. search space
5. graphical representation
6. define/redefine constraints
7. scope of constraints

(high reporting frequency)
(moderate reporting frequency)
Design is a universal process in all fields of engineering, so the development of such a skill needs to be done in a way that it is not tied to a domain. SOP is the first step in Design TS. Problem decomposition needs to be a part of the SOP framework. The future work is expected to implement the TELoTS framework for Problem decomposition and propose a TEL system.

3.3 Future Work

The future work that I intend to do based on this seminar report is as follows:

1. Identify the placement of Problem decomposition in design process. By doing so I am trying to answer questions like: (i) Does problem decomposition happens before SOP, within SOP or parallel to SOP. (ii) Where does it come in Thinking Skill space?

2. Find answer to questions like: (i) Does problem decomposition have any other terms? (ii) What is the relation of problem decomposition with problem representation? (iii) Are they one and the same?

3. Look for studies which show that improvement in problem decomposition improves solution design.

4. Conduct inductive analysis by looking at design processes of experts.

5. Identify if there is a strong relationship of problem decomposition with domains

6. Apply TELoTS pedagogical framework to problem decomposition skill.
4. References


25


