Development and assessment of engineering design competencies using a Technology Enhanced Learning Environment

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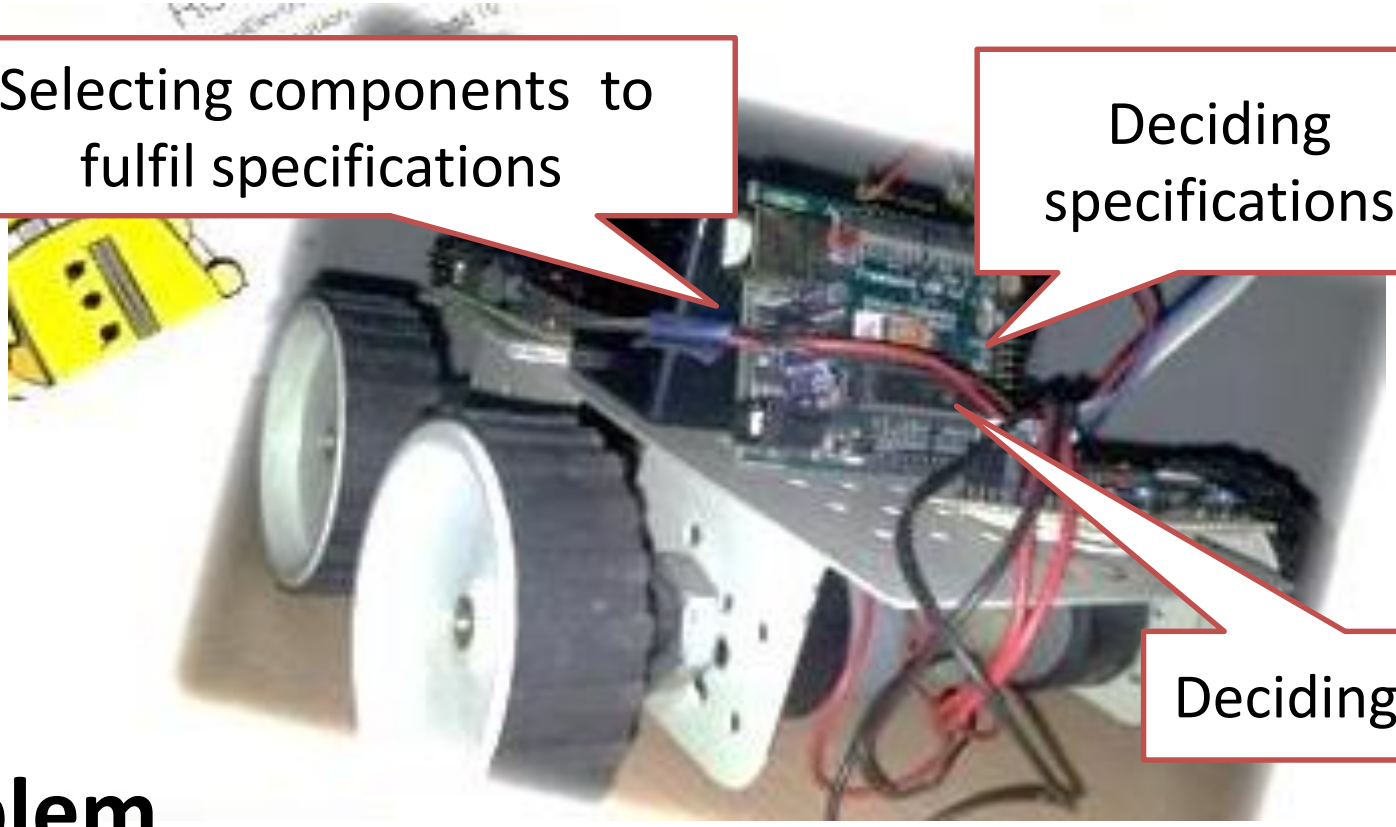
Background & Motivation

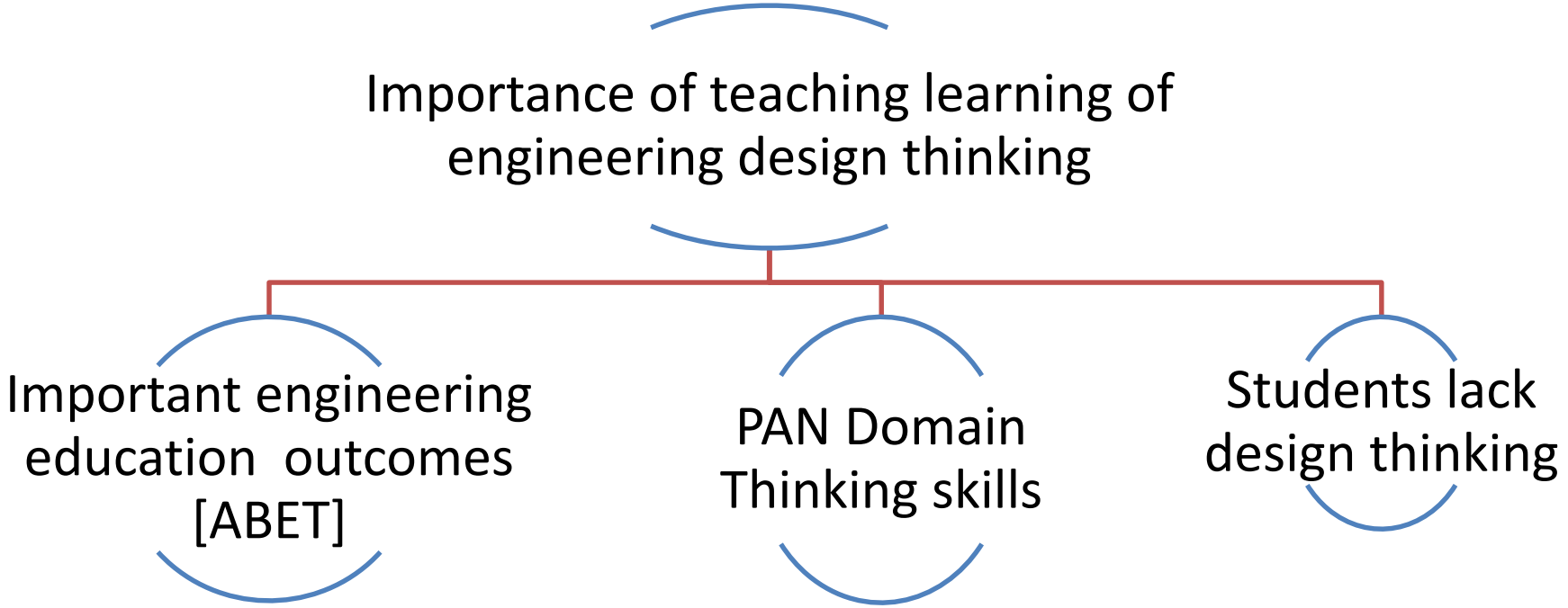
Engineering design thinking skill – What?



Problem

Teaching of engineering design thinking skill

Engineering design thinking skill-motivation



[ABET,2012; Eckerdal et al., 2006; May & Strong, 2011]

Engineering design thinking skill- Background

Engineering design thinking is complex cognitive process and combination of inquiry, prediction, decision making, problem solving, estimation etc.

Why teaching engineering design is difficult?

Students assessed for final product through presentations

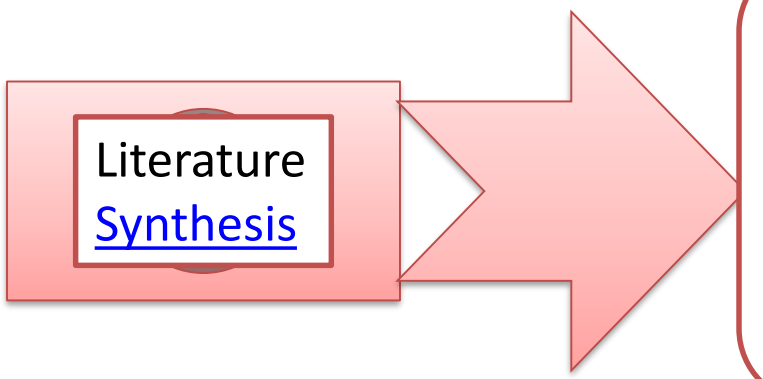
Many diverse perspective about engineering design definition.

Different teaching methods exist.(resource intensive, mostly problem oriented)

Problem statement

Engineering design thinking-competency approach

- One of the recommended approaches(ABET) is use of measurable competency.
- Competency based approach selected to define engineering design thinking skill.



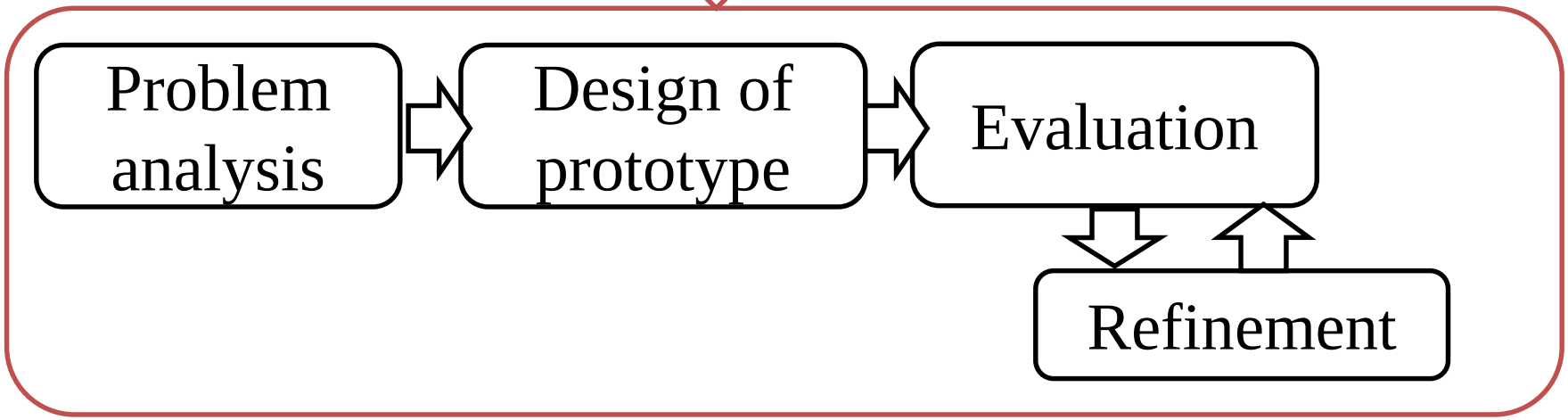
- **Structure open problem (SOP)**
- **Information Gathering(IG)**
- **Multiple Representation (MR)**
- **Divergent Thinking (DIV)**
- **Convergent Thinking (CONV)**

[Davis et al 1995, Sheppard, 1997, Atman, 2001, Dym, 2005, Aurisicchio et al., 2007,Ahmed,2007]

Research Questions

How to develop and assess engineering design competencies?

Implemented using Educational Design Research
[Van den Akker et al.,2012]



Scope of Solution

Domain:-

Analog Electronics design problems.

Type of design problems:-

Types of design problems

Innovative design problems. Confidence to attempt creative problems.

Competency:-

Learning outcomes and assessment for all competencies.

SOP for intervention.

Types of problems

[Brown, D. C., & Chandrasekaran, B. (1989)]

- **Routine Problems** -

Effective problem decomposition is known, mapping of sub functions into physical components is clear, only task is to select appropriate components that optimise well established criteria.

- **Innovative problems** -

Top level functional decomposition is known, but physical realisation of sub functions require considerably more efforts, considering solution from scratch or making substantial functional or structural modifications to existing system.

SCOPE

- **Creative Problems** -

Functional specifications are open ended, effective decomposition is not known and designer need to evaluate multiple options.

Problem Analysis (Literature Survey)

How to develop and assess engineering design competencies?

Related work on engineering design competencies assessment

Related work on TEL environments for teaching thinking skills.

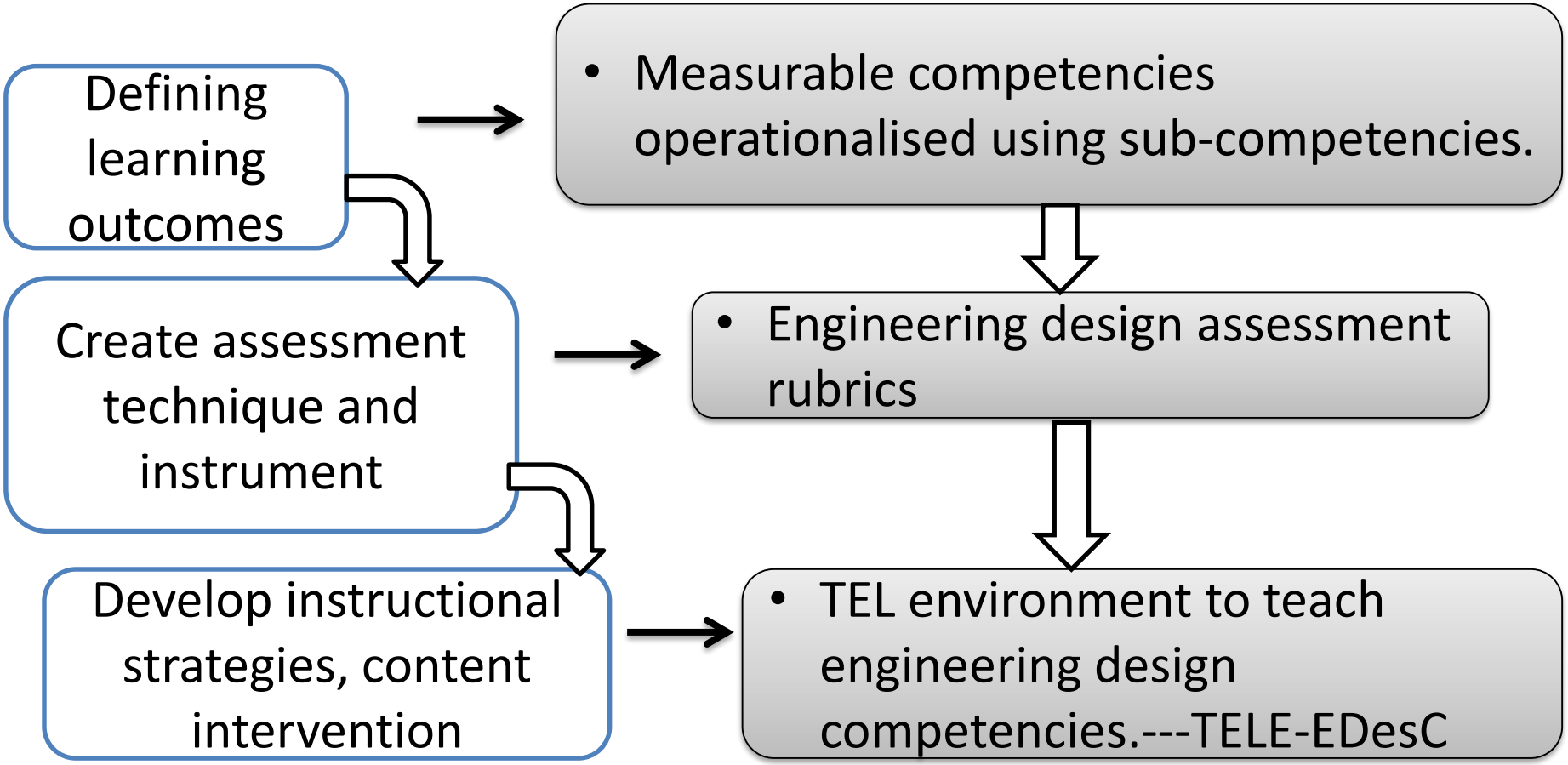
How to assess engineering design competencies?

How to design TEL environment to develop engineering design competencies?

Research Questions

Design of prototype 'backward design approach'

[Wiggins & McTighe, 2005]



RQ-Diagram

How to develop and assess engineering design competencies?

How to assess engineering design competencies?

What are measurable units of engineering design competencies?

Engineering design competencies and assessment

Operationalisation of competencies

- **RQ--What are measurable units of engineering design competencies?**
- **Data source**:- Semi-structured problem-solving interviews of 5 experts.
- **Sample**:-
  - Teachers (N=5) with more than 10 years experience in teaching design classes (experts).They solved open design problem for given application.
- **Data analysis-**:
  - Design scripts analyzed using content analysis method.
  - Codes and categories are identified from the scripts.

Scripts analysis

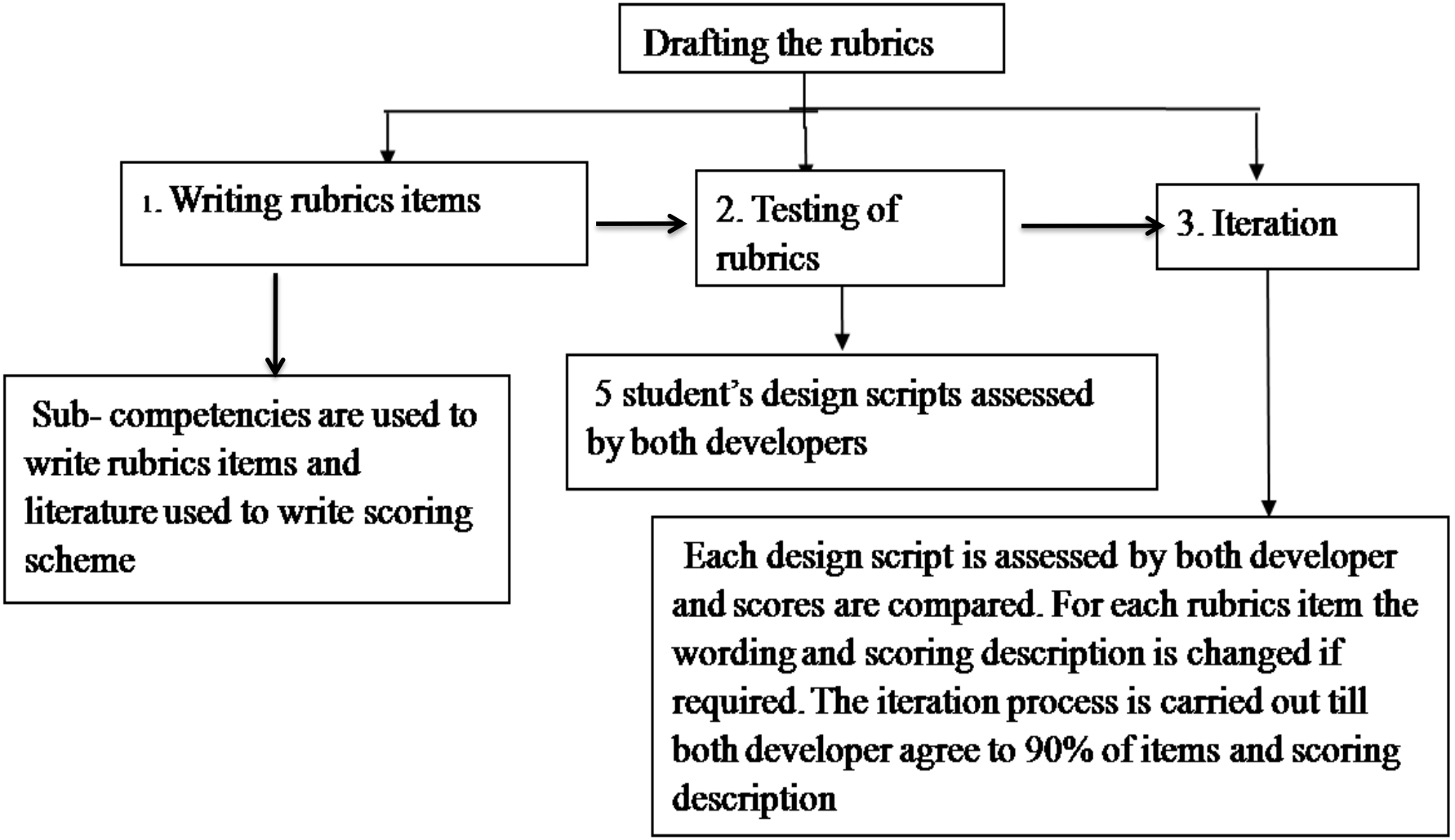
Sub competencies

Competency	**Sub -Competency**
Structure Open Problem(SOP)	Identification of specifications
	Use of specifications to structure open problem
	Implement design steps sequentially to structure problem
	Write structured problem statement

I have identified sub-competencies for all engineering design competencies.

Design of assessment instrument-Rubrics

Rubrics give timely detailed feedback. [Mertler 2001]



RESULTS: Rubrics for design competencies

- Example for Structure Open Problem Competency

Sub-competency	**Target performance(3)**	**Needs improvement(2)**	**Inadequate(1)**	**Missing(0)**
Is able to identify required relevant specifications from given open problem	All relevant visible and hidden specifications are identified and interpreted accurately. Irrelevant specifications are not identified.	An attempt is made to identify specifications. Most are identified but few hidden specifications are missing or need interpretation.	An attempt is made but most specifications identified are wrong or irrelevant or incomplete.	No attempt is made to extract specifications

I have developed rubrics for all engineering design competencies

Assessment of Engineering design competency - Rubrics

Details

Validity

- Content (expert , N=4)
- Construct [students solutions(N=20),expert solutions(N=5)]
- Criterion (comparing with design grade ,R^2=0.82)

Reliability

- Interrater reliability of rubrics (kappa=0.89) established with the help of design teacher (N=1)and researchers (N=2)

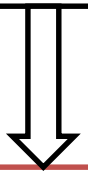
Usability

- 7 teachers applied rubrics for assessing their design solutions and usability survey indicated (SUS=72)

TEL environment intervention

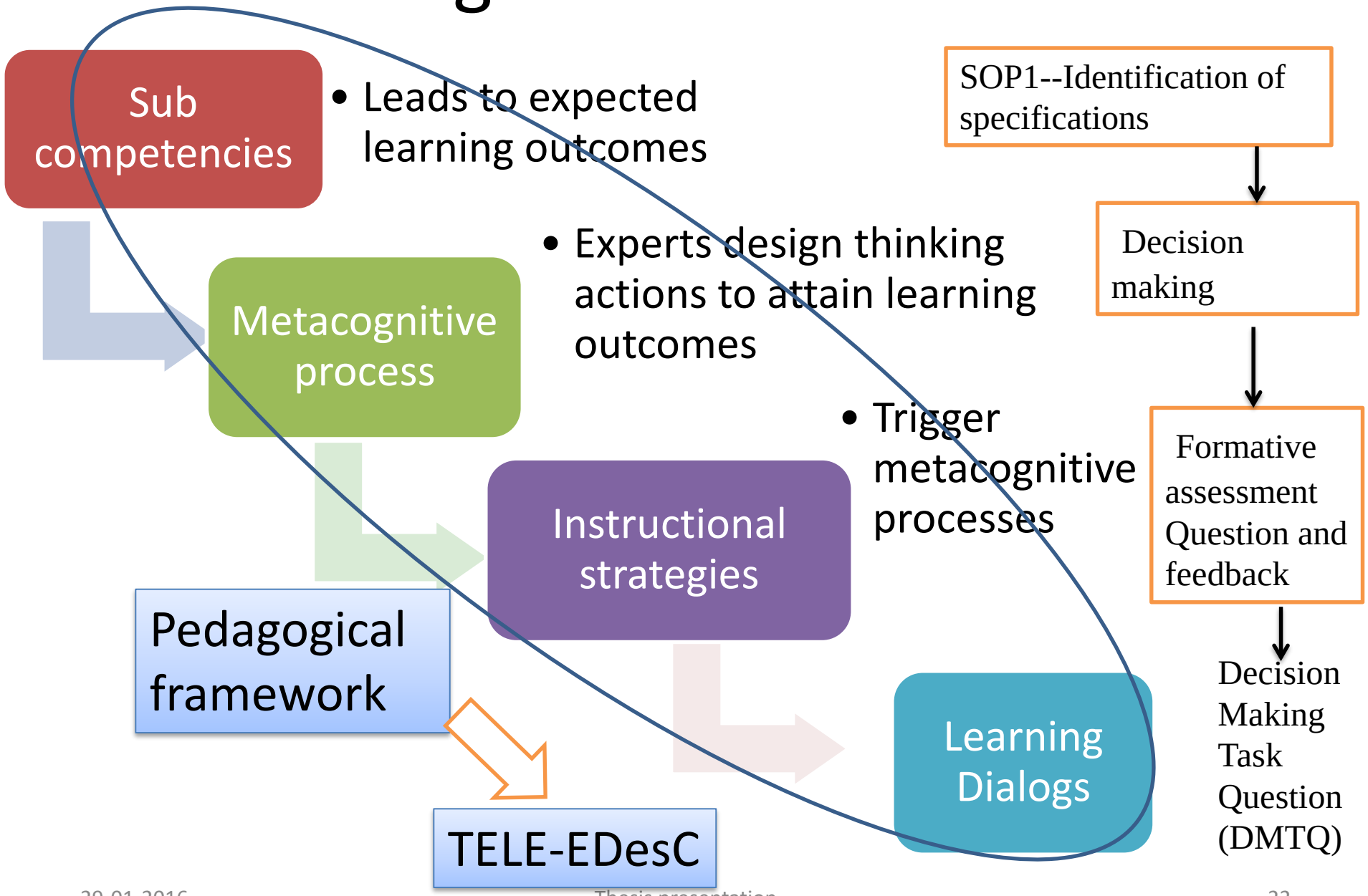
RQ-Diagram

How to develop and assess engineering design competencies?

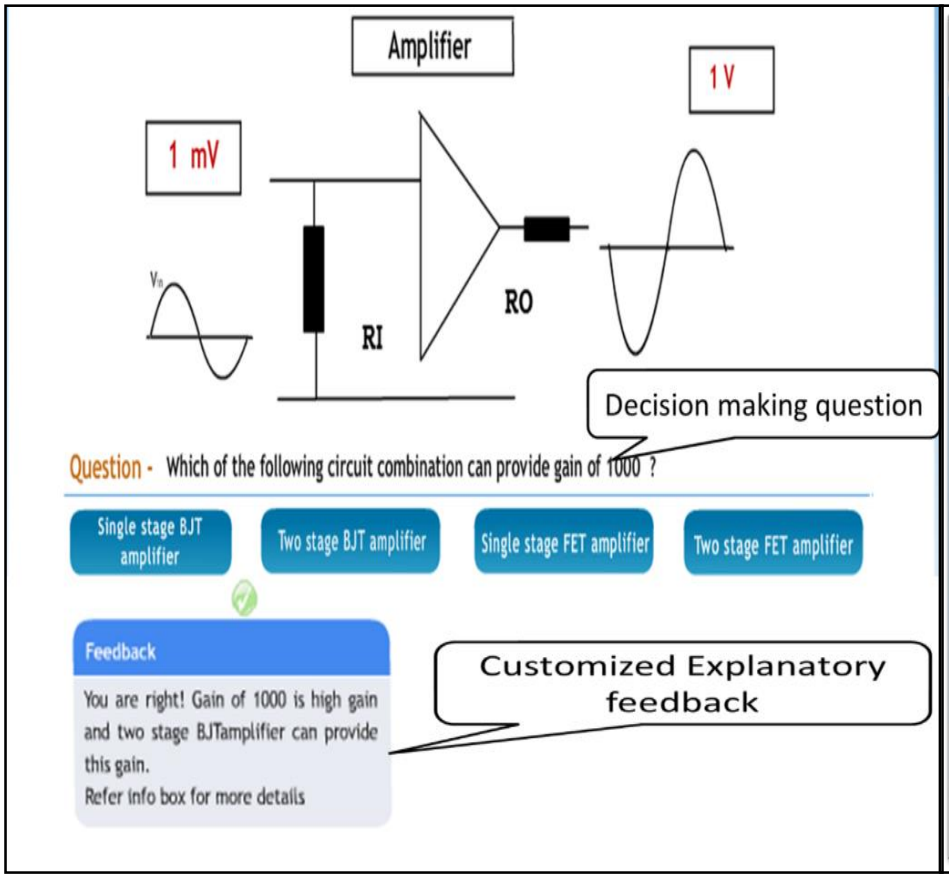


How to design TEL environment to develop engineering design competencies?

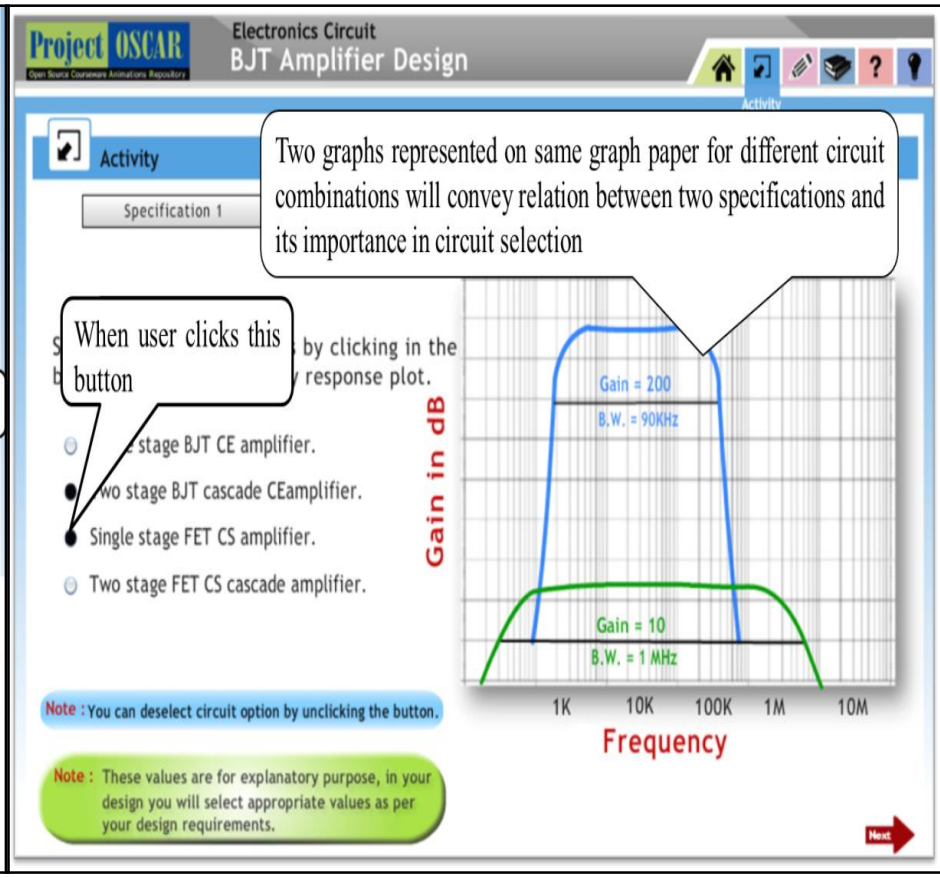
Design of TELE-EDesC



TELE-EDesC Learning Dialogs

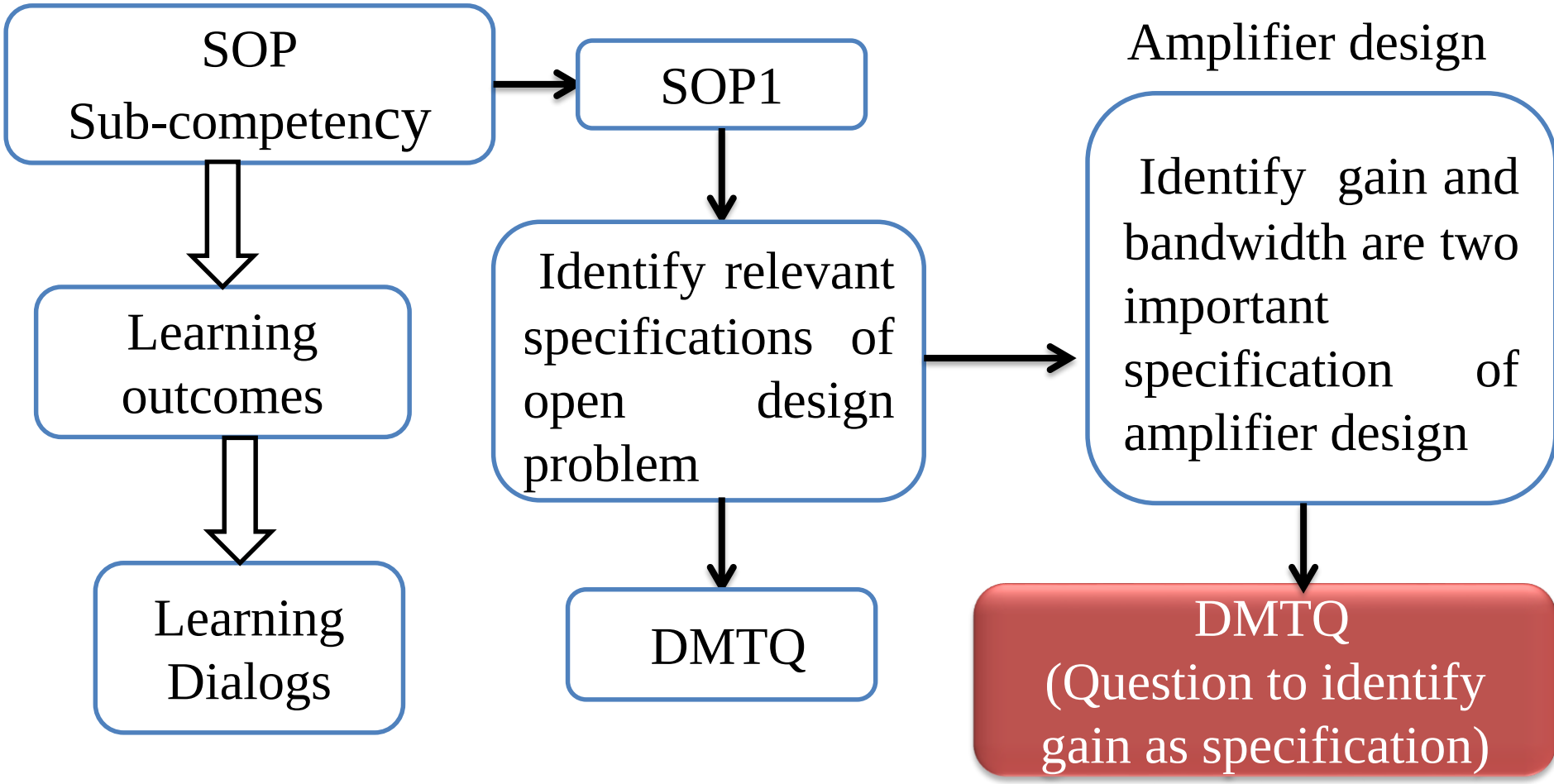


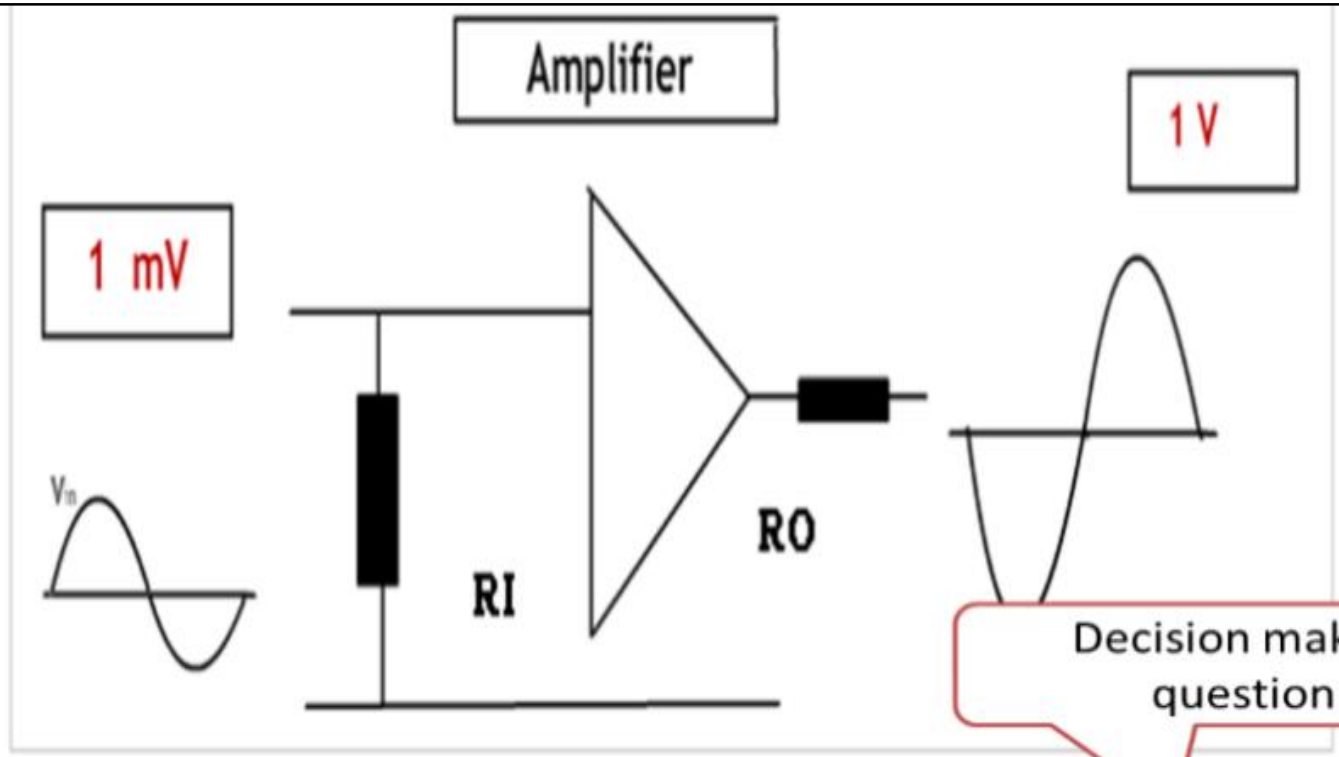
DMTQ



Simulative Manipulation

Learning Dialogs for SOP sub competency





Question - Which of the following specification will help you to decide number of stages in the amplifier circuit design?

Faithful amplification

Gain

Output voltage

Reasoning feedback

Decision supportive feedback

Feedback

Faithful amplification cannot decide number of stages in the amplifier circuit. It can decide Q point location in amplifier design.

Try Again

Feedback

You are right ! Gain is important specification in amplifier design ,since it can decide number of stages in the circuit and type of active devices in the circuit.

TELE-EDesC modules developed

Topic	Open Design Problem	TELE-EDesC learning modules developed
DC circuit design	Design of amplifier for given application	1.Importance of Q point in amplifier design
		2.Location of Q point in amplifier design
		3. Amplifier design based on gain and bandwidth
AC circuit design		4. Amplifier design based on impedance
Power amplifier	Design of audio power amplifier	5. Power amplifier design-impedance matching
		6. Power amplifier design based on power rating
OP-AMP	Design battery charge indicator	7. Identification of comparator circuit for charge indicator
OP-AMP		8. Design of LED indicator and OP-AMP comparator circuit

Evaluation

Evaluation phase – Testing effectiveness of TELE-EDesC

Following metrics used to test effectiveness of TELE-EDesC.

- *Learning effectiveness*
- *Learning behaviour*
- *Transferability of competency*

1.Learning effectiveness

Research Design

- Quasi-experiment(Controlled experiment).
- Two groups post-test only.

Sample

- 2nd year Electronics Engineering students (N = 295, expt = 146, Cntrl = 149).
- Random assignment to two groups.
- Two groups were matched based on their previous semester marks (analog electronics course).
- Students were familiar with topic of TELE-EDesC.

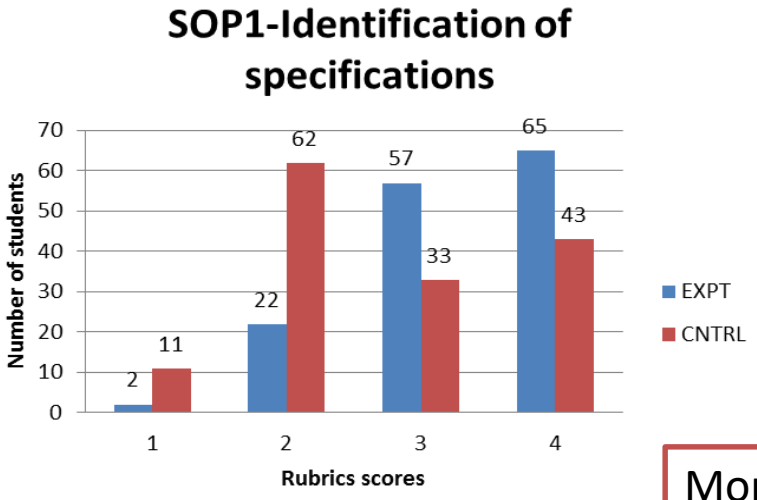
Instrument

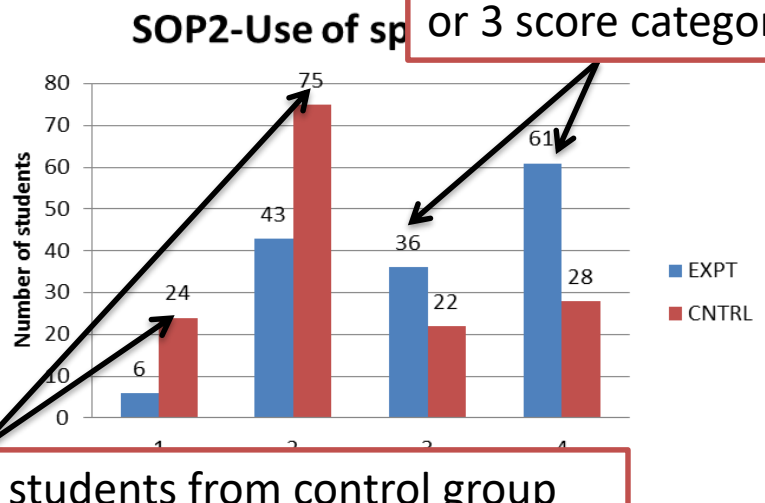
- Rubrics to assess "Structure Open Problem" competency.
- Rubrics have been validated and reliability also established

- Materials- 3 topics from analog electronics.
- Treatment
  - Experimental group: Technology enhanced learning environment to teach engineering design based on sub competencies.
  - Control group: Informative visualizations (ICT) with same content and diagrams with explanation.
- Students worked with material for 30 minutes in lab.
- Post-test: Students wrote responses to open-ended design problem related to instruction topic (30 min).
- Responses coded using rubrics.

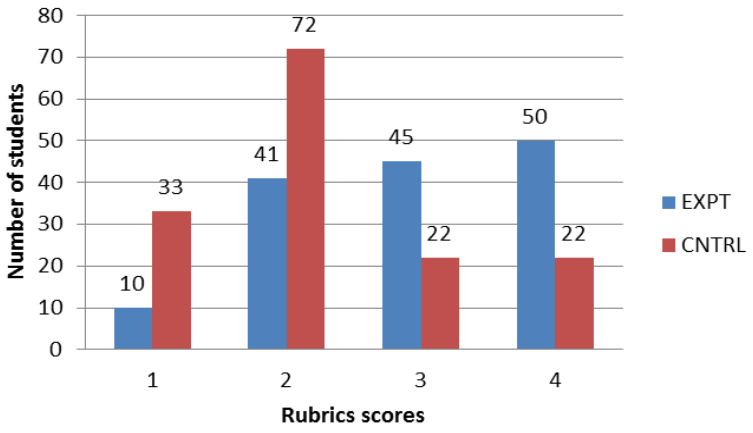
SOP scores comparison of control and experimental group

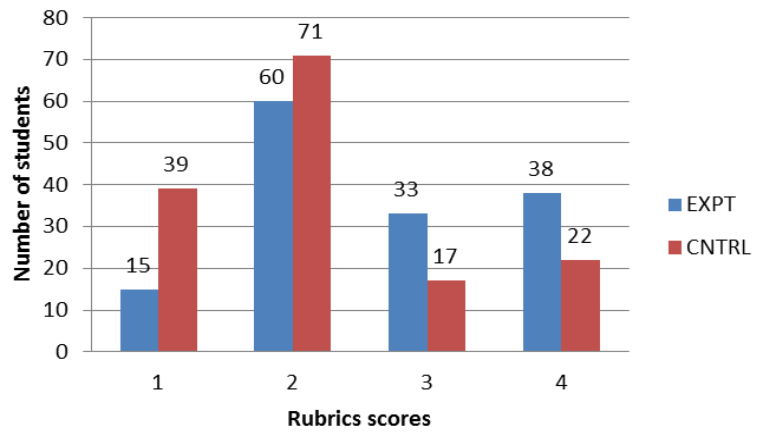
More students from experimental group for 2 or 3 score category





More students from control group fall in 0 or 1 score category





Sub-competency	Group	N	Mean rank	Mean scores	p-value
SOP1	experimental	146	171.60	2.26	< 0.01
	Control	149	124.86	1.72	
SOP2	experimental	146	175.63	2.04	< 0.01
	Control	149	120.92	1.37	
SOP3	experimental	146	177.02	1.92	< 0.01
	Control	149	119.56	1.22	
SOP4	experimental	146	169.19	1.65	< 0.01
	Control	149	127.22	1.14	

- **Students who worked with TELE-EDesC scored higher on each design sub-competency than students who worked with informative visualizations.**
- **Difference in the scores is statistically significant($p<0.01$).**

Role of prior knowledge

Topic wise comparison

Prior knowledge achievement

High, medium, low achievers of expt

Group	SOP1 (Mean rank)	SOP2 (Mean rank)	SOP3 (Mean rank)	SOP4 (Mean rank)
Low achievers (N=33)	45.1	42.0	44.1	44.0
Medium achievers (N=30)	49	53.8	50.9	44.5
High achievers (N=27)	42.1	40.6	41.1	48.5
Chi-Square	1.01	4.53	2.14	0.51
p-value	0.6	0.1038	0.343	0.77

- **No difference in SOP scores based on prior achievement level**

Summary - Learning effectiveness of TELE-EDesC

Metrics	**Inferences**
Learning effectiveness(SOP score comparison of two groups, topic wise, achievers levels)	TELE-EDesC intervention helped students to attain SOP competency in the amplifier design of analog electronics course for students of all achievement levels.

2.Learning behaviour

Research Design

- Qualitative analysis of screenshots of student interaction with TELE-EDesC modules**.**

Sample

- Students who worked with TELE-EDesC modules (expt. group in controlled study)
- Based on scores of design post-test: (5 Low scorers,5 High scorers).
- Students were equivalent in previous exams that tested conceptual understanding and traditional problem-solving.

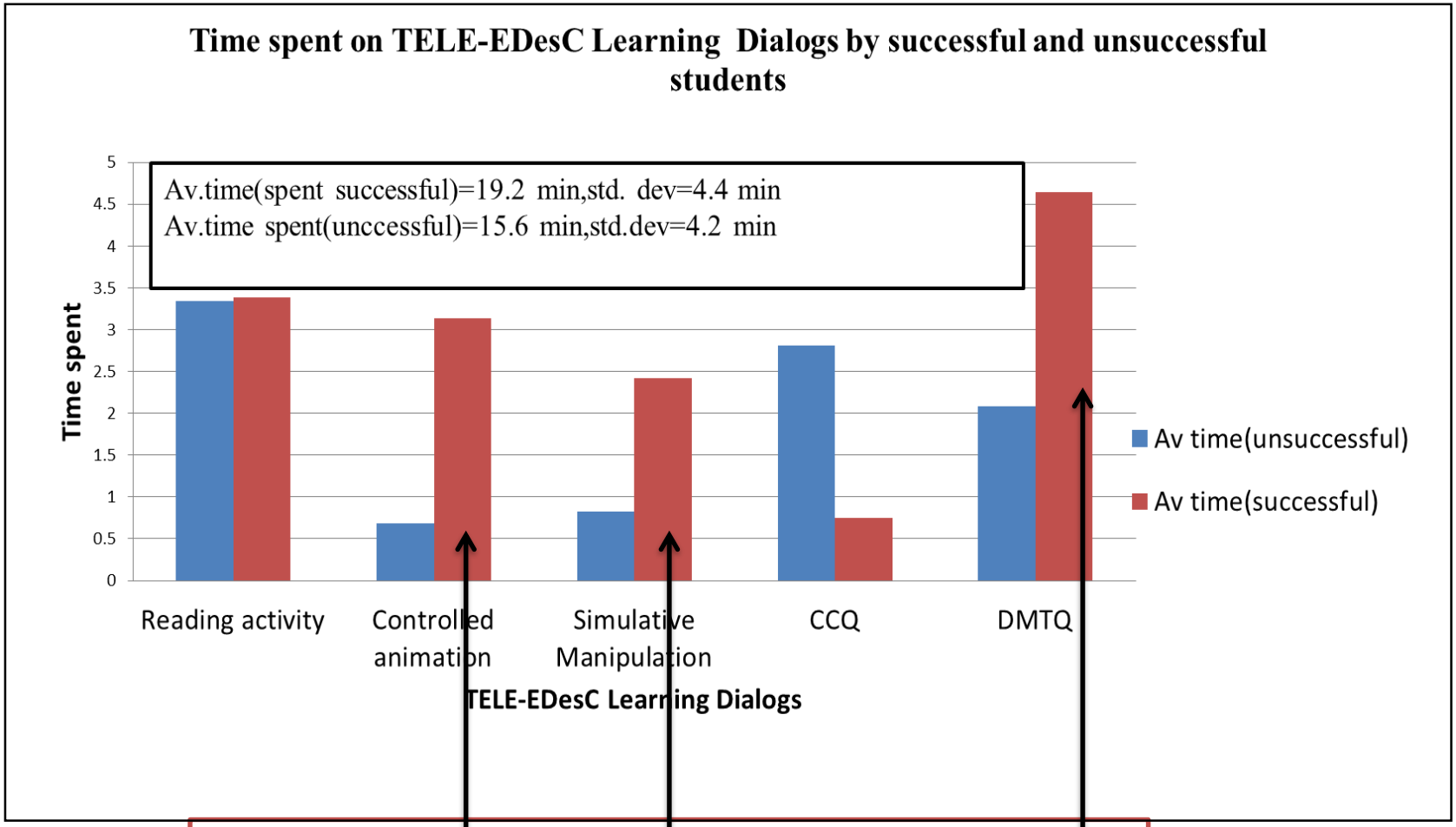
Procedure

- Screen activities of the students were captured by Cam-studio screen recording software.
- Recordings were coded and analyzed.

Data coding and analysis

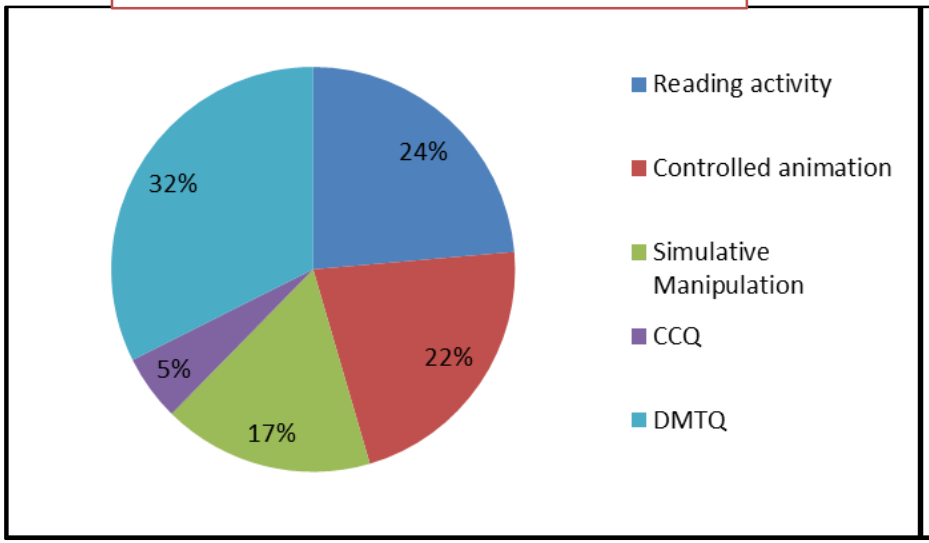
- Cam-studio recordings transcribed .
- Transcription parameters are start time, end time, Learning Dialogs interacted and action taken while interacting with Dialog by student.
- Coding scheme - Based on activities in the learning material and possible expected actions.

Results of Learning Behaviour

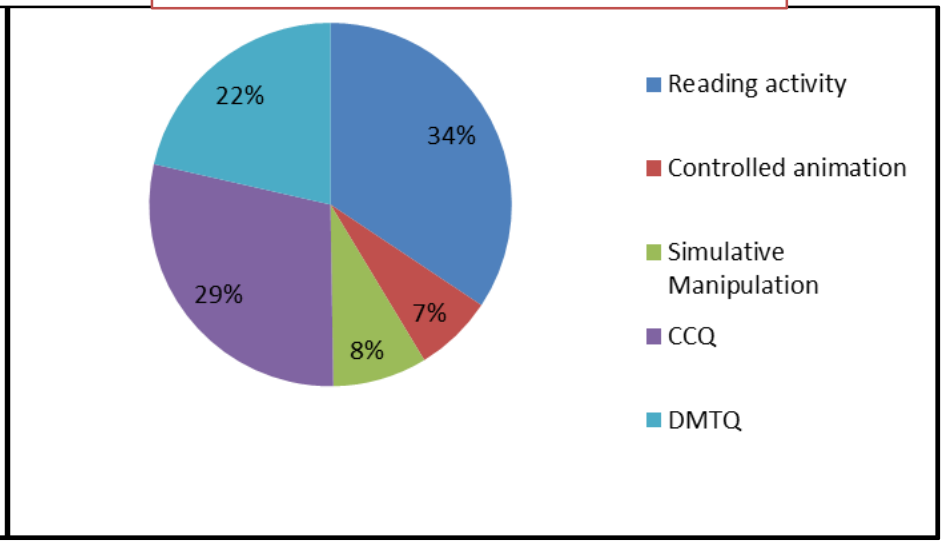


Successful students spent more time on Decision Making tasks and Simulative Manipulation and controlled animation Learning Dialogs.

Percentage of time spent per Learning Dialog out of total time(Successful students)



Percentage of time spent per Learning Dialog out of total time(Unsuccessful students)



Successful students:-

- Interacted with Learning Dialogs such as simulation and Decision Making Tasks Questions.
- Spent more time on these Learning Dialogs
- Revisited these Dialogs multiple times.

Unsuccessful students:-

- Spent largest fraction of time on reading and Concept Clarification Question
- Less time with Simulative Manipulation and Controlled Animation.

Learning behaviour with TELE-EDesC

Metrics	Inferences
Learning behaviour of TELE-EDesC	• Students who are successful in attaining SOP competencies employ an active learning process in which they are engaged with the Learning Dialogs at a high level. • On the other hand, the engagement level of unsuccessful students is lower, with reading being the primary mode of interaction.

3.Transferability of competency

Research Design

- Two groups post-test only controlled experiment

Sample

- 2nd year Electronics Engineering students (N =45, expt =23, Cntrl =22).
- Students were familiar with topic of TELE-EDesC (Amplifier design).

Treatment (first)

- Control group students studied TELE –EDesC (30 min). Experimental group studied TELE-EDesC with Rubrics .
- Post-test: Students wrote response to open-ended design problem related to instruction topic (30 min).

Transfer task

- Both control and experimental group was assigned informative visualizations in new topic (from the same course) (30 min).
- Post-test: Students wrote response to open-ended design problem in new topic (30 min) .

Instrument

- Rubrics to assess "Structure Open Problem" competency.
- Rubrics have been validated and reliability also established.

Data analysis

- Mann-Whiteny.

Results

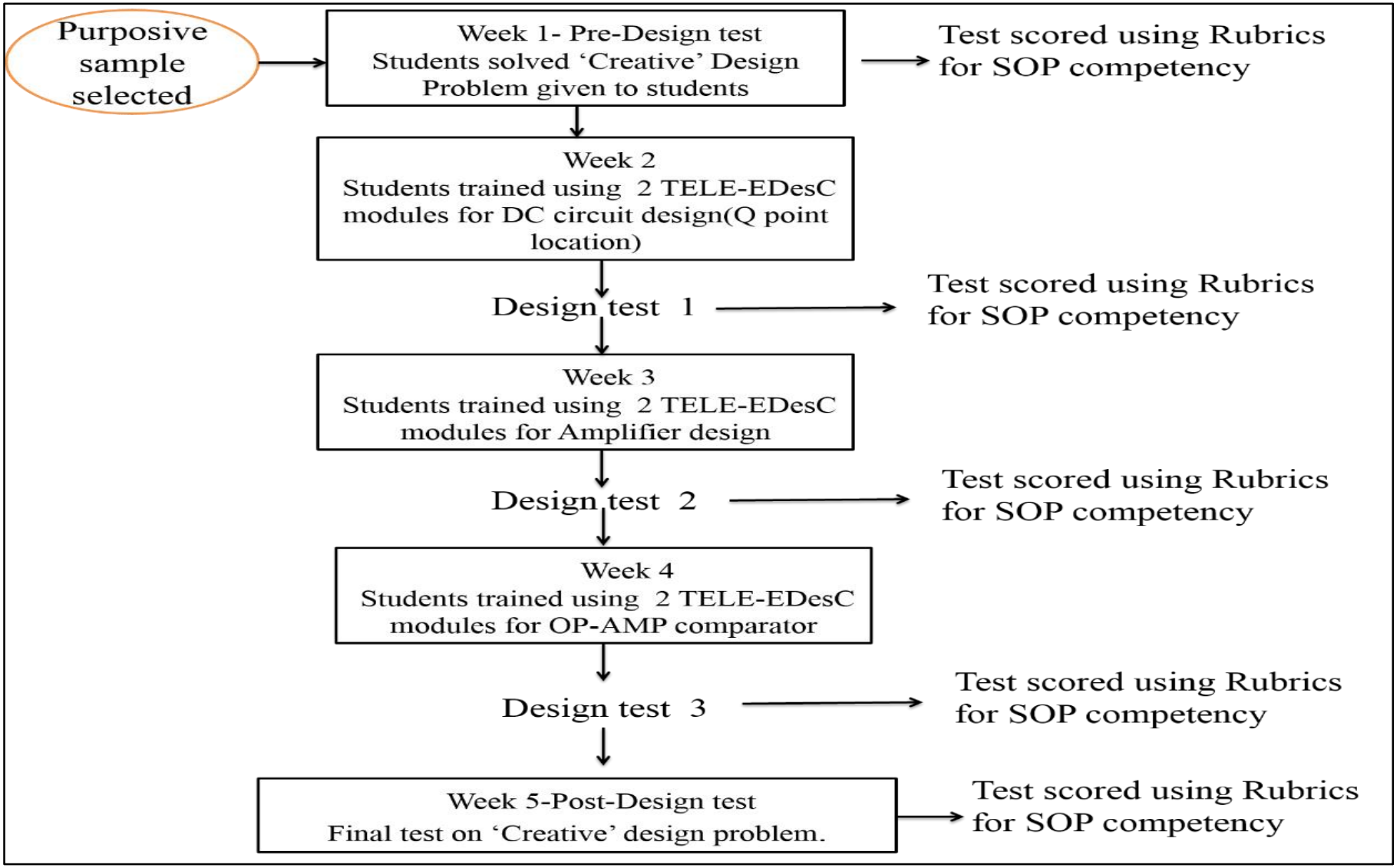
Sub-competencies	Group	Transfer test mean	Mean ranks	Z score	p-value
SOP1	Control	2.3	20.84	1.14	0.25
	Experimental	2.6	24.30		
SOP2	Control	2	19.65	1.74	0.08
	Experimental	2.5	25.61		
SOP3	Control	1.8	19.19	2.02	0.04
	Experimental	2.4	26.11		
SOP4	Control	1.4	18.89	2.11	0.03
	Experimental	2.04	26.45		

There was statistically significant difference between mean ranks of SOP3 (0.04<0.05) and SOP4 (0.03<0.05), but no statistically significant difference found in SOP1 (0.25>0.05) and SOP2 (0.08>0.05).

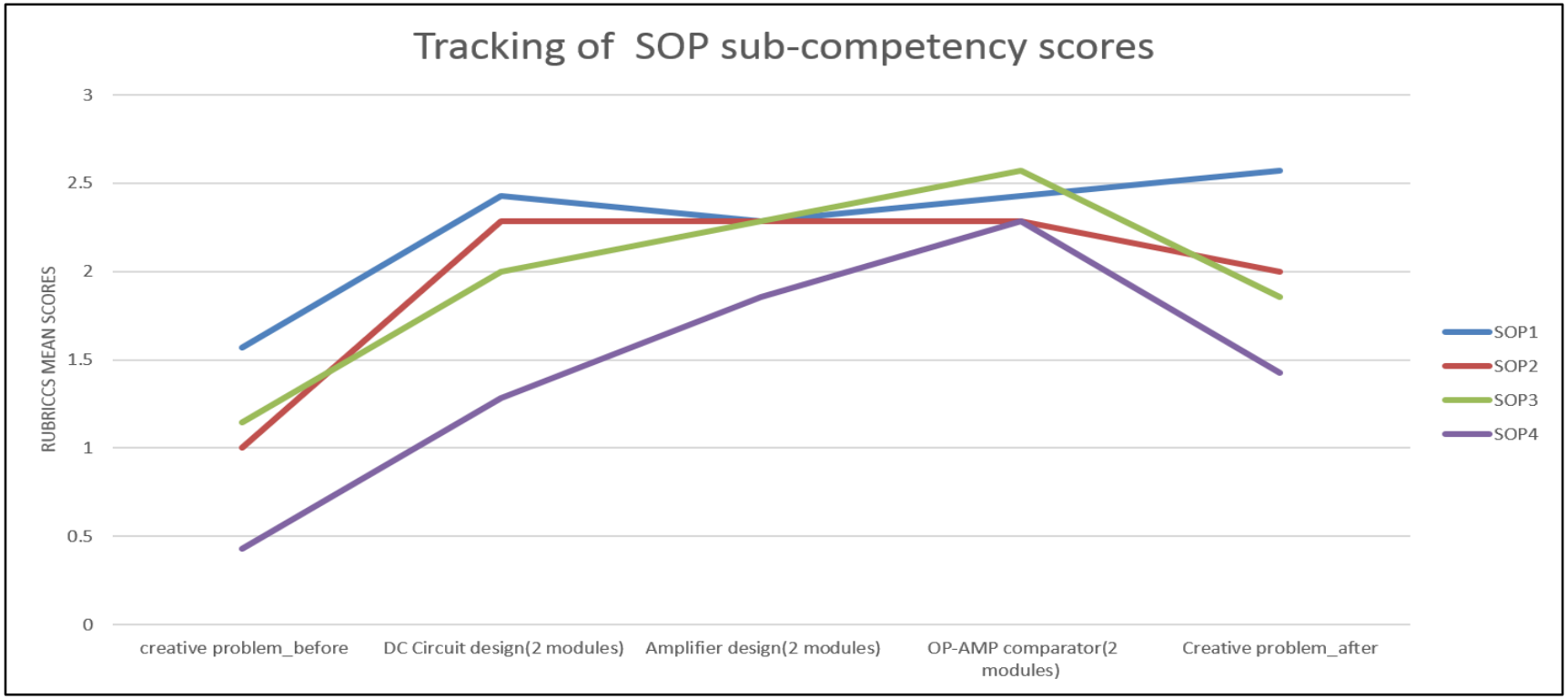
3.Transferability of competency

Metrics	**Inferences**
Transferability of competency	TELE-EDesC Learning Dialogs are sufficient to acquire and apply metacognitive processes required for SOP1 and SOP2. On the other hand, addition of self-assessment rubrics are necessary to acquire and transfer metacognitive processes required for SOP3 and SOP4.

4. Learning effectiveness over time



4. Learning effectiveness over time - result



Training with TELE-EDesC modules prepared students to attempt SOP competency for "Creative level" design problems

TELE-EDesC effectiveness

Effectiveness Metrics	**Evaluation Results**
Learning effectiveness	TELE-EDesC is able to develop SOP design competencies.
Learning behaviour	Interactive engagement with prescribed(by pedagogical framework) Learning Dialogs is recommended for successful attainment of SOP competencies.
Transferability of competency	• TELE-EDesC with self assessment rubrics is necessary for transfer of SOP competencies to new topic . • Long intervention of TELE-EDesC helped students to attain SOP in creative level design problem.

Discussion

Research Questions and Claims

Research Questions	**Claims**
RQ.1: How to assess engineering design competencies?	Formative assessment rubrics provide a valid, reliable and user-friendly technique of assessing engineering design competencies.
RQ.1.1: What are the measurable units of engineering design competencies?	Sub-competencies provide measurable units of design competencies.

Research Questions and Claims

Research Questions	**Claims**
RQ2: How to develop a TEL environment to teach engineering design competencies?	Developed pedagogical framework to identify specific Learning Dialogs for various engineering design competencies. Tested for SOP, MR. Framework provides steps and guidelines to TEL-environment designer create and sequence these Learning Dialogs into a learning module.
RQ.3.What is the effectiveness of TELE-EDesC to develop engineering design competencies?	1) TELE-EDesC modules effective to develop SOP competency in analog circuit design. 2) Successful students show productive engagement with learning dialogs. 3) Self-assessment rubrics enable students to transfer SOP competency to new topic.

Generalisability

Domain content

- 2 teachers designed Learning Dialogs for topics of antenna design and Operating systems.

TELE-EDesC learning modules to develop SOP can be designed for topics from different courses.

Design competencies

- Pedagogical framework is applied to identify Learning Dialogs of MR and preliminary testing of these Dialogs is done.
- Pedagogical framework is applied to identify metacognitive processes of other competencies

The pedagogical framework is applicable for developing TEL environments for all engineering design competencies.

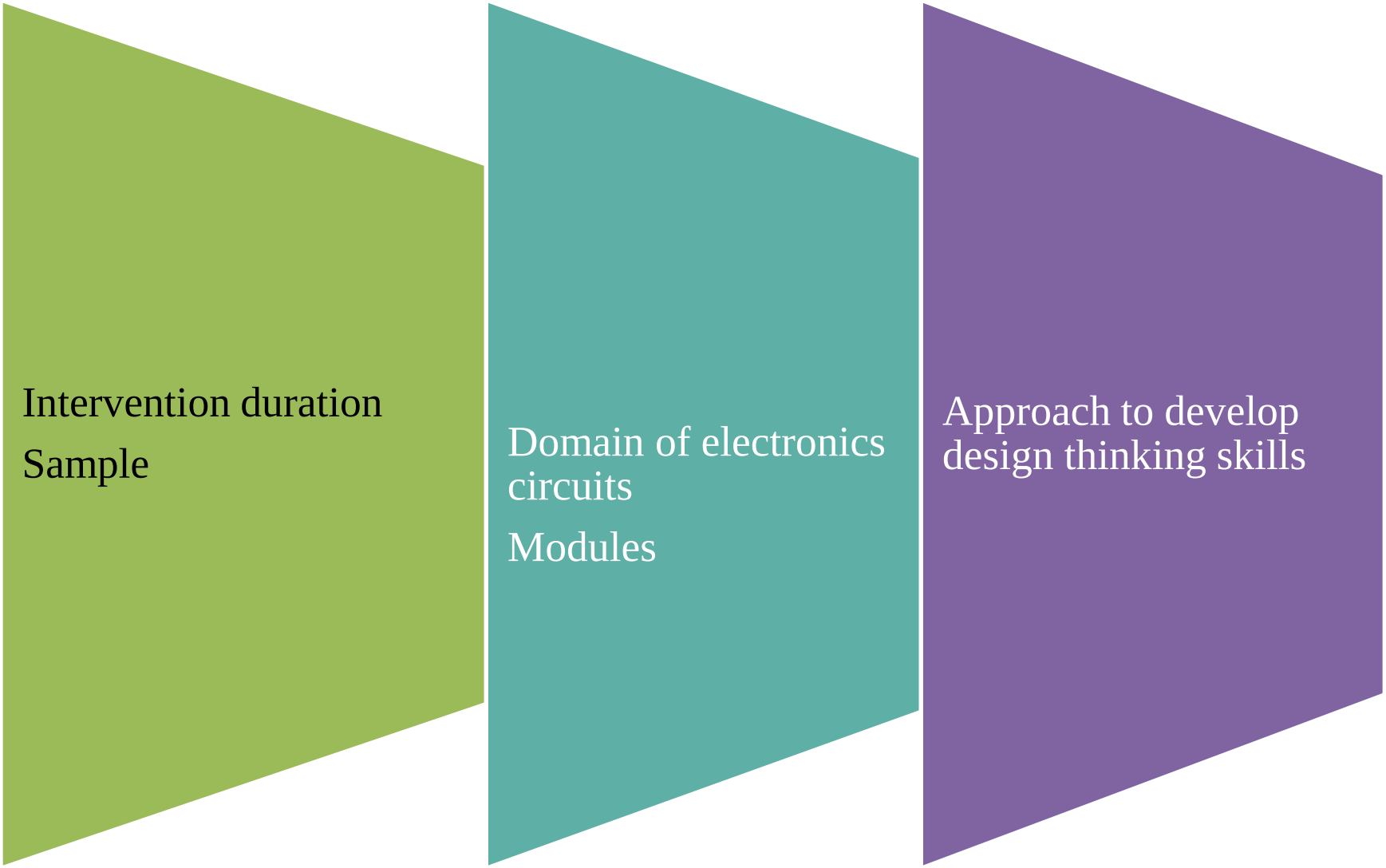
Generalisability

Level of design problems

5-week long intervention with TELE-EDesC learning modules was effective in students' being able to structure higher level (i.e. more open) design problems - Creative level problem

TELE-EDesC is useful for developing student's ability to structure open problems at various levels of 'openness', in topics related to electronics circuits.

Limitations



Contributions

Products

Eight TELE-EDesC modules developed

- Four topics
- Structure Open Problem competency
- Range of problems in analog electronics circuit domain.

Assessment rubrics for engineering design competencies developed.

- Valid (content, construct and criterion)
- Reliable(Inter-rater reliability (kappa=0.89))
- Useful (SUS= 72).

Process

A pedagogical framework to design TELE-EDesC proposed and tested.

For researchers:-

- Steps to design Learning Dialogs of TEL environments

For content developers:-

- The framework prescribes specific Learning Dialogs (and guidelines to create them) for SOP competency – DMTQ, SM, CCQ etc.

Contributions-contd…

Empirical studies

Effectiveness study of TELE-EDesC learning modules using quantitative and qualitative analysis is conducted.

- Learning Dialogs prescribed by the framework are required to develop Structure Open Problem design competency.

Other contributions

- Important competencies and sub-competencies for engineering design thinking identified
- Competencies are operationalized into measurable learning outcomes(domain of analog electronics circuits).
- For teachers, content creators and researchers:-
  - A template is developed to design TELE-EDesC modules for SOP.
  - Template contains specific guidelines to prepare content and write Learning Dialogs.

Future Work

- Expansion of pedagogical framework to develop TEL environments for various thinking skills.
- Training to faculty members to develop TELE-EDesC modules through spoken tutorials, elaborative guidelines and videos.
- Collaborative learning of engineering design competencies.
- Establishing Rubrics usability for other branches of engineering.

Publications related to thesis

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- Mavinkurve, M., & Patil, M. (2016). Impact of Simulator as a Technology Tool on Problem Solving Skills of Engineering Students-A Study Report, Journal of Engineering Education Transformations, 29(3), 124-131.

Other Publications

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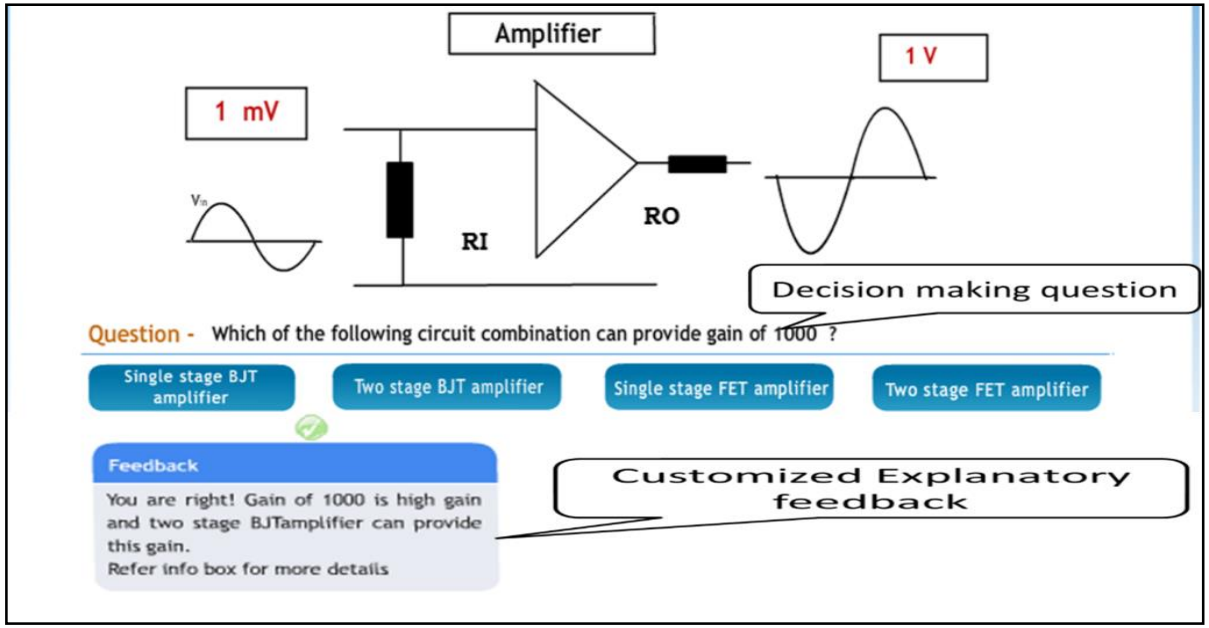
Appendix – Learning Dialogs

Learning Dialogs

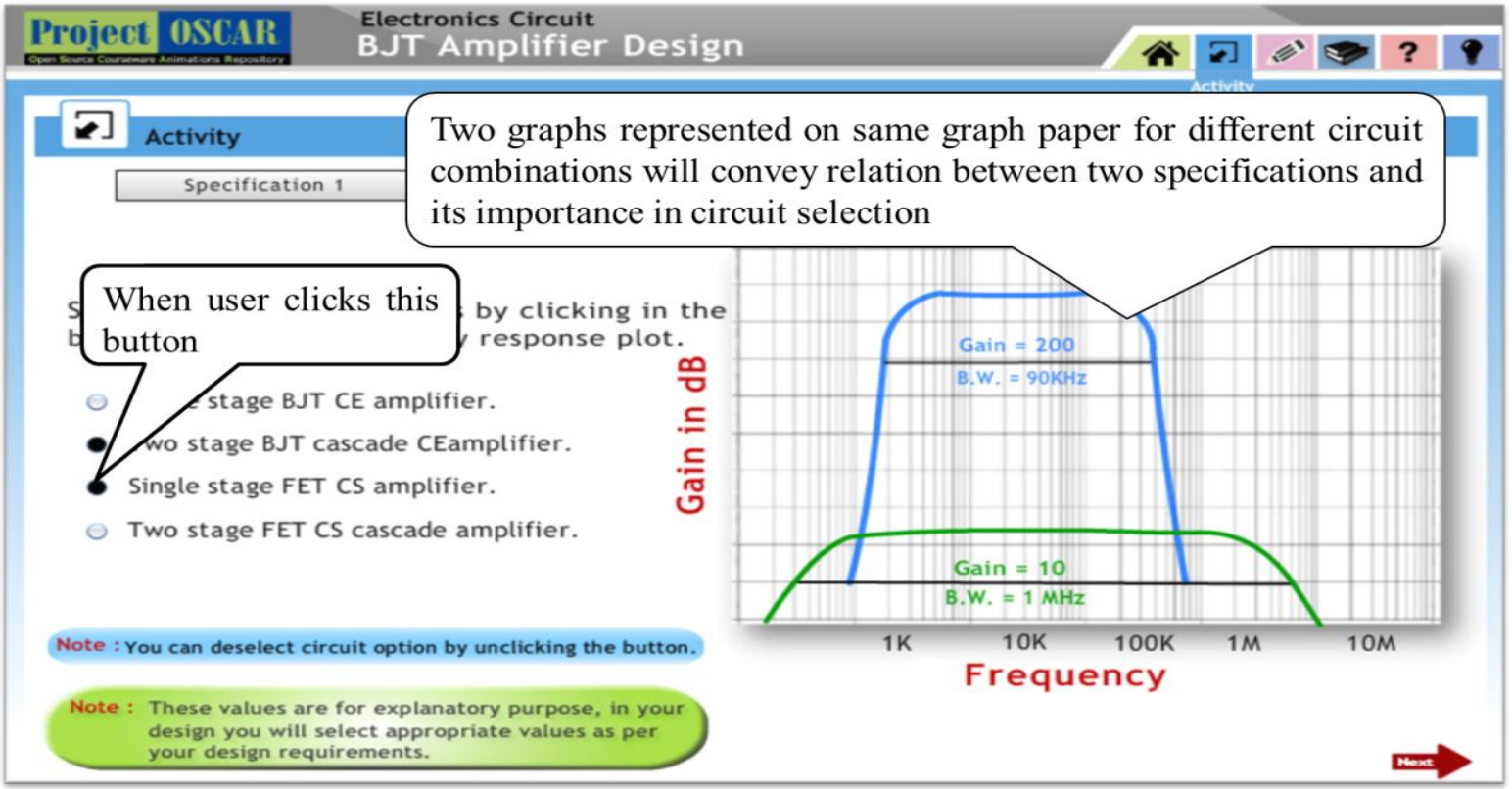
Metacognitive processes	Theoretical basis		Interactivity Design Principles	Learning Dialogs of TELE-EDesC
	Theory	Instructional strategies		
Decision Making	Metacognitive strategies	Formative assessment question	Guided activity and feedback	Decision Making Task Question(DMTQ)
	Self-regulation	Feedback		

DMTQ

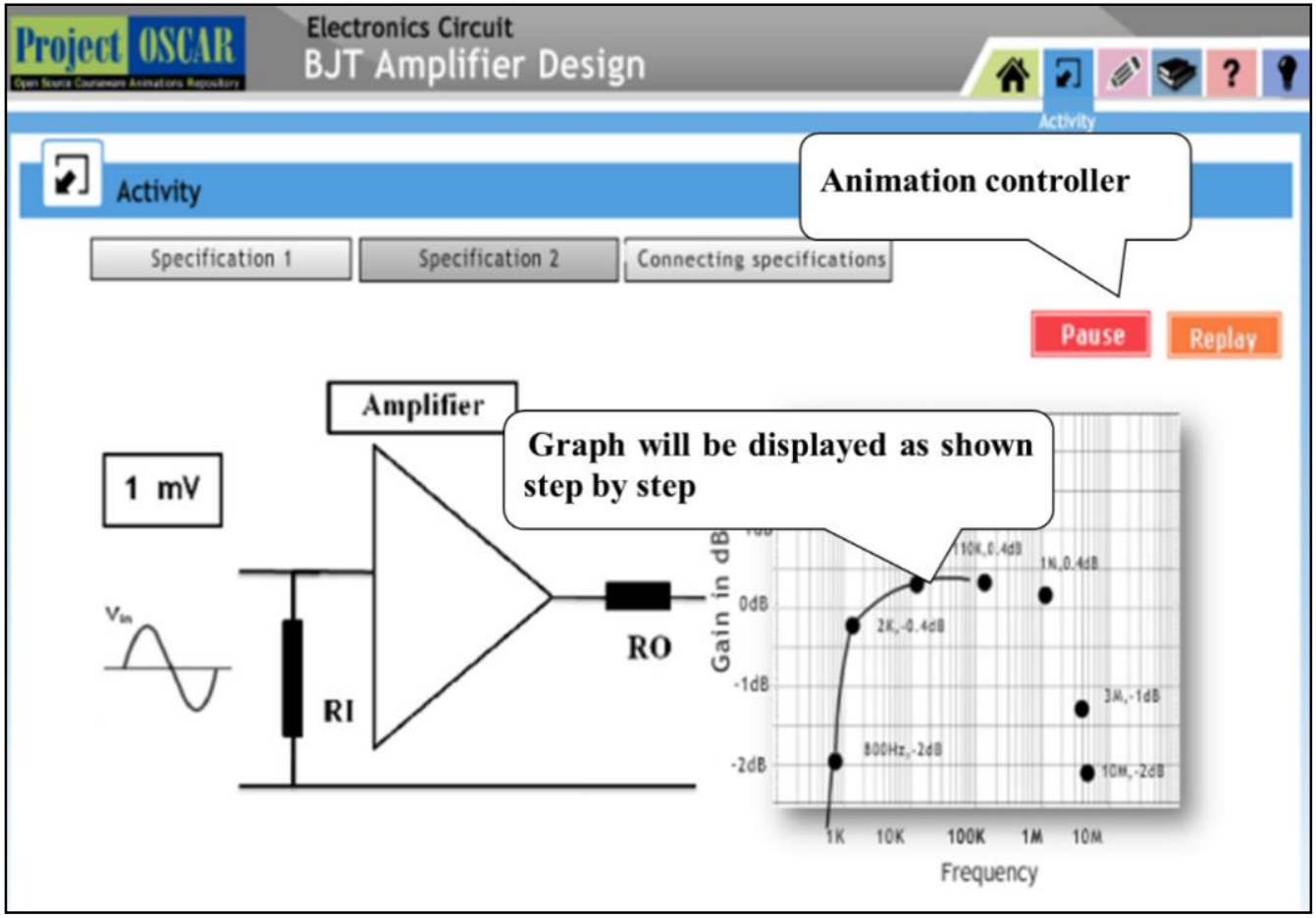


Learning Dialogs of TELE-EDesC

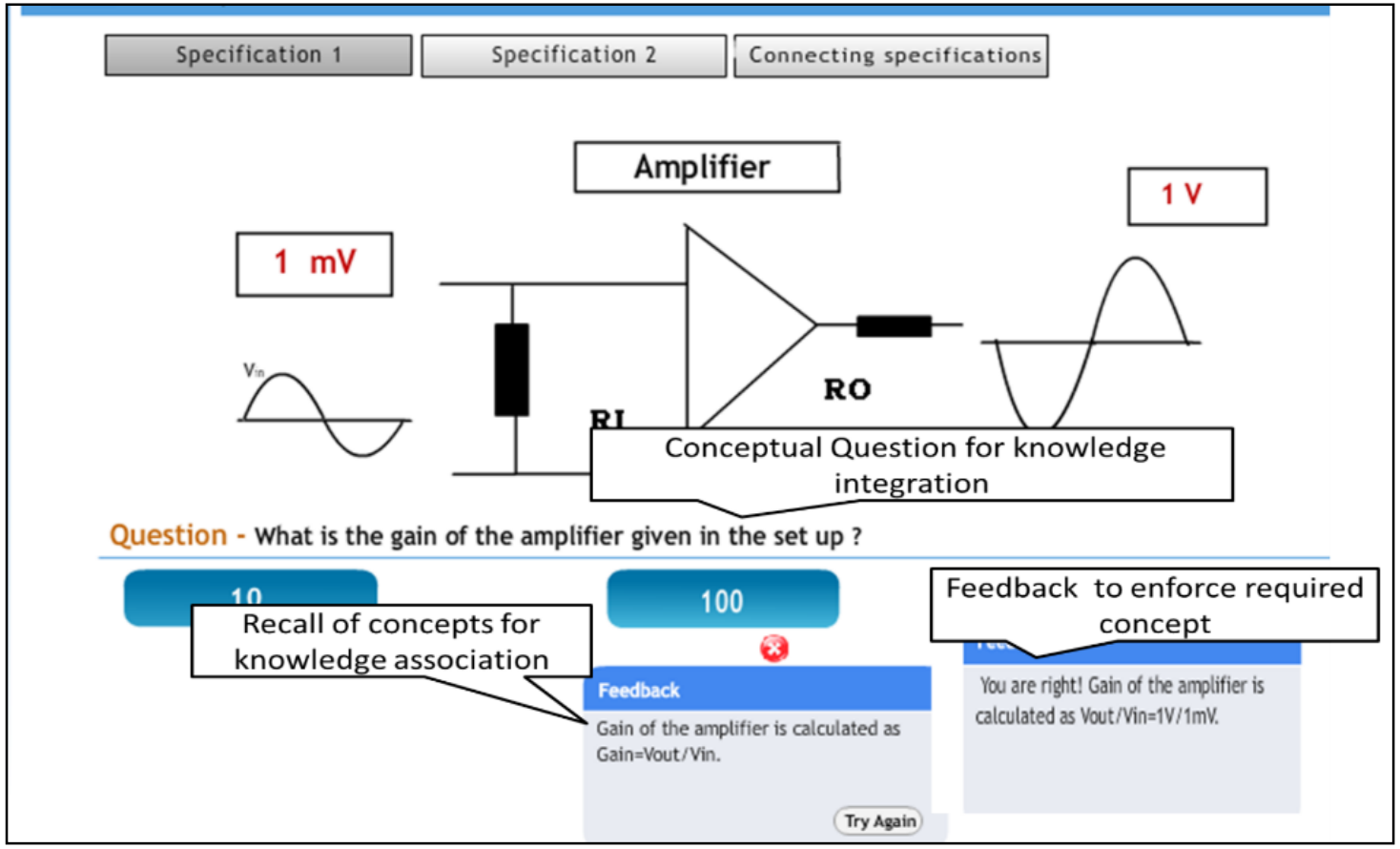
Simulative Manipulation



Controlled animation



Concept clarification



Capsule Recommendations