Teaching with visualizations in classroom setting: Mapping Instructional Strategies to Instructional Objectives

Abstract— Visualizations have been used for teaching and learning but research on their integration in classroom instruction is not that extensive. Recommendations by existing learning taxonomies for instructional strategies to use for given educational objectives are at a macro level. However, with instructors’ instructional objectives being at a more granular level, it becomes difficult for them to decide which strategy to use for their objective and how to implement it. The goal of this paper is two-fold – a) create and validate a mapping strategy between instructional objectives and instructional strategies with visualization and b) recommend an implementation plan for the chosen strategy. In this paper, we present a set of instructional objectives that instructors have while teaching with visualization in the classroom and mapped them to instructional strategies with visualization. A preliminary validation of this mapping was done through a qualitative survey. We also provide stepwise implementation plan for each strategy.

Keywords—instructional strategies; instructional objectives; visualizations; problem solving

I. INTRODUCTION

Computer-based visualizations like animations and simulations are effective teaching-learning resources at tertiary level of education across domains [1], [2], [3]. They assist in the creation of mental models [4] by making the invisible visible [5] or displaying a phenomenon using multiple representations [6] which in turn promotes problem solving skills [7]. Extensive research has been done in creating such well-designed visualizations based on learning theories [8]. However the assumption that given a well-designed visualization, instructors know how to implement them as instructional aids in the classroom is not valid [9]. It has often been reported that instructors simply play the visualization thereby reducing it to a visual textbook [9], even for topics that have potential to benefit from visualization. This attains significance since in majority of cases students are introduced to the process of learning with visualization through their instructors [10]. Thus instructional strategies that instructors use with visualizations have significant impact on their learning effectiveness.

There have been efforts to map instructional strategies to educational objectives identified by existing learning taxonomies like Revised Bloom’s [11], Component Display Theory [12] or extended content-performance matrix [13]. However, these strategies often allude to instruction delivery mechanisms like lectures, visualizations, and/or refer to support activities [14] for different types of educational objectives. These strategies are at a macro level and the guidance they provide to instructors in operationalizing these strategies is not sufficient.

In the current paper, we address instructional objectives which instructors generally have while teaching with visualization that are at a granular level and map them to instructional strategies. We also attempt to operationalize these strategies by providing a detailed implementation plan which can be easily followed by novice instructors.

In the current study, we opt for definition of instructional strategy as “specific methods to implement guidelines emerging from learning theories [15] in order to achieve a specific objective” [14]. We scoped strategies to classroom teaching with visualizations. We aim to address this issue for engineering college instructors for classroom instructions, scoped to the domain of ‘Signals and Systems’ within ‘Electrical Engineering’, a domain which can potentially benefit from visualization.

We did a qualitative study adopting grounded theory approach to explore the instructional objectives that instructors propose while teaching with visualizations. We mapped the instructional objectives to instructional strategies and a stepwise implementation plan for each instructional strategy is outlined. We identified six categories of instructional objectives along with seven types of instructional strategies for visualizations. Each category of objective was mapped to a single or multiple strategies. The resultant mapped table is expected to assist instructors in choosing and implementing the appropriate strategy for a given type of instructional objective while teaching with visualizations in the classroom.

II. RELATED WORK

We did literature survey of existing learning taxonomies that define the different types of learning levels, focused on their applicability for visualizations. We also investigated prior empirical studies for the range of instructional strategies reported to have been used successfully with visualizations in classroom instruction. In the subsections
below we present an analysis of the reviewed (and synthesized) literature.

A. Existing Learning Taxonomies with Mapped Instructional Strategies

There are a few learning taxonomies like Revised Bloom’s [11], Component Display Theory (CDT) [12], Extended Content Performance matrix [13] and SOLO taxonomy [17] where there has been an attempt to map instructional strategies to different levels of educational objectives. Of these, Revised Bloom’s taxonomy is the most frequently used consisting of six different cognitive levels. These levels were mapped to instructional strategies like summarize, chart organizers, analogies [18] which are essentially practice activities. Component Display Theory outlines an instructional strategy set for a complete lesson unit. The strategy set can be chosen based on three major factors – i) content type (Facts, Concepts, Procedures, Principles) and performance objectives expected from students (Remember, Use, Find) ii) set of four primary presentation forms and associated secondary presentation forms and iii) rules relating presentation forms to content-performance matrix. Thus for content type concept at User level, the strategy set recommended is give definition followed by give examples and then ask students to classify new entities. Morrison et al. [13] also bases their work on a content-performance matrix where performance is restricted to Recall and Application and instructional strategies to four categories of generative strategy – Elaboration, Organizational, Integrative and Recall. For example, for content type concept at Application level, the recommended strategy is integrative wherein learner generates or determines new examples and non-examples. The SOLO taxonomy [17] classifies learning outcome into five levels based on their complexity – prestructural, unistructural, multi-structural and extended abstract. [16] did an empirical study to map instructional strategies to different SOLO taxonomy levels in text-based online environment. For example, the strategies recommended for the highest two levels, are brainstorming and webquest. Since problem solving is a key competency in engineering education, including the selected domain of ‘Signals and Systems’, we looked at a taxonomy of problem solving activities [19] to complete the picture. This taxonomy classifies problem solving activity into five types and recommends teaching technique, support activities and instructional media for each type of problem solving. However, a stepwise implementation plan of the teaching technique is not provided. All the strategies identified are mapped to broader level educational objectives and as such is difficult for novice instructors to operationalize into classroom strategies with visualizations. We thus came up with multiple types of instructional objectives, each related to a type of problem solving and mapped them to strategies.

B. Learning with visualization

The literature analysis was scoped to research studies focusing on learning with visualizations. We found that the student engagement level taxonomy with visualization [20] hypothesized that learning from visualization increases with increasing levels of student engagement with visualization. These hypotheses have been proved by multiple empirical studies where the different engagement levels have been operationalized by using active learning techniques involving visualizations in various domains including ‘Signals and System’ like making students respond to quiz questions [2] or prediction activity [21] integrated within visualizations, solve exercise sheets while exploring visualization [22, 23], flipped classrooms with visualization [24] and project-based learning using visualization [25]. All the above strategies however, have been implemented in self-study instructional setting. For classroom instruction, strategies reported with visualization that have led to increase in conceptual and/or procedural understanding are solving prediction worksheets [26] or summarizing worksheets [27] with visualization, peer instruction [1] and think-pair-share [28]. However, such clear classroom strategies of how to use visualization tools in the classroom have not been reported from the ‘Signals and Systems’ field.

C. Need for our work

From analysis of literature presented above, it is evident that there is paucity of work focused on mapping instructional strategies with visualizations to instructional objectives. From comparison of learning taxonomies, what emerges is that the educational objectives are defined at a macro-level (Table I), which adequately addresses the framing of assessment questions but does not provide sufficient aid to instructors on what strategy to use for their instructional objective with visualizations, given that instructors’ objectives are often at a micro level. In the current study, we aim to address this gap by coming up with a set of instructional objectives specified by instructors themselves and map them to instructional strategies recommended by the instructors with experience in teaching with visualizations and also prior empirical studies. We also provide a stepwise implementation plan for the mapped strategies called ‘Strategy Protocol Diagram’ (Fig.1) along with guidelines for generating a lesson plan integrating visualization in classroom teaching. Thus, the current work intends to aid instructors in making a choice of instructional strategy to use with visualizations in classroom instruction.

<table>
<thead>
<tr>
<th>Learning Taxonomy</th>
<th>Examples of mapped Instructional Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revised Bloom’s</td>
<td>Summarize, chart organizers, analogies</td>
</tr>
<tr>
<td>Component Display Theory</td>
<td>Give definition then Give examples then Ask students to classify new entities</td>
</tr>
<tr>
<td>Extended Content-Performance Matrix</td>
<td>Integrative strategies: learner generates or determines new examples and non-examples</td>
</tr>
<tr>
<td>SOLO (Biggs)</td>
<td>Webquest, Brainstorming</td>
</tr>
<tr>
<td>Problem Solving activities</td>
<td>Heavy prompting to guide students towards correct choice</td>
</tr>
</tbody>
</table>

TABLE I. COMPARATIVE ANALYSIS OF INSTRUCTIONAL STRATEGIES PROPOSED BY LEARNING TAXONOMIES
based on the type of objective and also provide guidelines to generate an implementation plan for the chosen strategy.

III. RESEARCH QUESTIONS

Since mapping strategies to meta-level objectives like ‘Understand’ may not benefit the instructor who is looking for strategies that address objectives at a finer level, our research goal is therefore to map instructional strategies with visualizations to micro level instructional objectives to ensure the objective is successfully attained. In order to address this goal, the specific research questions to answer are:

- What are the different types of instructional objectives that instructors have for teaching with visualizations, scoped to ‘Signals and Systems’ topics?
- What are the different types of instructional strategies that can be used with visualizations in classroom setting?
- How can instructional strategies with visualizations be mapped to specific type of instructional objectives?

IV. METHODOLOGY

The current study follows a qualitative research methodology. Grounded theory approach was adopted to explore possible types of instructional objectives that instructors commonly have for teaching with visualizations in lecture setting, scoped to four topics of ‘Signals & Systems’. The reason for adopting grounded theory, instead of established learning taxonomies like Bloom’s, was that instructors often find the classification of their instructional objectives in Bloom’s Taxonomy ambiguous [19]. For example, a problem-solving task of diagnosis type is a combination of multiple Bloom’s levels like knowledge, comprehension and application [19]. We also wanted to examine the range of instructional strategies suggested by instructors for a particular type of instructional objective with visualization. In addition, we reviewed literature for instructional strategies that have successfully been implemented with visualizations in prior research studies. Thus the content of the instructional strategy set for visualizations for classroom instruction were sourced from interview data analysis as also from literature. To validate the mapping between instructional objectives and instructional strategies thus obtained, a qualitative validation survey was conducted with a second set of instructors.

A. Sample

In the first round, six instructors with at least five years experience in teaching ‘Signals and Systems’ course were interviewed to identify categories of instructional objectives and corresponding instructional strategies. Three of them were also researchers in ‘Educational Technology’ field. In the validation round, eight instructors were drawn from the same population to give their feedback on the mapping done between instructional objectives and instructional strategies.

B. Visualizations Used

Visualizations were chosen from the open-source animation repository (OSCAR) [29] that was created as part of Government of India’s National Mission on Education through ICT (NMEICT) which is targeted towards tertiary level science and engineering domains. These visualizations were interactive animations wherein the user could manipulate the values of various parameters like time scaling factor or time shifting factor and visually observe the relationship between the different parameters. Visualizations on four related topics of ‘Signals & Systems’ course were chosen: Transformation of continuous & discrete time signals and Convolution of continuous & discrete time signals. These topics were chosen since their learning is expected to benefit from visualization use by making the invisible visible and showing displacement with time. These were well-designed visualizations containing the following features: a) Chunked content presented in sequence b) Speed control available c) Phenomenon represented through multiple representations d) Highly interactive with provision of multiple variable manipulations e) Clicker questions on the topic in the quiz section.

C. Instruments

The interviews with instructors were semi-structured with questions like ‘Given this visualization, what will be your instructional objectives?’ or ‘How will you use this visualization in the classroom to achieve this instructional objective?’ The mapping between instructional objectives and instructional strategies obtained through these interviews were validated through a qualitative survey that contained both open and close-ended questions. As part of this survey, instructors were presented with the results of the interviews in terms of a set of instructional objectives where each objective is mapped to a set of recommended instructional strategies. Prior to answering the survey, all the instructors watched the same visualization on ‘Transformation of continuous time signals’.

As part of the survey, they were required to rank the strategies from most favored to least favored and specify the criteria for their ranking. Each type of objective was illustrated with an example for better comprehensibility. For example, if the instructional objective was ‘Given a transformation equation, students should be able to identify the sequence of transformations performed’ (Problem solving by identification), the example given was ‘If y (t) = 2x (t-2), identify the sequence of transformation performed’. The corresponding instructional strategies were detailed out with stepwise implementation plan.

D. Procedure

Grounded theory approach was followed [30, 31] for identifying the range of instructional objectives that instructors have while teaching with visualizations and the instructional strategies they recommend for a type of objective. A semi-structured interview was conducted with six instructors. Each interview was of 40-45 minutes duration. Each instructor was interviewed for two visualizations belonging to signal transformation and convolution topics. Thus twelve responses were analyzed for the four visualizations. All interviews were done by the same researcher. The recorded interviews were transcribed and analyzed for open coding. The phases of interviews were
interleaved with open coding [30]. The final set of open codes, obtained after all the interviews were done, was classified into categories as part of axial coding stage. The coding was done by two researchers to establish inter-rater agreement (Unweighted Kappa = 0.81) for the coding process. In selective coding phase, the instructional objective type codes were taken as the core category to which category of instructional strategy was mapped. To make the instructional strategy set complete, prior research studies were analyzed to identify instructional strategies used with visualizations and their purpose of use was noted for mapping them to instructional objectives. The mapping between instructional objectives and instructional strategy was validated through a qualitative online survey with ‘Signals and Systems’ instructors. Details of how the survey was conducted are given in the previous subsection. For a particular type of instructional objective, a weighted average was calculated for each strategy in the strategy set.

V. CREATION OF MAPPING SCHEME BETWEEN INSTRUCTIONAL OBJECTIVES AND INSTRUCTIONAL STRATEGIES

The data analysis and results obtained thereof have been presented in four sub-sections below according to the three research questions stated above.

A. Identifying types of instructional objectives with visualizations

The possible types of instructional objectives for the four visualizations were identified through coding of responses to the following interview question, ‘Given this visualization, what will be your instructional objectives while teaching in the classroom?’ The responses were analyzed and the patterns that emerged helped us to assign open codes to the responses as illustrated in Table II. The open codes were further analyzed to categorize them into axial codes (Table II).

We got a total of six axial codes representing different types of instructional objectives that instructors expect students to perform after studying with the visualization. These tasks broadly fall into two sub-types - explaining and problem solving where explaining categories can be considered as precursors to problem solving activities. This is in alignment with the importance of problem solving activities in engineering courses. We attempted to base the identified types of problem solving tasks into an established taxonomy of problem solving activities [19], as illustrated in Table V (after References section).

B. Creation of Instructional Strategy set

We isolated the implementation techniques suggested by faculty in their interviews, corresponding to each type of instructional objective and coded them into established instructional strategies wherever possible. This process is delineated in Table III.

To create our instructional strategy set, we included only those strategies that were suggested by multiple faculties and could be substantiated from learning theory. For example, the strategy of ‘Observe and Learn’, where students actively try to make sense of what is happening on screen follows the principles of ‘Discovery Learning’. In order to make the instructional strategy set complete, we analyzed literature for successful empirical studies with visualizations in classroom settings. We identified two such strategies from literature that had been implemented for similar types of instructional objectives with visualizations in classrooms (Peer instruction and Think-Pair-Share). Thus, seven instructional strategies were identified for visualizations in classroom instruction for the six types of instructional objectives identified above. These instructional strategies are listed in Table IV with short explanations. Strategy protocol diagrams (stepwise implementation plan) for two of the strategies is shown in Fig.1 (after References section) that depicts the constant flow of student-instructor interactions around the visualization.

### TABLE II. CODING OF INSTRUCTIONAL OBJECTIVES

<table>
<thead>
<tr>
<th>Faculty member’s response (verbatim)</th>
<th>Open code</th>
<th>Axial code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Given the mathematical operation, should be able to carry out the operation on the signals.</td>
<td>Demonstrate-Math to graph</td>
<td>Problem solving applying MR: to solve problems related to a single process</td>
</tr>
<tr>
<td>Given the signal, should be able to write down the mathematical expression</td>
<td>Demonstrate - Graph to Math</td>
<td></td>
</tr>
<tr>
<td>Explain how graphical operation is getting represented mathematically</td>
<td>Relate graphical to mathematical</td>
<td>Explain a process using MR: by drawing graphs/write math expression</td>
</tr>
<tr>
<td>Explain graphically what these transformation operations mean</td>
<td>Explain by drawing graphs</td>
<td></td>
</tr>
<tr>
<td>Given an equation, they should be able to identify the type of transformations going on</td>
<td>Identify transformation types</td>
<td>Problem solving by identification to identify the steps in a process</td>
</tr>
</tbody>
</table>

### TABLE III. CODING OF INSTRUCTIONAL STRATEGIES

<table>
<thead>
<tr>
<th>Faculty member’s response (verbatim)</th>
<th>Coding of instructional strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose 2 waveforms from the interactivity portion start the animation &amp; pause it. I will ask them to draw the waveforms in notebook. Continue the animation to help students understand if their answer was right or wrong. Repeat this for the whole example. Then do 1 more example likewise.</td>
<td>Faded strategy</td>
</tr>
<tr>
<td>Solve problems on the board &amp; give hints on how to crack like problems. Let them do Drill &amp; practice themselves. Use LO afterwards to confirm understanding by giving a problem which is addressed in LO then compare answer by with LO.</td>
<td>Faded example</td>
</tr>
</tbody>
</table>
TABLE IV. INSTRUCTIONAL STRATEGY CATEGORIES

<table>
<thead>
<tr>
<th>Instructional Strategy with visualization</th>
<th>Teaching Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observe &amp; Learn (OL)</td>
<td>Before parallel commentary, set the scaling factor for time scaling to a specific value &amp; ask students to tell what they observed.</td>
</tr>
<tr>
<td>Elicit-Confront-Resolve (EC)</td>
<td>Ask students to answer a question, show visualization (viz.) so that students can compare their answers with what is shown, followed by instructor’s parallel explanation with viz.</td>
</tr>
<tr>
<td>Faded example (FE)</td>
<td>Solve the problem stepwise with the viz. with parallel explanation. In next step give a similar problem and solve partially with the viz. Ask students to complete the solution. Let viz. play in the background. Now give a third problem for students to solve entirely by themselves. Show viz. again to give feedback.</td>
</tr>
<tr>
<td>Predict &amp; Learn (PL)</td>
<td>Show students the viz., pause and ask students to predict ’what-if’. Now play viz. to show and explain the answer.</td>
</tr>
<tr>
<td>Peer Instruction (PI)</td>
<td>Give the problem as a clicker question. Ask students to discuss in groups and vote. Then show viz. and ask students to modify their answers if required and vote again.</td>
</tr>
<tr>
<td>Think-Pair-Share with viz. (TPS)</td>
<td>Ask students to solve parts of the same problem individually. In Think phase, ask them to pair up and combine the part solutions to answer the bigger problem given. In share phase initiate discussion by comparing student answers with what is shown in viz.</td>
</tr>
</tbody>
</table>

C. Mapping Instructional Strategies to Instructional Objectives

The instructional strategies, sourced from the interview, were implicitly mapped to instructional objectives by the instructors themselves. The instructional strategies sourced from literature were mapped to instructional objectives based on the characteristics of the strategy outlined in prior studies [1], [29]. For example, Think-Pair-Share (TPS) being ideal for multistep problem solving [29] was mapped to problem-solving applying multiple representations for multiple/single operations. Of the six types of instructional objectives, two types could be mapped to a single strategy, two other objectives were mapped to a set of two strategies each and the remaining two were mapped to set of four strategies each (Table V, after References section).

VI. VALIDATION OF MAPPING SCHEME

To validate the mapping presented in Table V [after References], we did a preliminary validation through a qualitative survey with eight instructors including three instructors from the first round who were ‘Educational Technology’ experts. They were all instructors who have taught ‘Signals and Systems’ course in engineering colleges of Mumbai University.

A. Validation Process

All instructors viewed the same visualization ‘Transformation of continuous time signal’ and were presented with the table of instructional objectives mapped to strategies with visualization. Each instructional objective was illustrated with an example from ‘Signal Transformation’ topic for better comprehensibility of the mapping table. The instructors then ranked the mapped strategies against each objective with justification for their rankings. In the two cases of one-to-one mapping, instructors were asked whether they agreed with the mapping and to provide justification for the same. For the rest of the instructional objective types, weighted average was calculated for each strategy in a set. In cases where one objective was mapped to a set of two strategies, the most favored strategy was assigned a weight of 4 and the other strategy was given a weight of 1. In cases where an objective is mapped to four strategies, the most favored strategy is given a weight of 4 with weights decreasing to 1 for the least favored. Thus, a strategy with a weighted average nearing 3.2 is clearly the strategy favored by majority of our respondents. This validation process is only the first step towards coming up with a valid and commonly acceptable set of strategies mapped to instructional objectives with visualization, given the constraints of college classrooms in Indian context.

B. Validation Results

The instructional objective of ‘Explain through MR verbally’ and ‘Problem solving by identification and prediction’ clearly mapped onto single strategies with a weighted average of 3.2. For the objective of ‘Problem solving by prediction’, the strategy ‘Predict & Learn’ was chosen by majority of the respondents with a weighted average of 2.6. But for the remaining four objectives, the instructor preference was fairly evenly spread out across the mapped strategies. For ‘Explain through MR by drawing graphs’, where MR refers to multiple representations, both the mapped strategies appear to be equally favored. In cases of ‘Problem solving applying MR’ objectives involving single or multiple processes, peer instruction is comparatively the most favored strategy. However, the weighted averages of all the strategies are quite close. An analysis of the justifications provided by instructors reveal that instructors used two criteria namely, ‘Complexity of the problem’ and ‘Student involvement’ to rank the strategies. As the complexity of problem increased from single to multiple processes, instructors favored Faded Example over TPS. One of the reasons given in favor of Faded Example was “students understand the approach to solve the problem
better” through this strategy. However, the validation results are based on the responses of only eight instructors. These should be treated as first round validations. We need to validate the mapping strategy between instructional objectives and instructional strategies with visualizations with a larger set of instructors. The instructor validations would then need to be confirmed through field experiments with students.

C. Usability Testing

As a preliminary step towards establishing the usability of the proposed guidelines and strategy protocol diagrams for operationalizing the proposed mapping scheme (Table V), two ‘Signals and Systems’ instructors were asked to generate lesson plans based on the proposed guidelines. The instructional objective chosen for both instructors was ‘Problem solving applying MR: to solve problems related to multiple processes’ for the topic of ‘Transformation of continuous time signals’. The proposed guidelines included the strategy protocol diagram for the strategy of ‘TPS with viz.’ (Fig.1) and detailed instructions to generate a lesson plan integrating the visualization. The instructions pertained to the type of problem to be chosen like the problem should be divisible into sub-parts and the solution of each sub-part can be assembled to find the final answer. It also included instructions on how to set up the activity within the lecture like each phase of the activity (Think, Pair, Share) should have a clear deliverable and the phases should be logically connected. A time duration for each phase was recommended to ensure students were given sufficient time to solve the problem posed in that phase. We found both instructors were able to produce a lesson plan as we had intended. An example of the ‘Think’ and ‘Share’ phase activities constructed around the visualization, by one of the instructors within their lesson plan, is shown in Fig.2.

VII. DISCUSSION AND SUMMARY

In this paper, we have attempted to identify the instructional objectives that instructors have while teaching with visualization in classroom instruction. We were able to identify, through grounded theory, six types of instructional objectives with visualization that were at a more granular level than specified in existing learning taxonomies and were mainly related to problem solving tasks. This may be because we scoped to Electrical Engineering domain where problem solving is an important skill in the curriculum. We were able to align these objectives to an existing taxonomy of problem solving activities. The types of instructional objectives identified with visualizations are however, currently scoped to ‘Signals and Systems’ topics. As part of future work, we would like to extend it to other sub-domains in Electrical Engineering.

Along with the objectives, we also identified seven categories of instructional strategies scoped to visualizations on four related topics of ‘Signals and Systems’. We tried to map these instructional strategies with visualizations to the identified objectives. We have also designed stepwise implementation plans for each of the strategies with visualizations. Thus, the current work aims to aid instructors by not only providing instructional strategies to adopt for a particular type of instructional objective but also provide them with a detailed implementation plan to execute the strategy with visualizations. The mapping of instructional strategies with visualization to instructional objectives was done on the basis of recommendations of experienced instructors as also on the features of the strategy suitable for the nature of the objective.

A preliminary validation of this mapping was carried out through a qualitative survey with eight instructors. All the instructors agreed with the mapping of two of the objectives, ‘explain verbally through MR’ and ‘problem solving by identification of process steps’ to a single instructional strategy each. For the objective of ‘problem solving by prediction’, the strategy of ‘Predict & Learn’ was partially favoured over ‘Elicit-Confront-Resolve’ strategy. For the remaining three objectives, the preference of strategies was spread out with no clear most favoured strategy. However, for problem solving tasks applying MR, involving either single or multiple processes, we found ‘Peer Instruction’ as the strategy marginally favoured by most instructors. Further analysis of instructor responses to the validation criteria adopted revealed that instructors employed two types of criteria to rank strategies, namely problem complexity and student involvement. For example, as the complexity of the problem increased from single to multiple processes, more instructors preferred an instructor-driven strategy like ‘Faded example’ over a student-centred strategy like ‘Think-Pair-Share (TPS)’. A possible reason may be instructors’ unfamiliarity with a strategy like TPS. However, the reasons for this needs to be explored further. Also experimental validation of our mapping between instructional objectives and instructional strategies need to be established through survey with larger number of instructors and field experiments with students.

REFERENCES


[18] IUPUI Center for Teaching and Learning,”Bloom’s Taxonomy “Revised” Keywords, Model Questions, & Instructional Strategies”, Indiana University Purdue University Indianapolis, December 2002.


[29] OSCAR LO repository, http://oscar.iitb.ac.in/oscarHome.do


---

**TABLE V. TYPES OF INSTRUCTIONAL OBJECTIVES MAPPED TO STRATEGIES**

<table>
<thead>
<tr>
<th>Class of Problem solving activity [20]</th>
<th>Types of instructional objectives</th>
<th>Example</th>
<th>Mapped Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precurso to problem solving activities</td>
<td>Explain a process verbally</td>
<td>Students should be able to explain verbally the process of time scaling for a given signal &amp; scaling factor</td>
<td>i) Observe &amp; Learn (OL)</td>
</tr>
</tbody>
</table>
|                                        | Explain a process using MR: by drawing graphs | Students should be able to explain the process of time scaling for a given signal & scaling factor by drawing the graphical representation with the mathematical expression | i) Predict & Learn (PL)  
  ii) Elicit-Confront-Resolve (ECR) |
| Diagnosis                              | Problem solving by identification to identify the steps in a process | Given a transformation equation , they should be able to identify the types of transformations performed | i) Peer- Instruction (PI) |
| Diagnosis                              | Problem solving by prediction to predict output of a step/ set of steps | Given a transformation equation , they should be able to identify the types of transformations performed | i) Predict & Learn (PL)  
  ii) Elicit-Confront-Resolve (ECR) |
| Routine                                | Problem solving applying MR: to solve problems related to a single process | If students are given an input signal & transformed signal, they should be able to write the transformation equation for any general waveforms. | i)Think-Pair-Share (TPS)  
  ii) Faded Example (FE)  
  iii) Elicit-Confront-Resolve (ECR)  
  iv) Peer- Instruction (PI) |
| Strategy                               | Problem solving applying MR : to solve problems related to multiple processes together | Given a continuous time signal & transformation equation , they should be able to plot output of multiple transformations on the signal | i)Think-Pair-Share (TPS)  
  ii) Faded Example (FE)  
  iii) Elicit-Confront-Resolve (ECR)  
  iv) Peer- Instruction (PI) |
Predict and Learn (PL)

<table>
<thead>
<tr>
<th>Instructor</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>- opens visualization, mentions in what sequence transformation operations will take place.</td>
<td></td>
</tr>
<tr>
<td>- sets variable for time shifting to 2 units and asks students to draw in their notebooks</td>
<td></td>
</tr>
<tr>
<td>- now plays and shows with parallel commentary. Pauses visualizations. Asks students to compare their answers.</td>
<td></td>
</tr>
<tr>
<td>- now sets variable for time scaling to 2 units and asks students to draw in their notebooks</td>
<td></td>
</tr>
<tr>
<td>- now plays &amp; shows with parallel commentary. Asks students to compare their answers.</td>
<td></td>
</tr>
</tbody>
</table>

Think and Pair-Share (TPS)

<table>
<thead>
<tr>
<th>Instructor</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>- gives the example problem to solve (say) Think Phase:</td>
<td></td>
</tr>
<tr>
<td>- asks a specific question about the topic e.g. Think individually and write down what are the transformation operations going on here &amp; in what sequence.</td>
<td></td>
</tr>
<tr>
<td>Pair Phase:</td>
<td></td>
</tr>
<tr>
<td>- asks another question, related to the previous one that is suitable to deepen the students' understanding of the topic e.g. discuss with your neighbor &amp; plot the transformed signal. Each student is paired with another student.</td>
<td></td>
</tr>
<tr>
<td>Share Phase:</td>
<td></td>
</tr>
<tr>
<td>- runs the visualization with the same input values. Shows the result highlighting the important points</td>
<td></td>
</tr>
<tr>
<td>- &quot;think&quot; about what they know or have learned, and write down their own INDIVIDUAL answer to the question.</td>
<td></td>
</tr>
<tr>
<td>- pair up &amp; share their thinking with each other and proceed with the task.</td>
<td></td>
</tr>
<tr>
<td>- compare their solution with what is shown in visualization. Get feedback from teacher</td>
<td></td>
</tr>
</tbody>
</table>

Qs.1) A continuous time signal \( x(t) \) is shown on screen. To get \( y(t) = x(4 - t/2) \), do the following:

- Think (individually): Time = 8 mins.
  a) Identify what transformation operations are happening
  b) In what sequence they are happening
  c) For each transformation, draw & write down mathematical expression for each transformation

Qs.1) A continuous time signal \( x(t) \) is shown on screen. Sketch the signal \( x(4 - t/2) \) and write mathematical expression after each transformation.

- Share: Look at the visualization Time = 12 mins.
  - Compare your answer with what is shown
  - You can ask questions if you have a confusion

FIGURE 1: STRATEGY PROTOCOL DIAGRAMS

FIGURE 2: EXAMPLE FROM LESSON PLAN FOR TPS ACTIVITY WITH VISUALIZATION