Ogata, H. et al. (Eds.) (2015). Proceedings of the 23rd International Conference on Computers in Education. China: Asia-Pacific Society for Computers in Education

How Reciprocative Dynamic Linking Supports Learners' Representational Competence: An Exploratory Study

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Abstract: Multiple External Representations (MERs) have been known to facilitate and strengthen learning processes, and are common in Technology Enhanced Learning (TEL) environments. However, learners face difficulty in translating between and connecting across MERs, leading to poorly developed representational competence. Improving representational competence requires additional support in enabling translation and integration of MERs. Although dynamic linking of MERs is a popular strategy, empirical studies are not unanimous in terms of its learning impact. The mixed nature of results demands further research that can contribute towards the design of meaningful interactions in TEL environments. This paper describes an exploratory study to investigate how additional interactivity in the form of *'Reciprocative Dynamic Linking'* could support learners in developing representational competence in TEL environments. Reciprocative Dynamic Linking is an affordance where a learner can select and manipulate each representation individually in a reciprocative manner. In this study, qualitative data was collected from screen captures, semi-structured interviews and open ended questions as students interacted with simulations incorporating Reciprocative Dynamic Linking. The results showed that Reciprocative Dynamic Linking promoted learners' ability to relate and translate among MERs, thus facilitated the development of representational competence. Reciprocative Dynamic Linking also supported learners' optimal management of cognitive resources and was useful in stimulating their inquiry process while integrating MERs.

Keywords: Multiple external representations, Interactive simulation, Representational competence, Affordance

1. Introduction

Multiple External Representations (MERs) are used extensively in the teaching and learning of science and engineering. Learning with multiple representations facilitates and strengthens the learning process by providing several mutually referring sources of information (Moreno & Durán, 2004). Technology enhanced learning (TEL) environments include a variety of multiple representations in the form of audio, videos, animations, tables and graphs. Learners can integrate concepts from different representation formats and sensory modalities into one meaningful experience (Moreno & Mayer, 2000). Using MERs, learners build abstractions that promotes deeper understanding of the domain (Ainsworth & van Labeke, 2004). The coordination of the different representations in a cohesive manner and explicit identification of their relations support students' understanding at a deeper level.

Representational competence refers to learner's ability to *'reflectively use a variety of multiple external representations or visualizations, singly and together, to think about, and act on the underlying physical entities and processes in a domain'* (Kozma & Russell, 2005). This includes an ability to translate and see the relation between representations. The learning benefits of MERs highly rely on how students translate between and connect across multiple representations (Ainsworth, 1999; Kozma & Russell, 2005; Wu & Shah, 2004).

Research findings related to the learning impact of MERs have consistently reported learners' difficulty in relating and translating in MERs. To overcome this learning difficulty, researchers have recommended support for learners in translation by means of appropriate design features and design guidelines (Tabachneck et al., 1994; Kozma, 2003). Dynamic linking, referred to as dyna-linking, in MERs has been one such popular strategy adopted for enabling translation among representations (Ainsworth, 1999). It is expected that dyna-linking helps learners to establish the relationships between representations (Kaput, 1989; Scaife & Rogers, 1996). However, the results of empirical studies have been mixed. Dyna-linking bears the risk of the user remaining a passive learner due to automatic transitions. Another concern of dynamic linking is that users experience more cognitive load due to the requirement of focusing on the multiple content of the learning environment (van der Meij & De Jong, 2006). In a comparative study, simply linking representations dynamically did not lead to improved learning compared to non-linking (van der Meij & de Jong, 2006). Thus, due to the mixed nature of results, there is a demand for further research to ensure learning benefits from dyna-linked MERs.

Our research study proposes the design for an affordance that enhances the learning benefits by overcoming some limitations of traditional dynamically linked interactive simulations, especially while translating among MERs. Considering the need to explore individual representation independently and to strengthen the to-and-fro linkage between representations, we propose an additional interaction in dynamically linked MERs. We refer to this as *'Reciprocative Dynamic Linking'*. It is an interactive affordance in simulations to select and manipulate each of the MERs individually in a reciprocative manner. With Reciprocative Dynamic Linking, the learner not just observes dynamic changes of MERs, but is also able to select, manipulate all representations one by one. The goal of this additional affordance is to strengthen learners' cross-representation cognitive linkage and to increase engagement of learner in the learning process, in order to promote representational competence.

This paper describes an exploratory research study to explore the learning potential of Reciprocative Dynamic Linking. It investigates how Reciprocative Dynamic Linking could support learners in developing representational competence through more meaningful interactivity in TEL environments. The context of this study was a course in 'Signals and Systems', a foundational, 2nd year course in a 4-year undergraduate Electrical Engineering program. Nine students participated in the study. The study involved analysis of rich qualitative data collected from screen captures, semi-structured interviews and an assessment test of representational knowledge. The findings of the study revealed the usefulness of Reciprocative Dynamic Linking in promoting relation and translation ability among MERs, further supporting representational competence. Our approach of Reciprocative Dynamic Linking contributes to the design of more meaningful interactions in TEL environments. This study also contributes to the body of educational technology research on how interface and interaction design relates to the cognitive processes of learners while interacting with TEL environments, and highlights the need for further research in this area.

2. Related Work

The main strength of MERs in Technology Enhanced Learning (TEL) environments lies in the different types of (dynamic) representations that can be included, and its ability to combine different representations in one interface. By using MERs, learners benefit from the properties of each representation. Additionally, learning with more representations facilitates and strengthens the learning process by providing several mutually referring sources of information (Kozma & Russell, 1997) which ultimately leads to a deeper understanding. By translating between representations, learners build abstractions that promotes deeper understanding of the domain (Ainsworth & van Labeke, 2004). MERs are commonly used for three main purposes i) for providing complementary information and processes, ii) for constraining interpretations, and iii) for constructing a deeper domain understanding (Ainsworth, 1999). The major learning demands from MERs on learners are i) to understand the semantics of each representation, ii) to understand which parts of the domain are represented, iii) to relate the representations to each other, and iv) to translate between the representations.

Research in cognitive and learning sciences has acknowledged that deeper learning with multiple representations depends on certain conditions, including how students translate between and connect across MERs (Ainsworth 1999, 2006; Kozma & Russell, 2005). The representational competence of learner subsumes learner's ability to comprehend how two representations are related and how they can be used together. Thus, representational competence influences learning from MERs. When learning with separate representations, learners are required to relate separate sources of information, which may generate a heavy cognitive demand, leaving less resources for actual learning, especially in dynamically changing MERs. Thus, learning from MERs places demands on working memory and creates challenges for learners (van Someren et al., 1998), especially those with low prior knowledge (Kozma & Russell, 1997; Yerushalmy, 1991). These challenges can cause students to interact with simulations randomly, instead of systematically (de Jong & van Joolingen, 1998). Such learning limitations affect learners' understanding and results into a discourse that is constrained by the surface features of individual representations. Thus, the unique cognitive demand while learning MERs is to understand how to translate between representations in dynamic learning environments.

Researchers recommended support for learners in this translation through appropriate design features and design guidelines (Tabachneck et al., 1994; Kozma, 2003). A variety of approaches in the form of guidelines such as implicit cues, integrated representations, static linking, dynamic linking and explicit instruction have been suggested to address students' such difficulties (Ainsworth, 2006; van der Meij & De Jong, 2004). While (Kozma, 2003) suggested design principles to increase connections between representations for supporting student domain understanding, DeFT (Design, Functions, Tasks) principles were implemented in the DEMIST learning environment (Labeke & Ainsworth, 2001). These principles recommended dynamical linking in MERs, when multiple representations are used to support complementary roles and information, and to constrain interpretation.

Dynamic linking or dyna-linking of MERs has been one such popular strategy for enabling translation between representations (Ainsworth, 1999). With dynamically linked representations, actions performed on one representation are automatically shown in all other representations. It is expected that dyna-linking helps learners to establish the relationships between the representations (Kaput, 1989; Scaife & Rogers, 1996). An environment using multiple dynamically linked representations can facilitate novices' learning (Kozma & Russell, 1997). While the simultaneously changing representations in dynamic linking has been conceived as a useful feature, it has also received criticism. Ainsworth (1999) cautioned that dynamic linking might leave a learner too passive in the learning process. Dynamic linking may discourage reflection on the nature of the translations, leading to a failure of learner in constructing the required understanding. Another problem with dynamic linking has been that with multiple dynamically changing representations learners need to attend to changes that occur simultaneously in different regions of various representations, leading to cognitive overload (Lowe, 2003). Empirical studies such as one with the SIMQUEST environment (van der Meij & De Jong, 2006) found that simply linking representations dynamically could not improve learning compared to non-linking. It showed some improvement in the learning only with spatially integrated linked representations. Such an integration of representations is not always possible, due to the nature of the learning materials or specific learning goals.

Thus, the nature of results of dyna-linking in MERs is mixed, and hence, there is a need for further research to form precise guidelines for appropriate designing of interactivity in dynamically linked TEL environments. Our research study explores the additional interactivity needed for ensuring learning benefits from dynamically linked MERs in TEL environments.

3. Design of Reciprocative Dynamic Linking in Interactive Simulation

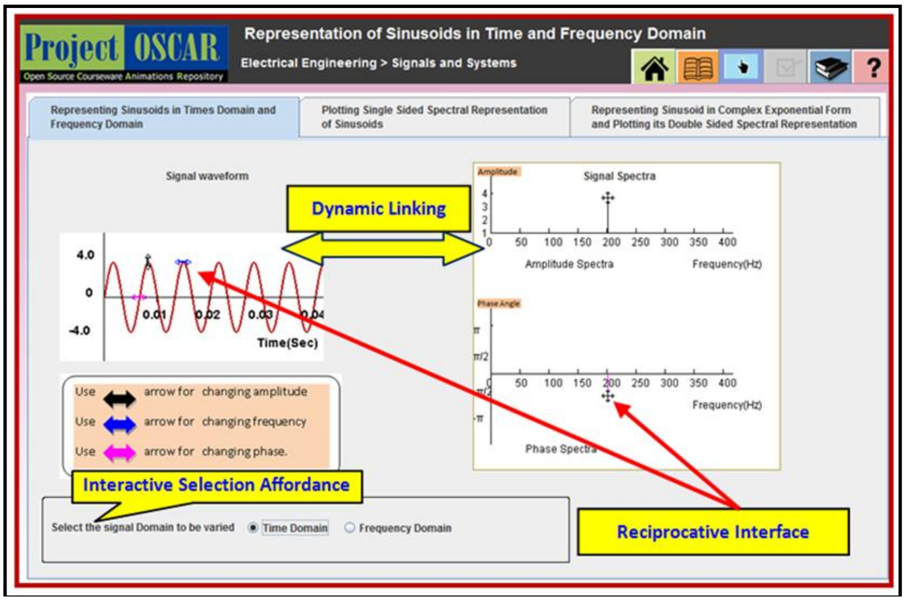
3.1 Features of Reciprocative Dynamic Linking

Reciprocative Dynamic Linking is an affordance offered in interactive simulations for learners to select and manipulate each of the MERs individually in a reciprocative manner. Its key features are:

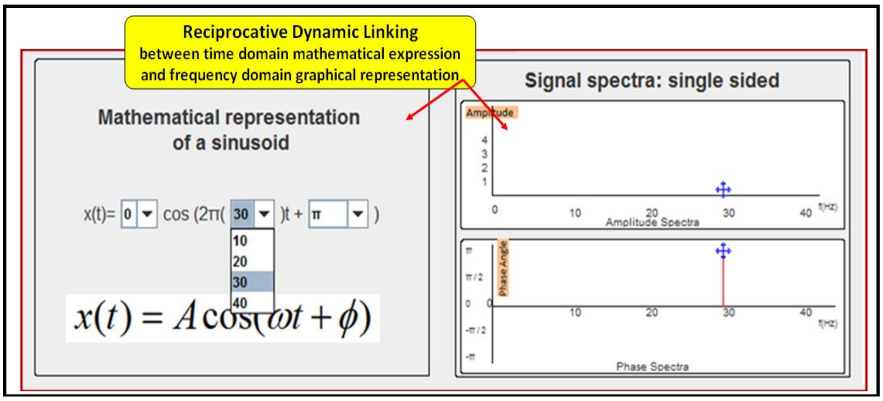
- *Dynamic Linking*: A change in one MER causes change in other linked MERs.
- *Reciprocative Interface*: The MERs are not just dynamically linked to each other, but <u>each</u> of them is designed with an interactive manipulating interface.
- *Interactive Selection Affordance*: User has to select the representation to be manipulated.

Figure 1 shows these features in the screen shot of a simulation in the topic of signal transformation. These features allow the learner to select, manipulate and observe all representations, one by one. Figure 2 shows how user selects one of the representations for manipulation using Interactive Selection Affordance. The learning material developed also had linking between different forms of mathematical expression and corresponding time/frequency domain graphical representations.

Most conventional Dynamically Linked Multiple Representations permit and offer only one representation for manipulation, and the corresponding change in other representations is displayed. In the proposed Reciprocative Dynamic Linking, the interaction and affordance are designed in such a manner that user is able to manipulate both the representations (and more than two if educational content demands). The learner is not just able to see automatic variation occurring in the second representation when the first representation is manipulated, but is also able to see the variation occurring in the first representation when the second is manipulated. More importantly, the learner is able to make an intentional choice about which representation is to be selected for manipulation.



<u>Figure 1.</u> Key features of Reciprocative Dynamic Linking



<u>Figure 2</u>. Screen shot showing Reciprocative Dynamic Linking between different representations

3.2 Theoretical basis for Reciprocative Dynamic Linking

The goal of the additional interactivity operationalized through Reciprocative Dynamic Linking is to promote representational competence by strengthening learners' cross-representation cognitive linkage. The three features described in Section 3.1 derive their base from relevant educational theories.

Dynamic linking: Dynamic linking in MERs in TEL environments helps learners in accomplishing the important task of translating between representations. Two important learning requirements govern the inclusion of this feature: i) The need to learn the content from complementary representations, and ii) the need to reduce cognitive load of making mental connections between representations (Wu & Puntambekar, 2012). The cognitive processes involved in learning from a simulation with MERs are described by the Cognitive Theory of Multimedia Learning (Mayer, 2001) and the dual channel assumption of Dual Coding Theory (Paivio, 1986). These theories support the use of dynamic linking of MERs to reduce the cognitive load upon the learner. As the translations between MERs are taken care by the technology in the learning environment, the learner is freed to concentrate on interpreting the representations and their consequences.

Reciprocative interface: This is based on contemporary theories of cognition such as distributed and embodied cognition (Glenberg et al., 2013). These theories postulate that external representations play more roles than merely decreasing cognitive load and can support operations that are difficult to do by imagination alone (Kirsh, 2010). Actions like manipulations could be a way of promoting integration of MERs (Chandrasekharan, 2009). The reciprocal interface is two-way manipulative, enabling learners to carry out meaningful switchover among MERs resulting in comprehension of the relations between them. This strengthens translation among MERs and promotes deeper learning.

Interactive selection affordance: Interactivity is a process of learner engagement with the content of a simulation. Lower interactivity implies a behaviourist character of a learner, while higher interactivity leads to constructivist learning (Schulmeister, 2001). One limitation of dyna-linking is the passive role of learner while learning from automatic transitions in simulations. The feature of interactive selection affordance brings in more meaningful interactions in learning environment promoting active learning.

Out of the three features mentioned above, only *dyna-linking* is incorporated in the control group learning material. In addition to it, the experimental group learning material has *reciprocative interface* and *interactive selection of affordance* as built-in integral features of *Reciprocative Dynamic Linking*.

3.3 Reciprocative Dynamic Linking in scientific visualizations in Signals and Systems course

The context of this research study and the learning material are from a course on Signals and Systems, which is a foundation course offered in the second year of all Electrical Engineering programs. The topic of the study, 'Representation of signals in time and frequency domain' demands learning from multiple representations. Deeper understanding of time domain and frequency domain representations, as well as mathematical-graphical translations are mandatory for understanding of this topic. The translation of a signal to its multiple representations has been reported as a key problem in the conceptual learning of this course (Fayyaz, 2014), hence it is an important topic to address. The learning material developed offered MERs of three kinds: i) linking time domain graph and frequency domain graph, ii) linking frequency domain graph and time domain mathematical expression, and iii) linking two different dynamically linked mathematical representations.

Fig. 2 shows two representations of a signal; mathematical time domain expression and graphical frequency domain representation. The learner can decide which representation should be selected first for manipulation. The reciprocative nature of dynamic linking allow learners to vary time domain mathematical expression and correspondingly observe dynamic changes happening in the frequency domain graphical representation of the signal, or vice-versa. Similarly, in the other tabs of the learning material, learners could implement reciprocative manipulation between two different graphical representations or two different mathematical expressions.

4. Research Method

The aim of this research study is to obtain insight into how students use the affordance of Reciprocative Dynamic Linking while learning from dynamically linked MERs. This insight is necessary to formulate a precise research problem to develop further hypotheses and subsequently test the learning benefits of the affordance. This exploratory study answers the following research questions:

RQ1. How do students use Reciprocative Dynamic Linking?

RQ2. How does Reciprocative Dynamic Linking influence learning from multiple representations?

4.1 Research design and participants

Considering the purpose of this research study, an 'exploratory sequential mixed methods' design was found to be appropriate. This research design involves initially gathering qualitative data to explore a phenomenon, and then collecting quantitative data to support the findings from qualitative data (Creswell, 2002). The study reported here is the first phase of collecting qualitative data to explore learning impact of Reciprocative Dynamic Linking.

Participants were students from second year Electrical Engineering program studying a course on 'Signals and Systems'. They were selected by purposeful sampling and were in the middle third of their cohort in terms of achievement level (grades). The reason for selecting medium level equivalent achievers was to avoid the potential risk of the research being biased towards either ends. Participants belonged to two engineering colleges affiliated to University of Mumbai. A total of nine students (N=9; female=3, male=6) participated in the study. The average age of students was 20 years. Participants were familiar with the use of ICT tools in learning through other courses and labs in their curriculum.

4.2 Data collection and instruments

Three data sources were used: i) Recording of screen capture during learner's interaction with interactive simulation, ii) individual semi-structured interview (audio-taped and transcribed) and iii) representational knowledge assessment instrument. The screen-capture analysis was used to understand how students use Reciprocative Dynamic Linking affordance to answer the first research question. The second research question was answered from the analysis of interview data and the representational knowledge assessment instrument. The qualitative data from screen-captures and semi-structured interviews were analysed using preliminary exploratory analysis to obtain a general sense of data as per six-step approach in analyzing and interpreting qualitative data (Creswell, 2002, pp. 237).

The representational knowledge assessment instrument consisted of eleven questions, with ten open ended questions and one question in multiple choice format. A sample question from the assessment instrument was: *"Observe signal waveform x(t). The signal x(t) is passed through a phase shifter that introduces phase shift of (-π/2). Predict the change in the spectra of signal x(t) after it passes through the phase shifter and plot its spectra"*. All questions required students to select, relate and construct multiple representations in the domain. The questions from the instrument were related to: i) student's understanding of the individual representation of signals i.e. time domain and frequency domain representation ii) students' ability to translate from one domain to the other i.e. from time domain to frequency domain and vice-versa and iii) students' comprehension of both the representations in an integrated manner. In the context of Signals and Systems, leaner's ability to comprehend signal representation in both the domains (time and frequency), to translate smoothly between domains and to apply the integrated representation of signal in newer contexts are indications of deeper learning. Three out of the ten open-ended questions were from an extended topic; Fourier Transform properties, which was not direct part of the simulation. These questions were from higher cognitive levels and helped in assessing students' ability in integrating MERs and applying it to a new topic.

4.3 Procedure

The overall procedure for the research study consisted of the following steps:

- Initial briefing: Initially, students were briefed about the study and its objectives. They were assured that participation in the study would have no bearing on their academic performance. The researcher was different from the course instructor and had no role in assigning course grades.
- Interaction with learning material: After initial briefing, students interacted with the learning material which consisted of an interactive simulation incorporating Reciprocative Dynamic Linking. The topic of the learning material was 'Representation of signals in time and frequency domain’. Screen captures of students’ interaction were recorded using CamStudio™ open source software. The screen captures were recorded for the entire time duration while students interacted with the learning material.
- Representational knowledge assessment instrument: After interacting with the simulation, students solved open ended questions on representational domain knowledge. They were instructed to show the working on the same answer sheet. Students took 30-35 minutes to complete the assessment test.
- Individual semi-structured interview: After the assessment test, semi-structured interviews were conducted using interview protocol. The objective of the interview was to know students’ perceptions about major issues like, 'what kind of learning support did students get through Reciprocative Dynamic Linking and 'what aspect of learning could get influenced by Reciprocative Dynamic Linking?’ The interviews were recorded for further transcription and analysis.

5. Results and Analysis

5.1 Results from screen capture analysis

The screen captures collected from nine students were analyzed to understand trajectory taken by students while exploring the content, and how the affordance of Reciprocative Dynamic Linking was used by students. The time for exploring the material ranged from 23 to 30 minutes (average of 27:10 minutes). While analyzing and interpreting the qualitative data using bottom-up approach, initially preliminary exploratory analysis was done to obtain a general sense of the data, and to get an idea about the organization of the data (Creswell, 2002). Three categories emerged from the preliminary exploratory analysis of learners' navigation actions: i) exploring menu icons, ii) linear movement through the content, and iii) selecting MERs for manipulation. The third category focussed on learners' navigational actions while using the Reciprocative interface and Interactive Selection Affordance.

Seven from nine students exhibited a common pattern. While exploring the MERs using Reciprocative Dynamic Linking, students manipulated the first MER, then the second. After this, they again reverted to manipulate the first MER. This pattern was observed for all the three different MERs in the simulation. Learners' manipulation of the first representation followed by the second is an expected navigation pattern, wherein the main goal is to explore the content (Exploratory search). However, coming back to the first representation after having explored both the representations indicates learner's intention of confirming the mental model created during the learning process (Confirmatory search) (Fig. 3). This observation is significant because it resembles the 'prediction and hypothesis testing phase' of inquiry cycle. Its elaboration follows in the Discussion section.

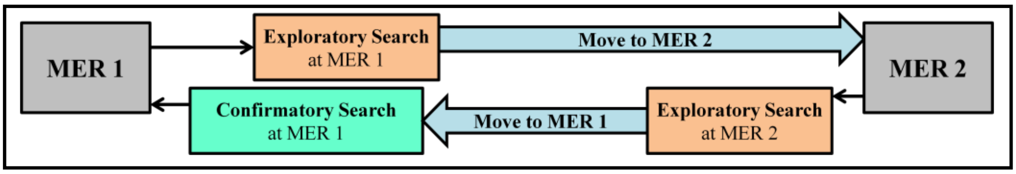


Figure 3. Screen capture analysis of navigation through learning material

5.2 Results from the representational knowledge assessment instrument

Students' answers were assessed to judge their ability in grasping mathematical and graphical representations, extracting relevant information from the given representation, constructing new representations, and integrating multiple representations. Not only the final answers, but also the intermediate steps taken by students were important for obtaining insight into the thought process and mental models students built while relating representations. The following are the results:

i. Students were able to successfully integrate multiple representations: Students showed translation process at a more granular level. They showed transition from the given representation to the translated representation with the help of intermediate representations. Although, only the final translated representation was expected, the intermediate representations showed clear explanatory links in the translation. Learners were not just able to grasp isolated representations, but also exhibited the interim steps of extracting relevant information from the given representation, and constructing new representations and finally integrating MERs. This clearly showcased learners' ability to develop strong cross-representational linkage in multiple representations integration, leading to the development of representational competence. For example, when the question demanded translation from time domain graphical representation to frequency domain graphical representation, students supported this translation additionally with the help of an intermediate state, i.e. a time domain *mathematical* expression as shown in Fig. 4. Comprehending translation in MERs at more granular level indicated deeper learning that could further strengthen the mental model of the phenomenon being learnt.

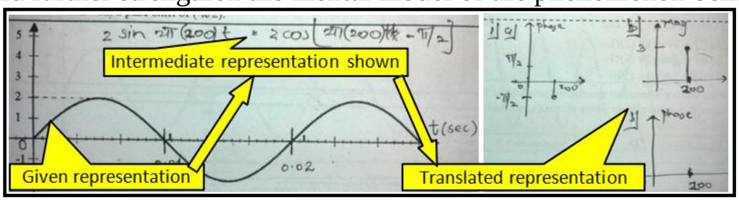


Figure 4. Translation process shown in the assessment test answers

ii. Students were able to answer higher level cognitive questions. Students exhibited their ability to answer questions with higher difficulty level and from less familiar domain. The assessment questions were spanned across three cognitive levels: understand, apply and analyze (Krathwohl, 2002). Students were successful in answering analyze level questions. The topic presented in the simulation involved understanding of amplitude, frequency and phase parameters of the signal in time and frequency domain. Typically, students are comfortable with amplitude and frequency aspect, but face difficulty in the phase aspect (Fayyaz, 2014). In this study, students were not only able to draw amplitude spectra correctly, but also drew phase spectra, showing their understanding from the less familiar domain.

iii. Students were able to answer questions from extended topic. Students could successfully answer questions even from the extended topics. The instrument had questions from extended topic, related to effect of signal processing on signal representation and its Fourier Transform. The ability to answer these questions indicated students ability not just to understand the actual content of the learning material (signal representation), but also to acquire whole, integrated knowledge promoting further knowledge building process (of analyzing signal processing in time/ frequency domain representation).

5.3 Results from semi-structured interviews

Semi-structured interviews were conducted to get students' perception about the Reciprocative Dynamic Linking affordance. Each interview lasted for 15-17 minutes. Students were asked how they used the learning material to learn the content, and which features they found useful in the learning process. Students were also shown their assessment test answer sheets and reasoning behind their answers was investigated. The recorded interviews were transcribed and analyzed further using Content Analysis method with a 'sentence' as the 'coding unit' (Cohen et al., 2007). The coding was done keeping in mind the objectives of the questions asked. Accordingly, three categories of the codes emerged from the analysis -i) Feature, ii) Reason, and iii) Learning impact. The details of the coding categories and some corresponding verbatim responses are given below:

i. Features are those aspects of the simulation that learners mentioned as being useful.
"I can change both the graphs", "...both are interrelated, so both should be allowed to vary."

ii. Reasons are learners' perception about why a particular feature is important.
"It [reciprocative interface] will make me comfortable in each domain.", "I can also check how this [second graph] varies."

iii. Learning impact is learners' perception about the impact of the feature/s on their domain knowledge.
"... more variation, more learning.", "... now, I will be more comfortable in lecture... I know how they are related.", "Oh, now I know how those vertical lines [spectral line] change... I can understand Fourier series and also how to draw Fourier spectra" (extended topic), "I am now more confident".

All students appreciated reciprocative affordances. When asked whether manipulating only one of the representations was sufficient, all students mentioned it to be insufficient for learning and advocated the need for having two-way reciprocative manipulation affordance. The perceived benefits of the reciprocative affordances as reported by students were: more exploration opportunities, faster grasping, clarity of concepts, increased confidence due to both way manipulation and translation, developing understanding by comparison, ease in learning of advanced / extension of the topic, and the ability to cross-check relations by manipulating both representations.

6. Discussion

The goal of this exploratory research study was to get insight into how Reciprocative Dynamic Linking can support learners' representational competence. The interpretation of collected data collectively helps in answering the research questions of this study.

The screen capture and interview data helped in understanding how students use the affordance of Reciprocative Dynamic Linking (RQ1). Students' navigation through the simulation consisted of two types of search manipulations: exploratory and confirmatory. During the initial exploratory manipulation, students interacted with the first representation in order to comprehend the topic. Due to dynamic linking, they could observe the changes happening in the second representation. The reciprocative nature allowed students to manipulate the second representation as well, giving them the opportunity to relate both representations. Generally, it is a default cognitive action to imagine or visualize the change that the second representation could cause in the first, while observing the change in the second representation due to the first. In our case, learners would have used the reciprocative nature of interactivity to offload the burden on working memory while doing so. Thus, the reciprocative affordance could have led to reduction in the cognitive load demand. The opportunity to manipulate the second representation supported an operation that would have been difficult for the learner to do by imagination alone. Thus, the reciprocative interactivity helped learners in comprehending the representations in isolation as well as the relation and translation between representations. This helped students in the development of representational competence. The granular translations shown in the assessment test is an evidence of the development of representational competence in students.

A more interesting phenomenon observed in screen capture data was that learners returned again to the first representation after manipulating the second, that is, the confirmatory manipulation. We conjecture that while manipulating both the representations, the leaner generated a hypothesis as part of mental inquiry process and returned to the first representation again to test or confirm the hypothesis. We have support for this conjecture via interview data, wherein students reported that they used the feature that allowed variation in both the graphs for checking how representations were related. This data related to students' confirmatory manipulation also helps answer our second research question of how Reciprocative Dynamic Linking influences learning from MERs. This affordance was used by students to get support in the learning process that managed their cognitive resources optimally, and also supported their inquiry process thus leading to deeper learning. However, we found it difficult to get direct confirmation for students' formation & testing of mental model from students themselves. Students, not trained to reflect on their own learning process typically do not realize these subtle aspects about their own learning and mostly tend to accept reasons for learning as provided (de la Harpe, et al., 1998).

The need for scaffolding to support learning from MERs has been well emphasized by researchers (Wu & Puntambekar, 2012). We expect the affordance of reciprocative dynamic linking to improve learning from MERs. The findings of this study are useful in formalizing hypotheses to test the contribution of Reciprocative Dynamic Linking: we hypothesize that students who learn with Reciprocative Dynamic Linking are able to develop the ability to reason behind relations, thus leading to the development of representational competence; as compared to students learning without Reciprocative Dynamic Linking. This also contributes to answering our second research question focusing on the learning influence of Reciprocative Dynamic Linking.

Although this has been an exploratory study, the findings from the data collected from different methods are encouraging. The students' performance while translating between and integrating representations is evident from the assessment test and the feedback given during interviews. A confirmatory research study in the future can confirm the potential of the Reciprocative Dynamic Linking in support of representational competence, especially, while using MERs for supporting complementary information and developing deeper understanding of the domain.

The feature of *Interactive selection affordance,* i.e. selection of the representation by the learner, can address the problem of learner remaining passive while learning from dynamically linked MERs. The actions of selecting representation, manipulating content and the to-and-fro navigation among representations can increase learners' ownership of the learning process and can improve engagement. This ultimately will lead to more meaningful interactivity in TEL interactive environments. The design features of Reciprocative Dynamic Linking derive their base from the relevant educational theories. The positive results of this study, thus, not only support the appropriateness of the relevant theoretical basis used for designing these features, but also recommend researchers to adopt and link contemporary theories of cognition with multimedia principles while designing TEL environment features.

Although small sample size is a limitation of this study, we expect to confirm our results with larger sample. Additionally, we also expect to get more insight and richer inputs about students' learning process. Apart from the reported results related to learning process of students, the study also contributed to the instrument development process. Students' ability in answering questions from unfamiliar, extended topics indicated the level of sensitivity that the instrument should possess. We recommend that while assessing cognitive skills such as representational competence, instrument should cater to questions of at least 'analyze' cognitive level from extended topics.

7. Conclusion and Future Work

This exploratory research study has proved to be valuable in the process of formalizing hypothesis for the future confirmatory research study to confirm learning benefits of Reciprocative Dynamic Linking in support of representational competence. The results of this study have also indicated how different metrics could be considered for measuring learning from MERs in the future. From a subject-domain perspective, Reciprocative Dynamic Linking will be of great help while developing interactive learning material for the courses those demand learners' understanding of MERs and translation among such representations. Our design approach of Reciprocative Dynamic Linking contributes to the TEL environment creation in designing more meaningful interactions while developing representational competence. This paper also contributes by highlighting the need for focused research on how interface and interaction design should relate to the cognitive processing of learners.

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