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# An Investigative Study on the Effects of Pedagogical Agents on Intrinsic, Extraneous and Germane Cognitive Load: Experimental Findings With Dyscalculia and Non-Dyscalculia Learners

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**ABSTRACT** Several studies have warranted the need to explore the relationship between pedagogical agents in the learning environment and the cognitive load on the learners, specifically, to study the influence on learner populations with different learning and motivation needs. The present work investigates the effects of the presence of a pedagogical agent in the learning environment on intrinsic, extraneous, and germane cognitive load for the dyscalculia and non- learner population. The proposed system intelligently investigates the learner, recommends an exclusive learning dyscalculia path and after tutoring assesses learning gain, and retention. Learner experience and effects of the pedagogical agent on types of cognitive loads are discussed on basis of post tutoring analysis. Samples of 82 learners have been studied, experimental findings based on research questions have been reported and conclusions discussed. Our assumption that 'a well-articulated and well-designed instructional design exerts a minimal extraneous cognitive load on learners and facilitates learning gain and retention' is consistent with the obtained results. The result concludes that pedagogical agent does not add to intrinsic and extraneous cognitive load. An improved Germane Cognitive load and a good amount of knowledge retention are noticed post learning.

**INDEX TERMS** Dyscalculia, dysgraphia, dyslexia, intelligent tutoring system, leaning disability, pedagogy agent.

## I. INTRODUCTION

Intelligent tutoring Systems are software systems for the Individualised Education Program with keeping an account of the learning needs and preferences of the learners. ITS applies the learning principles of artificial intelligence and educational psychology in providing domain-specific knowledge to the learner. ITS developed so far has covered a diverse range of specializations including medicine, engineering, law, science, and technology. Although human tutor's one to one teaching has its advantages in terms of face-to-face interaction, there are some shortcomings when interacting with large-group of learners. In such situations, the instruction delivery through ITS have higher achievement rates

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than human-teacher, textbooks, and non-ITS based instruction methods. ITS provide cognitive learning by providing content, feedback, and performing the assessment. ITS is also capable of keeping track of learner's responses and emotional state during learning path [1].

The general architecture of ITS has four components:

1) Student/Learner Model – This model maintains learner's data during assessment /interaction with ITS during the learning process. It keeps the track of the learner's knowledge level at various stages of gaining knowledge.
2) Domain/Expert Model – This model represents the knowledge specifically designed for subject-specific learning. It contains the concepts, rules, and problem-solving strategies of the domain to be learned.
3) Pedagogical/Tutoring Model – This model represents the learning strategies, learning techniques required for ease of learning. It uses the teacher's skills for content delivery.
4) User Interface Model/Communication Model – This model works as an interface between learner and ITS, receives interaction, and presents instruction. It provides an environment for the learning process [2].

### A. PEDAGOGICAL AGENT

Pedagogical agents are autonomous agents that interact with the learners to facilitate learning. Pedagogical agents often have an animated persona that responds to the action of the learner. It facilitates interactive learning environments by providing customized feedback to the learners. The lifelike persona of the pedagogical agent motivates learners to spend more time in the learning environment and a significant improvement is observed in the quality of learning. Pedagogical agents can engage learners in a continuous conversation, similar to the conversation between physical educator and learner. They give a believable and lifelike persona in terms of gaze, emotional expression, and body language. In recent years, pedagogical agents have become increasingly popular and are based on the real video, geometric 3D models, and animated drawings [3]. Pedagogical agents can be categorized into three categories- text-based, audio-based, and visual, considering the form of presentation of the agent [4].

- Text-based pedagogical agents interact with the learner through text messages and provide feedback through sentences or words.
- Audio-based pedagogical agents use speech to interact with the learner and provide feedback and guidance to the learner in audio form.
- Visual pedagogical agents are in the form of-
  - Lifelike agent (an animated or human image).
  - Gestures (using drawings or images of human gestures).

### B. LEARNING DISABILITY

As per *The Children with Specific Learning Disabilities Bill 2016* [5], Specific Learning Disability (SpLD) is a psychological process disorder in either one or more of following learning abilities: an understanding or using language or the imperfect ability to listen, think, speak, read, write, spell or do mathematical calculations. SpLD includes perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, dyspraxia, dyscalculia, dysgraphia, and development aphasia. The commonly found SpLD are Dyslexia, Dysgraphia, and Dyscalculia. These are commonly known as difficulty in reading, difficulty in writing, and difficulty in mathematics respectively but they affect a single or combination of associated learning skills. [5] Dyslexia affects speech, vocabulary, pronunciation, phonological awareness, spelling, and reading. Dysgraphia affects the fine motor skills, handwriting skills, psychomotor coordination, comprehension, and visuospatial response and Dyscalculia affects Memory (Recall –Remember), Counting (Forward, Backward, Gap Counting), Calculations (Transferring, symbols), Numbers (Place value, Chronology), Spatial/Temporal (time-telling, Left Right Confusion (LRC)) and Measures (Money, time, Maths concept, map)). Individualised Remedial Education Plan (IEP) helps learners to overcome these difficulties largely [6]. The focus of the present study is Dyscalculia [5].

### C. SPECIAL ACADEMIC NEEDS OF DYSCALCULIA LEARNERS

The focus of the present study is Dyscalculia. The learning requirement of Dyscalculia learners are quite different from the Non-Dyscalculia learners. This difference is because learners with dyscalculia have difficulty understanding number-related concepts or applying symbols, formulae and logic in math problems [5]. The Dyscalculia learner have following learning requirements in comparison to Non-dyscalculia learners:

- Remembering/ Identifying mathematical concepts:
  - Recognising numbers: sometimes will reverse or transpose numbers (36: 39).
  - Recognising math symbols: +, -, X, /, >, < etc.
  - Recognising 2-Dimension and 3-Dimensional Shapes and Patterns.
- Understanding mathematical concepts:
  - Understanding numbers: counting forward, counting backward and number series.
  - Understanding math symbols: +, -, X, /, >, < etc.
  - Understanding 2Dimension and 3Dimensional Shapes and Patterns.
  - Difficulty with elementary tasks (adding, subtracting, multiplying, dividing, Fraction, Shapes).
  - Difficulty with mental math. Calculating without drawing lines or using fingers.
- Applying mathematical concepts:
  - Difficulty telling time using clock.
  - Difficulty with directions and maps.
  - Difficulty following multiple instructions.
  - Difficulty grasping and remembering math concepts.

- Difficulty in real life implications of maths concepts.
- Speed and accuracy problem.
- Difficulty with estimation and approximation.
- Difficulty in word problem.
- Trouble with identifying critical information required in problem solving.

### D. COGNITIVE LOAD

Human cognition is dependent on gathering and recalling information. Human cognition has three components: Working Memory (WM), Long-Term Memory (LTM), and Schema (structured interconnected mental information). Unlike LTM and Schema, WM can process new information but has limits for the retention of information available.

[7] defined cognitive load as the used amount of working memory resource and suggested Instruction Design can manipulate the cognitive load. Cognitive Load Theory is based on the limited capacity of the working memory of a person. It states that if a learning experience surpasses this limit, there is a chance of learning disturbance. High cognitive load can reduce learning [8].

Following are the three types of Cognitive Load:

1) Intrinsic Cognitive Load – It is defined as the amount of mental effort with any Specific topic and is affected by the level of complication of learning material. It is constant for a given activity.
2) Extraneous Cognitive Load - It is defined as mental effort due to poorly designed learning material and the information processing technique.
3) Germane Cognitive Load – It is defined as the amount of work done to permanent store a piece of information known as knowledge schema and then retain it or integrate it with new information. [7]

This work is aligned to an Intelligent Systems application, as, an Intelligent Tutoring System is proposed, that over a pre-test, identifies the characteristics of the learner, such as background knowledge of the learner, and accordingly delivers need based content to the learner, through a learning sequence/pathway, exclusively designed for the learner. The system offers a learning environment, within which, the learner is to make choice of a pedagogical agent and a learning companion, that will steer the learning process for the leaner. Learning is monitored and assessed, through interaction quizzes. The analysis of test results reveals learning gain which is indicative of the success of the learning process. Performance in tests conducted after a pre-decided time period, is used to assess the retention of the knowledge. The performance parameters of dyscalculia and non-dyscalculia learners have been used to study cognitive load and its types. The effects of pedagogical agents in the learning environment, as support to the learning process, have been studied and findings reported.

## II. LITERATURE REVIEW

### A. ITS WITH PEDAGOGICAL AGENT

During the last two decades, various researches have been conducted into pedagogical agents, their effectiveness, uses, and limitations. One of the earliest agent-based learning environments was introduced in 1994 called MEMOLAB that distributed roles among multiple agents. Each agent took a different learning approach for teaching purposes [9].

In 1996, IntelliMedia presented an animated pedagogical agent (looked like an insect), named Herman the bug. This was the first agent that entered the virtual learning environment. This pedagogical agent explained botanical anatomy and physiology to the students in various hypothetical environments [10].

[11], the authors discussed a 3D pedagogical agent named STEVE that was developed at CARTE (Center for Advanced Research in Technology of Education). The aim of developing this agent was to support the apprenticeship model of learning in networked virtual environments. This agent demonstrates skills to the learners, observes learners during performing tasks, responds to the queries of the learner, and provides help if learners feel any difficulty.

[12], the authors discussed an animated agent SMART-EGG that was developed at the University of Canterbury using the ADELE animation toolkit. The agent presented feedback messages to the learners in an enjoyable manner to motivate them and increase the effectiveness of the learning environment.

[13], the authors discussed a pedagogical agent named ALI (Automated Lab Instructor) that was developed at the University of Southern California to provide flexible feedback to the learners in virtual labs. This agent explained the relationships in the simulation model to the learners and later tested the understanding of the learner.

[13], the authors discussed a pedagogical agent named Alife-personal tutor that responds to the learner in natural language. This agent was developed for a question and answer learning environment on internet browsers.

[9], the authors used a multimedia environment for the delivery of a lesson in a computer literacy course. In this study, the authors found that using human voice in pedagogical agents reduces the cognitive load and also increases the interest of the learner

### B. INSTRUCTIONAL DESIGN MODELS

An Instructional Design Model is a structured and sequenced learning path for achieving learning objectives. These guidelines of Instructional Model are based on learner-centric pedagogical strategies for maximum learning gain and better learner experience. Instructional Design Models are based on the teaching principles and techniques. It provides learning opportunities to learners using Multi-sensory approach for effective teaching. For effective teaching, a sequence and standard structure is followed. Positive feedback is provided to ensure learner motivation. Following are some existing

Instructional Design models, which are widely used in education and e-learning domain:

1. Blooms Taxonomy of Educational Objectives (1956) – B.S Bloom proposed a cognitive learning map with six categories. These categories are organized from simple to complex stages of learning, as under

Knowledge ⇒ Comprehension ⇒ Application ⇒ Analysis ⇒ Synthesis ⇒ Evaluation

For any concept, Knowledge about specifics is the first level of interaction with concept, leading to Comprehension. This level includes ability to classify, translate or interpret the knowledge. Next level, Application is the ability to apply that knowledge when required. Next level of Analysis is the ability to formulate relationships using concepts. Next level of Synthesis is the production of new hypotheses that leads to the final level of Evaluation, which is the ability to evaluate and judge the hypothesis and concepts [14].

2. Revised Bloom Taxonomy (2002) - D. R. Krathwohl revised the Blooms Taxonomy into 6 new categories and more detailed 19 sub categories

Remember ⇒ Understand ⇒ Apply ⇒ Analyze ⇒ Evaluate ⇒ Create

Remember is the ability to recognise and recall a learned concept. Understand is the ability to interpret, classify, summarise, explain and compare that concept. Apply is the ability to Execute and Implement the learned knowledge. Analyze is the ability to Differentiate and Organise the related concept. Evaluate is the critical ability to check the fact and finally, create is the ability to generate new results from learned concepts. Karthwohl also categorised the knowledge dimensions into four levels of: Factual, Conceptual, Procedural and Metacognitive knowledge. These together form the Cognitive Process Dimension [15].

3. Gagne's nine events of instructions (1992) - Gagne's nine levels of instruction to enhance learning performance. It is used in e-learning platforms. It includes nine events as following [16].

Grabbing Attention ⇒ Learning-Objectives ⇒ Previous Knowledge ⇒ Learning Material ⇒ Guidance ⇒ Practice ⇒ Feedback ⇒ Assessment ⇒ Knowledge Retention

4. ADDIE Model (around late 80's or early 90's) – The Addie model is accepted widely but the source of origination is not known with certainty. Many researchers elaborate the ADDIE model. The model involves the following process:

Analysis ⇒ Design ⇒ Development ⇒ Implementation⇒ Evaluation.

Analysis is more alike to a detailed Diagnostic Assessment of learners. The Design phase involves creation of learning objectives and sequencing lesson plans. The development phase is the creation of learning content. The implementation phase involves the content delivery and training sessions. The evaluation phase consists of Assessments [17].

5. ASSURE Model (1999) – Heinrich and Molenda developed this model for effective teaching. It involves the following levels:

Analyze ⇒ Leaning Goals ⇒ Teaching Material ⇒ Utilize Teaching Material ⇒ Active Participation ⇒ Evaluation and Revision.

Analysing a learner's need and knowledge is the first step followed by the setting of learning objectives. The next steps are the selection of learner-centric materials and utilising them in the teaching process. Next is ensuring the active learner participation leading to the final step of evaluation of the accomplishments of learning goals [18].

### C. INSTRUCTIONAL DESIGN AND COGNITIVE LOAD

[11], points out the fact that in presence of high cognitive load, learning is hard. A good Instructional Design can manipulate this cognitive load. Intrinsic load can be reduced by following the approach of simple to complex. Sweller suggests breaking the learning content into sequenced and successive levels of difficulty. Extraneous load is highly dependent on instructional control. Use of different teaching strategy and style can reduce extraneous load. It can also be reduced by not providing a large and repetitive amount of information [18], [19].

[20] suggests that pedagogical agents are more engaging to learners and create motivational impact. Pedagogical Agents are better in STEM (Science, Technology, Engineering, and Mathematics) than Humanities subjects are. Agents are better than text and voice-only content. They also comparatively decrease the cognitive load.

[8] later in their study explored cognitive load in a video with and without a pedagogical agent and found no significant difference. [21] suggests that intrinsic load is not only influenced by subject matter but also by learner's prior knowledge. [7] Instructional Design cannot reduce intrinsic cognitive load but the bad instructional design can increase intrinsic and extraneous load. [22] studied the effectiveness of embodied pedagogical agents and reported a positive impact on motivation and a smaller impact on retention of knowledge.In-State Machine Compilation Approach, a state machine is generated to adapt to the action of the learner at run time [23].

[24] stated that instructional design has a role in providing learning gain, and a good instructional design may contribute to reducing cognitive load. A good instruction model should activate the cognitive process of the learner and propose that for measurement of cognitive load a questionnaire is better and reliable.

## III. RESEARCH METHODOLOGY

Several studies in the recent past have focussed on the influence of pedagogical agents on the learners. Different content and delivery mechanisms have been explored and the results have been reported on their no or mild influence in certain learning scenarios whereas a good learning gain and significant influence in some other learning scenarios. A good number of studies have recommended that while the presence of agents and its behavior has mostly shown a positive impact on the learners, it is essential to study the effects of the agents

for different populations of learners and for the learners with different learning and motivation needs. [7]–[11], [20] Taking a future direction from this, the present study has been conducted where the effect of the pedagogical agent in terms of its relation to the cognitive load of the learners presenting Dyscalculia has been studied. A systematic research methodology with design, development, and implementation of an instructional environment to deliver content through a pedagogical agent developed for this purpose, has been formulated, studied and reported. The Research methodology consists of the following:

1) **Selection of target group**: A sample population in equal numbers, of children (aged 8-12 years) presenting and not presenting Dyscalculia are selected. 41 learners with different levels of Dyscalculia (mild, moderate and severe) and equal number of non-Dyscalculia learners were randomly selected.
2) **Research Question/ Hypothesis**: Research questions are designed by studying the parameters affecting the cognitive load in learners.
3) **Development of Questionnaire and Assessment Tools**:
   i. Extraneous Load Questionnaires (ELQ) is developed for Rating Learner Experience
   ii. Pre and Post Assessment for Intrinsic Load Assessment
   iii.Questionnaire for Germane load Assessment
4) **Research Implementation**: Design and Development of Multi-model Architecture
5) **Statistical test conducted:**
   1. **Intrinsic Load**: Depending upon the nature and type of data we select a t-Paired test to find out the learning significance before and after session on diagnostic and Post learning scores. This test is done for all participants. To find out the significance difference between the groups (Dyscalculia learners and Non- Dyscalculia Learners) ANOVA-Two factors without replication is used. The same test is also conducted to find out difference in conditions of with and without presence of Pedagogical Agent.
   2.**Extraneous Load**: Extraneous cognitive load is directly related to instructional material and learner experience. Learners experience regarding various features and examining Learners activity during learning session to find out distraction and disinterest during learning is performed.
   3.**Germane Load**: The retention of knowledge is directly related to Germane load. The f-Test Two Sample for Variance is performed on Assessment immediately after completion of teaching, and re- assessment. This test is used as we have same sample group.

A sample population in equal numbers, of children (aged 8-12 years) presenting and not presenting Dyscalculia has been part of this study. Research questions have been designed. A systematic research methodology with design, development, and implementation of an instructional environment to deliver content through a pedagogical agent developed for this purpose, has been formulated, studied and reported.

**TABLE 1. Demographics of sample population.**

| Demographics | Frequency |
|---|---|
| Sample Population | 82(100%) |
| Age(8-12years) | 82(100%) |
| Boys | 45 (58%) |
| Girls | 37(42%) |
| Dyscalculia | 41 (50%) |
| Non-Dyscalculia | 41 (50%) |
| Poor Academic Performance | 24(29%) |
| Average Academic Performance | 33(40%) |
| Good Academic Performance | 25(31%) |

### A. RESEARCH QUESTION/HYPOTHESIS

Many types of research have been conducted to study the effect of the pedagogical agent on learner's motivation and interest. This study is conducted to study the effect of the pedagogical agent on learner's cognitive load. This study is conducted under project (Ref. No: SEED/TIDE/133/2016) sanctioned under 'Technology Interventions for Disabled and Elderly' (TIDE) scheme of Department of Science and Technology (DST). The sample population taken in this study are Learners with Dyscalculia and Learners without Dyscalculia, in equal numbers. This study will address the following research questions

1) Is there any influence of a pedagogical agent on the intrinsic cognitive load of Dyscalculia and Non-Dyscalculia learners?

2) Is there any influence of pedagogical agents on the extraneous cognitive load of learners with and without Dyscalculia?

3) Is there any influence of pedagogical agents on the germane cognitive load of Dyscalculia learners?

### B. PARTICIPANTS

A total of 82 learners (41 Dyscalculia and 41 without Dyscalculia) were selected from eight schools and one Psychotherapeutic Centre as in Table 1. 37 out of them were girls and the rest were boys. The age group of the sample population is 8-12 years. These learners have a basic introductory knowledge of shapes.

### C. MATERIALS

#### 1) EXTRANEOUS LOAD QUESTIONNAIRES (ELQ) FOR RATING LEARNER EXPERIENCE

We collect data on a 5-point Likert-Typescale ranging from Worst, Bad, Average, Good, and Perfect Table 2. In the proposed research design, a 7- item-scoring rubric is developed to evaluate the experience of the learner with the system (during the pre-test, learning process, and post-test). This questionnaire will be presented to the learner and their special educators.

#### 2) PRE-POST ASSESSMENT QUESTIONNAIRE FOR INTRINSIC LOAD ASSESSMENT

We collect pre and post-assessment score data of learners for a 15 questions questionnaire to assess intrinsic load. The questionnaire is categorized into three levels of, remembering (Identifying the basic Concept), Understanding (Compare and Classifying), and Application (Word Problem) with 5 questions each. The questionnaire structure is explained in Table 3. Each question has 2 marks.

#### 3) RETENTION OF KNOWLEDGE QUESTIONNAIRE FOR GERMANE LOAD ASSESSMENT

To assess the Germane load, same 15 questions questionnaire structured as in Table 3 is formed in two categories - with and without pedagogical agent.

### *D. INSTRUCTIONAL DESIGN*

The proposed instruction model is based on the teaching principles of Cognitive Constructivism and follows a learner-centric approach. Learning is possible if the learner is curious about the learning concept and knows its use.

#### 1) INSTRUCTIONAL DESIGN MODEL

This instructional Model is for engaging learners with Dyscalculia shown in Figure 1 It is structured into the following steps:

1) Learning Warm-up: This step is for introductory purposes. Learners will feel connected and welcome. Also, this is to excite a learning attitude and develop curiosity for Mathematics subject/discipline.
   - Setup a Virtual Learning environment (Engage with conversation).
   - General Awareness about Math Learning (Use in daily life /General Use).
2) Diagnostic Assessment: This step involves a descriptive analysis of learners and finding Problematic Academic Skills. This will help in analyzing problems and breaking problems into micro lessons.
   - Initial or Pre - Assessment (Dyscalculia Academic problem).
   - Pre knowledge skill assessment (Academic Learning Skill related to Dyscalculia).
   - Sequencing and Structuring of Problems into Micro Level (Single Problem Teaching).
3) Content Sequencing: This step involves sequencing and structuring the learning content and providing a Pedagogical Agent as a Special Educator and a Learning Companion. This is the learning environment set for maximizing learning and reducing cognitive load.
   - General Awareness about the concept (Use in daily life /General Use).
   - Structured Learning Content (Pedagogical Agent as an Educator and Learning Companion).
4) On-going Learning Assessment and Feedback: This step involves the assessment of learner's engagement during ongoing learning. Here, the content is adapted as per feedback from the learner.
   - Assessment during learning (Interaction quiz regarding Concept understandable or not).
   - Provide feedback (positive vocabulary).
   - Adaptation (as per assessment)-Resume/Repeat Learning.
5) Final Assessment of Learning: This step involves the final assessment of learners at three levels to keep account of the learner's stage of cognitive development. Final Assessment of:
   - Knowledge of the concept.
   - Understanding of the concept.
   - Application of the concept.

#### 2) CONTENT DESIGN

Need responding Content has been designed to meet the learning requirements of Dyscalculia learners. A sample lesson plan is shown in Table 4. The following features have been built in the content: Applied Learning Strategies – The learning approaches used are Scaffolding, Inductive-Deductive Method, Exploring, Verbal and Non – Verbal Communication and Practice-based.

Cognitive Constructivism – One Pedagogical agent as a Teacher and another as a learning companion share the knowledge and experience with learners. The learning is active and designed for Dyscalculia learners. The concerning topics of mathematics faced by children presenting Dyscalculia discussed here are: Numbers, Shapes, Reasoning, and Problem Solving.

Socio-Cultural Context- Pedagogical Agent provides some emphasis on social learning by creating a classroom-learning environment. It establishes opportunities to learn with teacher-like and companion-like agents. A Teacher – like takes the role of the teacher and a Companion –like agent joins the learning journey with the learner.

Stages – Knowledge, Understanding, and Application phases based that make use of prior knowledge and learning assessment are the stages of learning.

Structure – A sequenced structure is provided by dividing topics into micro levels from easy to difficult offering learning of a single concept at a time.

Teaching Implication – Developing a positive learning attitude towards mathematics, strengthening of Math Vocabulary, and generating curiosity for related topics so that learners can apply knowledge and solve mathematical problems in daily life, with ease. Learners should be able to seek patterns, make connections of learned concepts, and retain the knowledge.

A Sample lesson plan for teaching 2D and 3D Shapes is presented in Table 4. The first level is Knowledge and provides General introduction of Shapes. Learners will be able to recognize and recall shapes and figures. The second level is Understanding and provides the facts for better classification and comparison of these figures. Learners will be

**TABLE 2.** Extraneous load questionnaire.

| Sl. | Principle | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Colour combination | Does not like the look and feel of screen | Colour combination is distracting | Only bright colours are used | Colour combination is fine | Perfect colour combination |
| 2 | Learning content | Content is unrelated with the problem of the learner | Content material is not up to mark | Content material is fine | Content material is fine along with presentation style | Content is fun to watch and contributes to the understanding of the topic |
| 3 | Agent features | Agent appearance is distracting | Does not like appearance of the agent | Agent is ok | Only a particular agent is preferred | Agent is motivating and helps in learning |
| 4 | Agent gestures | Always demotivating gestures | Always default (smile) gesture | Changes gestures in time | Satisfactory gestures | Gestures are motivating |
| 5 | Question-naire quality | Questions do not make sense | Questions are not up to the mark | Questions are satisfactory | Questions are topic related and assess problem correctly | Questions are fun to solve and assess problem correctly |
| 6 | Feedback quality | Does not provide related feedback | Includes only brief feedback | Provide feedback only when error occurs | Provide feedback when help is needed | Offers re-teaching the topic along with feedback |
| 7 | Learning environment | Does not meet expectations of the learner | Only agent is of choice of the learner | Preferred agent but content sequence is not in order | Preferred agent and content is correctly sequenced | Learner is comfortable with agent, content and interaction quiz |

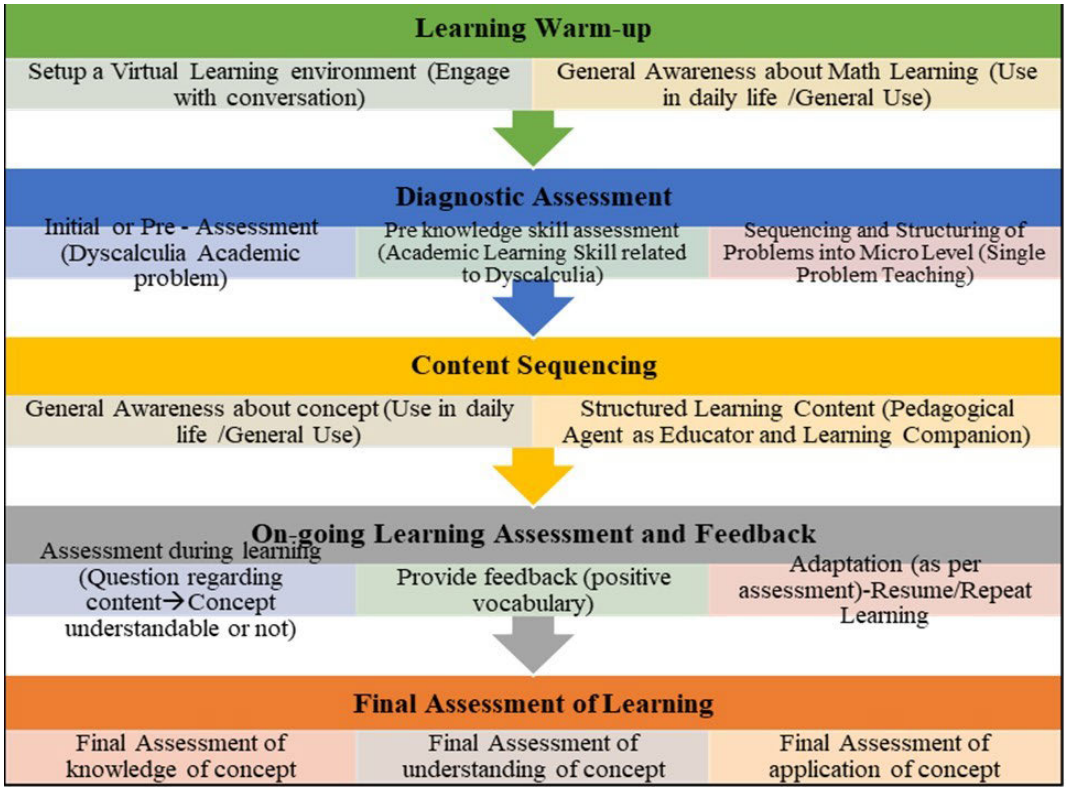


**FIGURE 1.** Instructional design model.

able to understand concepts and discriminate between various features of shapes. The final level is Application and provides the use and application of these concepts. Learners will be able to apply the concepts and knowledge related to shapes (Perimeter, Area, and Volume).

### *E. MULTI MODEL ARCHITECTURE OF ITS WITH PEDAGOGICAL AGENT*

In previous ITS works and learning environments, pedagogical agents have multiple issues like a representation of domain knowledge and student model, choosing appropriate

**TABLE 3. Pre-Test and Post-Test structure.**

| S.No | Cognitive Level | LD (Academic Skill) | Topic Related |
|---|---|---|---|
| 1 | Remembering (Identifying) | Dyscalculia (Spatial) | Basic Shapes<br>Closed Shapes<br>Open Figures<br>Plane Figures<br>Solid Figures |
| 2 | Understand (Compare, Classify) | Dyscalculia (Basic Calculations) | Sides of Figures<br>Angles of Figures<br>Vertex of Figures<br>Edges of Figures<br>Faces of Figures |
| 3 | Application (Word Problem) | Dyscalculia (Reasoning) | Circumference<br>Perimeter (Plane fig)<br>Area (Plane Fig)<br>Area (Solid Fig)<br>Volume (Solid Fig) |

pedagogy strategy and, adapting to learners' behavior during the learning process. In this paper, Multi Model architecture is proposed to address these issues that uses Behaviour Sequence approach. In behavior sequence approach, pedagogy agents are specified by

1) behavior space that contains vocal behavior and gestures of the pedagogical agent,
2) design-centered context model that deals with constructive problem representations and problem solving tasks, and
3) behavior sequence engine that dynamically selects pedagogical agents' actions to create effective pedagogical behavior [10].

In the proposed architecture, behavior space is represented as an agent model to store pre-defined pedagogy agent characteristics, gestures, and behavior. The pedagogy agent is selected from the agent model as per the requirement of the learner. For making the proposed architecture adaptable to the learner, a monitoring agent is placed in the learning environment to observe the behavior of the learner during the learning process and change features/ characteristics or agent itself as per the requirement. The proposed architecture represents six models as shown in Figure 2-

1) Learner model
2) Instruction model
3) Pedagogical Agent model
4) Domain model
5) Expert model
6) Learning environment

The learner model contains pre-knowledge of the learner and assigned tasks based on the pre-test result. The instruction model contains tutoring strategy that includes instruction plan, interaction quiz and post test. The pedagogical Agent model contains verbal dialogues, gestures, and characteristics of the agent. The domain model contains learning content, pre-test, and post-test questionnaire. The expert model delivers learning content according to the need and preference of each learner, and adapt according to the needs of the learner. The learning environment presents pedagogical agents, learning content, and quiz to the learner.

### 1) LEARNER MODEL

The learner model has following sub-components:

1) Pre-knowledge: Pre-knowledge of the learner is determined on the basis of pre-test and stored in learner model.
2) Problem area: The problematic academic skill of the learner is identified on the basis of pre-test score and learner is presented learning content on the basis of his/ her problem area.
   In the proposed ITS, 6 target skills are included that are taken as 6 topics. In pre-test, 10 questions related to one individual topic are presented to the learner. So total 60 questions are presented to the learner in pre-test. The score achieved in individual topic is termed as 'Topic Score' and score achieved in pre-test is termed as 'Pre-test Score'. Fuzzy inference system have been used in this work due to its wide usage in taking decisions based on imprecise and non-numerical information [25]–[30]. To determine the degree of 'Performance' of the learner, fuzzy rules are applied to the input variables Pre-test Score and Topic Score. For each input variable, 3 fuzzy sets are used to describe score of the learner. Both Pre-test Score and Topic Score is calculated out of 100 as follows:
   a) Low: The degree of positive response from the learner ranges from 0% to 50%.
   b) Medium: The degree of positive response from the learner ranges from 40% to 80%.
   c) High: The degree of positive response from the learner ranges from 70% to 100%.

   To describe the Performance of the learner in individual topic, two fuzzy sets are used for the output variable as follows:
   a) Poor: The degree of Performance ranges from 0% to 80%.
   b) Good: The degree of Performance ranges from 70% to 100%.

   Three intervals of membership functions are determined by each input variable as shown in Figure 3. The membership functions of output variable are shown in Figure 4. The membership functions of output variable represent poor and good performance of the learner in particular topic. Both input variables and output variables are positioned in a scale ranging from 0 to 100.
   In this work, fuzzy rules are configured using input variables (Topic Score and Pretest Score) and output variable (Performance). The set of rules using IF-THEN logic are as follows:
   - If the (Pre-test Score is Low) and (Topic Score is Low) then Performance is Poor.

**TABLE 4.** Sample content design for shapes.

| Learning Objective | Topic | Topic-Breakup | Academic Learning Skill | Learning Methods | Teaching Objective |
|---|---|---|---|---|---|
| Knowledge | Shapes | Shapes in life<br>Closed<br>Open<br>Plane<br>Solid | Reasoning | Inductive -Deductive Method<br>Verbal Communication<br>Non-verbal Communication<br>Scaffolding Approach<br>Simple to-Complex<br>Audio– Visual Teaching | Curiosity- Generation<br>Basic Knowledge<br>Classific-ation and Comparison<br>Application of learned concept |
| Under-standing | Plane<br>Solid | Sides<br>Angles of Vertex<br>Edges<br>Faces | Counting Calculation | | |
| Applica-tion | Plane<br>Solid | Circum-ference<br>Perimeter<br>Area<br>Volume | Word Problem | | |

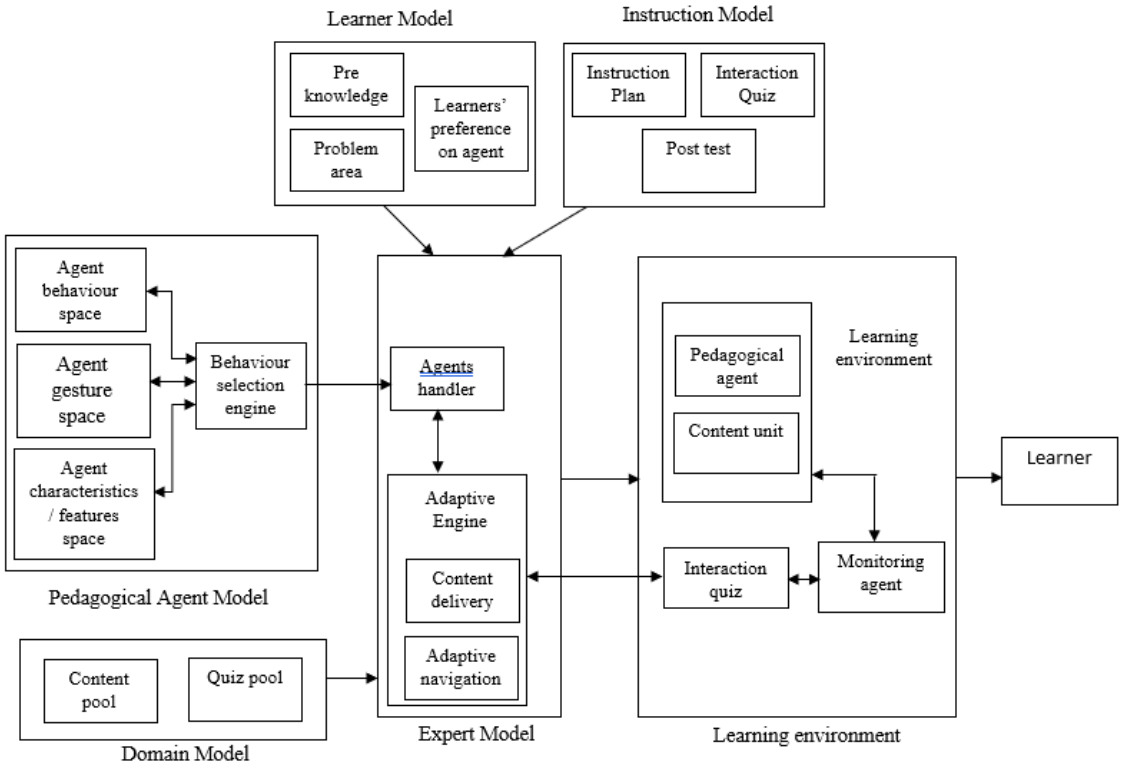


**FIGURE 2.** Multi model architecture.

- If the (Pre-test Score is Low) and (Topic Score is Medium) then Performance is Poor.
- If the (Pre-test Score is Low) and (Topic Score is High) then Performance is Good.
- If the (Pre-test Score is Medium) and (Topic Score is Low) then Performance is Poor.
- If the (Pre-test Score is Medium) and (Topic Score is Medium) then Performance is Good.
- If the (Pre-test Score is Medium) and (Topic Score is High) then Performance is Good.
- If the (Pre-test Score is High) and (Topic Score is Low) then Performance is Poor.
- If the (Pre-test Score is High) and (Topic Score is Medium) then Performance is Good.
- If the (Pre-test Score is High) and (Topic Score is High) then Performance is Good.

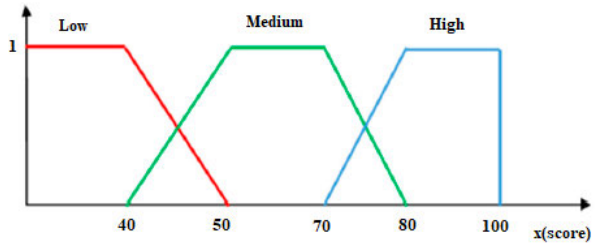


**FIGURE 3.** Membership functions of input variables.

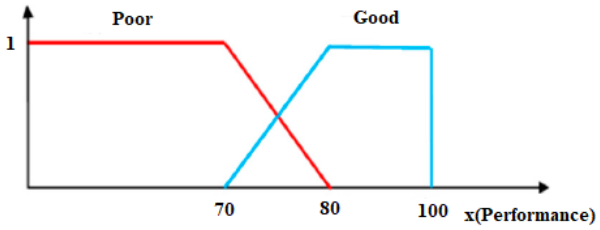


**FIGURE 4.** Membership function of output variable.

3) Learners' preference on agent: One of the pedagogical agents has been given the persona of a learning companion. Learning companion learns with learners and motivates learners to learn more and solve more problems. The other two pedagogical agents have been given the persona of a special educator. Thus, each learner has presented two special educator personas (one male and one female) and asked which one out of two personas is preferred by him/her to support the learning process. Based on the choice, the Pedagogical agent is presented for the learner, through the learning process.

### 2) INSTRUCTIONAL MODEL

The instruction model has following components:

- Instruction Plan: The learner is provided an instruction plan. Instruction plan contains a sequence of learning contents according to the problematic academic skill of the learner. Only one learning content is presented to the learner according at a time.
- Interaction quiz: After one learning content is over, an interaction quiz is presented to the learner that contains quiz related to the current topic.
- Post-test: After the instruction plan is completed by the learner, post-test is presented to the learner, to evaluate the performance of the learner

### 3) PEDAGOGICAL AGENT MODEL

The pedagogical agent model has following components as shown in Figure 6:

- Agent behavior space: Agent behavior space displays a variety of behaviors that an agent can offer to the learner during his/her time in the learning environment. The agent behavior space consists of three major categories

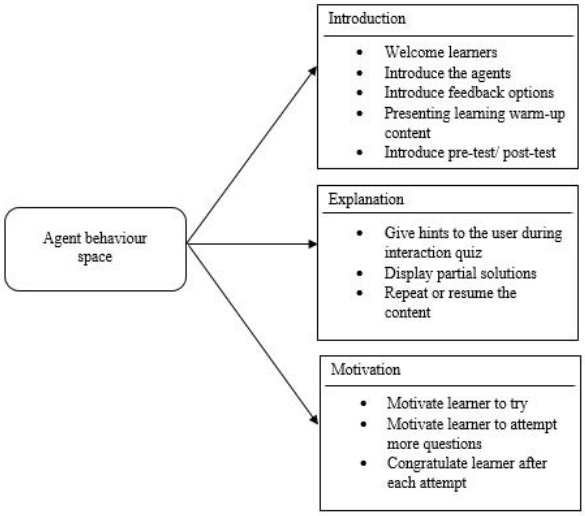


**FIGURE 5.** Agent behaviour space.

(Fig 4) Introduction behaviour category contains following features:

- Welcome learner when he/ she first logs in to the system.
- Introduction of the agent (as special educator)
- Introducing feedback options to the learner
- Providing learning warm-up content.
- Presenting pre-test/ post-test questions to the learner.

The explanation behavior category incorporates hints from the domain model and presents it to the learner in an interesting manner. It offers general guidelines for solving a problem and different levels of feedback in the form of simple hints, partial solutions and repeats the whole topic, as per requirement. Motivation behavior category motivates learners to try a new problem or attempt more questions by displaying motivational messages to the learner during quiz sessions and congratulates the learner after attempting a question that motivates the learner to attempt more questions.

- Agent gesture space: The agent gesture space includes gestures such as Smile (default), explain, nod, surprised, confused, pointing, and speak, to make the pedagogical agent more lifelike. In the presence of a lifelike agent, the learner may feel obliged to give their best performance (Fig 6).
- Agents characteristics/ features space: In the proposed architecture, three pedagogical agents are introduced-two special educators (one male and one female) and one learning companion. Special educators incorporate teacher persona and give instructions to the learners during learning procedures on how to solve a problem. A learning companion incorporates a friend persona and learns a topic with the learner
- Behaviour selection engine: The behavior selection engine selects the behavior of the agent from agent

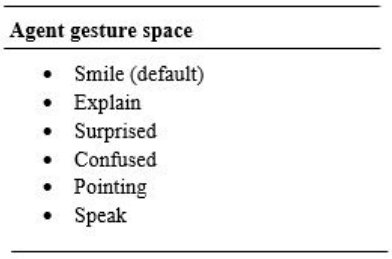


**FIGURE 6.** Agent gesture space.

behavior space, gestures from agent gesture space, and features/ persona of the agent from agent characteristics/ features space as shown in Fig 5.

#### 4) DOMAIN MODEL

The domain model has following components:

- Content pool: In the present case, it contains content pieces of basic geometry that will be provided to the learner during the learning process.
- Quiz pool: It contains pre-test and post-test questionnaires that are presented to the learner before and after the learning process, and interactive quiz that is presented to the learner after each learning material is completed by the learner, to check the level of understanding of the learner in the current topic

#### 5) EXPERT MODEL

The expert model delivers instruction plan to the learner based on the problematic academic skill and preference of the agent. The expert model has following components:

- Agent Handler: Agent handler takes input from the learner handler about the preference of the learner on pedagogical agent and contacts behaviour selection engine to provide selected persona, and forwards it to the learning environment.
- Adaptive engine: Adaptive engine is responsible for generating instruction plan and manipulation of the links in case of negative performance shown by the learner. Adaptive engine is responsible for following tasks
- Content Delivery Adaptive engine generates personalized learning path according to the score achieved in problematic academic skills. In pre-test, problematic academic skills of the learner are determined using the score achieved in individual topic. In instruction plan, learning content at each stage are arranged in increasing order of the scores achieved. Here, topic in which learner is facing most difficulty, is provided first as learner will be able to understand the topic better when learning with clear mind and focus better. For generating personalized learning path, bubble sort is used in this paper.After completion of pre-test, the system provides an initial score Pre-test $Score_a$. Assuming learner is provided n questions in N topics, the score for each topic is Performance(i), here taken as $P(i)$ and the score of each question is Pre-test $i(j)$. Here, '$i$' represents the number of each topic that ranges from 1 to $N$ and $P(i)$ represents score of each topic and the score (Pre-test $Score_a$) for initial capability can be calculated as:

$$P(i) = \sum_{j=1}^{N} \text{Pre-test } i(j);\ 1 <= i <= N \tag{1}$$

$$\text{Pre-test } score_a = (1/N) \sum_{i=1}^{N} P(i) \tag{2}$$

ITS compares $P(i)$ score for each module with the list of learning content. It marks the topic as already covered in which learner receives full marks. After that $P(i)$ score is used by Bubble Sort algorithm to generate personalised learning path. To generate personalised learning path following formula is used:

$$\text{Personalised-learning-path} = \text{Bubble-Sort}(P(i)) \tag{3}$$

Here, six topics are included in this study. Suppose a learner receives $P(1) = 60$, $P(2) = 30$, $P(3) = 80$, $P(4) = 90$, $P(5) = 20$ and $P(6) = 40$. For generating personalised learning path, formula 3 is processed as follows:
Initial marks: $P(1), P(2), P(3), P(4), P(5), P(6)$.
The original path will be Topic(1), Topic(2), Topic(3), Topic(4), Topic(5), Topic(6).

1) Processing 1: $P(1)$ ← compare with → $P(2), P(3), P(4), P(5), P(6)$
2) Processing 2: $P(2), P(1)$ ← compare with → $P(3), P(4), P(5), P(6)$
3) Processing 3: $P(2), P(1), P(3)$ ← compare with → $P(4), P(5), P(6)$
4) Processing 4: $P(2), P(1), P(3), P(4)$ ← compare with → $P(5), P(6)$
5) Processing 5: $P(2), P(1), P(3), P(5), P(4)$ ← compare with → $P(6)$
6) Processing 6: $P(2)$ ← compare with → P(1), P(3), P(5), P(6), P(4)
7) Processing 7: $P(2), P(1)$ ← compare with → $P(3), P(5), P(6), P(4)$
8) Processing 8: $P(2), P(1), P(3)$ ← compare with → $P(5), P(6), P(4)$
9) Processing 9: $P(2), P(1), P(5), P(3)$ ← compare with → $P(6), P(4)$
10) Processing 10: $P(2), P(1), P(5), P(6), P(3)$ ← compare with → $P(4)$
11) Processing 11: $P(2)$ ← compare with → $P(1), P(5), P(6), P(3), P(4)$
12) Processing 12: $P(2), P(1)$ ← compare with → $P(5), P(6), P(3), P(4)$
13) Processing 13: $P(2), P(5), P(1)$ ← compare with → $P(6), P(3), P(4)$
14) Processing 14: $P(2)$ ← compare with → $P(5), P(6), P(1), P(3), P(4)$
15) Processing 15: $P(5), P(2)$ ← compare with → $P(6), P(1), P(3), P(4)$

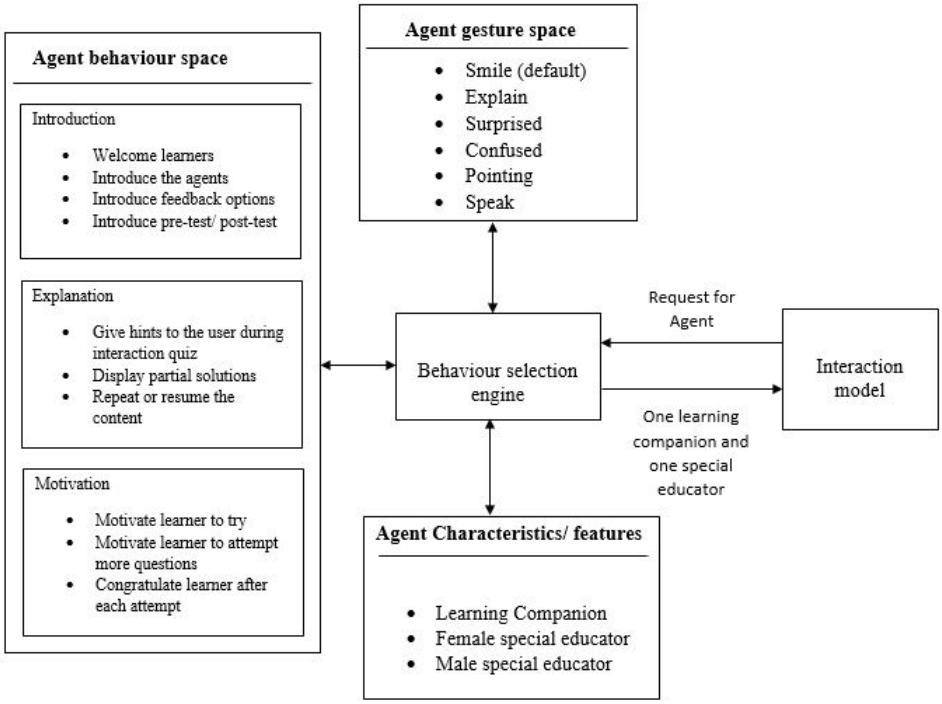


**FIGURE 7.** Pedagogy agent model.

The processed scores after using bubble sort will be $P(5)$, $P(2)$, $P(6)$, $P(1)$, $P(3)$, $P(4)$

*Personalised learning path:* Topic(5), Topic(2), Topic(6), Topic(1), Topic(3), Topic

- Adaptive Navigation: Adaptive navigation refers to manipulation of learning content sequence. In the proposed system, the performance of the learner in each topic is determined using interaction quiz response. After one learning content is completed, an interaction quiz related to the topic is presented to the learner. If learner provides positive response in the interaction quiz, then next learning content is provided according to personalised learning path. If learner provides negative response in the interaction quiz, then same learning content is repeated so that learner can better understand the topic.

#### 6) LEARNING ENVIRONMENT

The learning environment is an interface between ITS and the learner, and presents the learner with the following components:

- Pedagogical agent as a special educator and learning companion,
- Content piece/topic/unit from the content pool, as per a sequence based on the problem of the learner,
- Interaction quiz to check if the learner has understood the concept and learned the topic, as expected. If the next content can be presented to the learner or if the previously presented content needs to be repeated.
- Monitoring agent to observe and assess the performance of the learner during the learning process.

### *F. DEVELOPMENT OF ITS USING MULTI MODEL ARCHITECTURE*

In the first phase of developing ITS, the instruction design of the proposed architecture is designed, based on, teaching principles of cognitive constructivism. Learning material is developed for teaching basic geometry concepts to the learners that are stored in the content pool of the domain model. For the assessment of pre-knowledge level, assessing learning gain and immediate topic understanding level, pre-test questionnaire, post-test questionnaire, and interaction quiz is developed and stored in the quiz pool of the domain model. Three pedagogical agents (one learning companion and two special educators) are developed in the present scenario. In the second phase, when the learner logs in to the system, an introduction (learning warm-up) is presented to the learner for initiating conversation and setting up a virtual environment. After this, a pre-test questionnaire is presented to the learner for determining the pre-knowledge level of the learner that is stored in the learner model. Based on the pre-test score, the learning sequence that is to be delivered to the learner is determined. After completion of the pre-test, the learner is asked for his/ her preferred pedagogical agent and this information is also stored in the learner model. Based on information stored in the learner model, a unique learning sequence is presented to the learner along with one learning companion and one special educator agent that is preferred by the learner. While the learner is reading the

learning material, he/ she is observed by the monitoring agent. An interaction quiz is presented to the learner to check the understanding level of the topic.Based on the response of the learner, the monitoring agent updates information stored in the learner model and learning sequence, or the pedagogical agent is updated. After the learning sequence completes, a post-test is presented to the learner to check the learning gain of the learner. Learners are also presented with a questionnaire after one week of the learning process to check the retention of knowledge. All the data from pre-test, post-test, and retention test is collected. In the third phase, data is analysed for determining learner experience and effects of using pedagogical agents during the learning process and its impact on the cognitive load.

## IV. IMPLEMENTATION

The present research work is conducted under three steps:

- Phase 1: Development of Instructional Design, Content Design, and Pedagogical Agent for content delivery.
- Phase 2: Data Collection from the process of pre-test, post-test, and one - week later reassessment test (to assess retention of knowledge).
- Phase 3: Analysis of data as per the research questions.

A learner with Dyscalculia finds various difficulties in a mathematical domain like Numeracy Skill, Counting, Basic Calculations, Shapes, Time, Word problems, and Reasoning. Here the concept of Shapes is chosen and various learning skills of calculation, word problems, and reasoning related to Shapes are identified for tutoring. When a learner logs in to the system, a learning warm-up is provided to the learner for giving learners an introduction to basic geometry. After learning warm-up, a pre-test is presented to the learner. On the basis of the score of pre-tests, a learner profile is created that contains information on the pre-knowledge of the learner and the problem of dyscalculia that the learner is facing. After the pre-test, all three pedagogical agents (2 special educators and 1 learning companion) are presented to the learner and the learner can choose the pedagogical agents that will assist him/ her during the learning process. Pre-knowledge, problem area, and preference on the pedagogical agent are then stored in the learner model. After the pre-test is over, the learner is provided a learning sequence which he/ she has to follow to complete the course successfully. For presenting the learning sequence, the interaction model follows the following steps:

- At first, learner handler takes input from learner model in form of problem area and preference of the learner on pedagogical agent.
- Task handler chooses content sequence and interaction quiz from the domain model according to the problem area of the learner.
- Learner preference on pedagogical agent is forwarded to the behaviour selection engine which then provides selected agent to the interaction model.

Learning content along with a pedagogical agent is then presented to the learner. After one content piece is over, the post-test quiz is presented to the learner. On the basis of the response in the interaction quiz, the monitoring agent makes a decision whether the same content needs to be repeated or the next content can be presented to the learner. The screenshot of proposed ITS and pedagogical agents are shown in Figure 7Figure 8Figure 9.

## V. RESULTS AND DISCUSSION

### A. RESEARCH QUESTION 1: IS THERE ANY INFLUENCE OF A PEDAGOGICAL AGENT ON THE INTRINSIC COGNITIVE LOAD OF DYSCALCULIA AND NON DYSCALCULIA LEARNERS?

The pre-test and post-test are used as an indirect measure to find cognitive load [21]. To find the impact on intrinsic cognitive load, statistical tests are conducted under following two parts:

1) A t-Paired test is done to find out the learning significance before and after session on diagnostic and Post learning scores
2) An ANOVA-Two factors without replication is used to find out the significant difference in Dyscalculia learners and Non- Dyscalculia Learners in conditions of with and without presence of Pedagogical Agent.

The t-Test Paired Sample for Means is performed on Pre and Post Assessment scores without considering equal variance to ascertain if null hypothesis, which is an answer to our Research question 1 also. This test is used since we have same sample group and we are supposed to find out the significant differences in mean scores in learning during pre-test and post-test assessment test and impact on intrinsic cognitive load.

*Hypothesis: There is no significant difference in mean of each sample before and after session.*

Table 5 represents P(T<= t) two tail(7.53E-09) gives probability of absolute value of t-Statistics (6.9105) is larger in absolute value than Critical t value (2.007). Since p value is less than alpha 0.05, it rejects the null hypothesis that there is no significant difference in mean of each sample.

The above test results declare that in 82 learners the post assessment scores were significantly improved than the pre diagnostic test scores. This improvement in learning is due to the pedagogical agents (learning companion and tutor agent). It is concluded that presence of Pedagogical Agent provides significance improvement in mean scores and improves the learning of both Dyscalculia and Non Dyscalculia learner.

ANOVA Two Factor without Replication Table 6 shows the ANOVA Test in Post assessment scores with and without presence of Pedagogical Agent. The Rows are assigned the Pre-test and Post-test mean scores and Columns are assigned to Dyscalculia and Non-Dyscalculia learner. This test is to find out the significant differences in learning during post-test and significant difference in learning among Dyscalculia and Non- Dyscalculia learners.

Now, p-values for rows is 0.1112 which is greater than alpha value of 0.05. This shows there is no significant

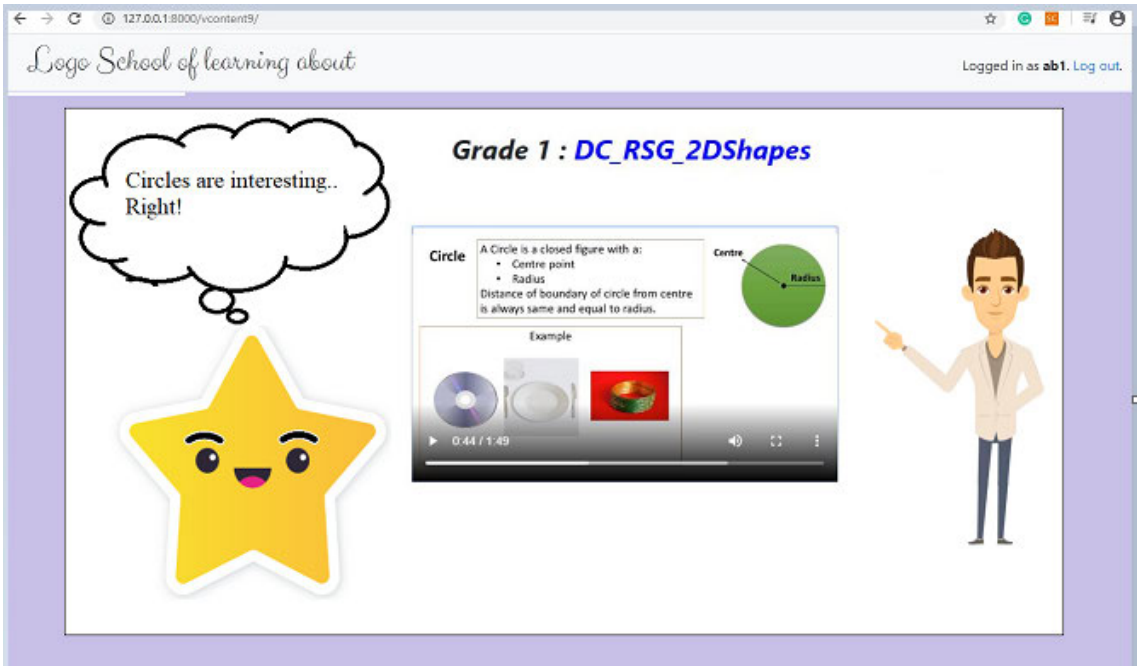


**FIGURE 8.** Preview of pedagogical agent and learning companion during teaching.

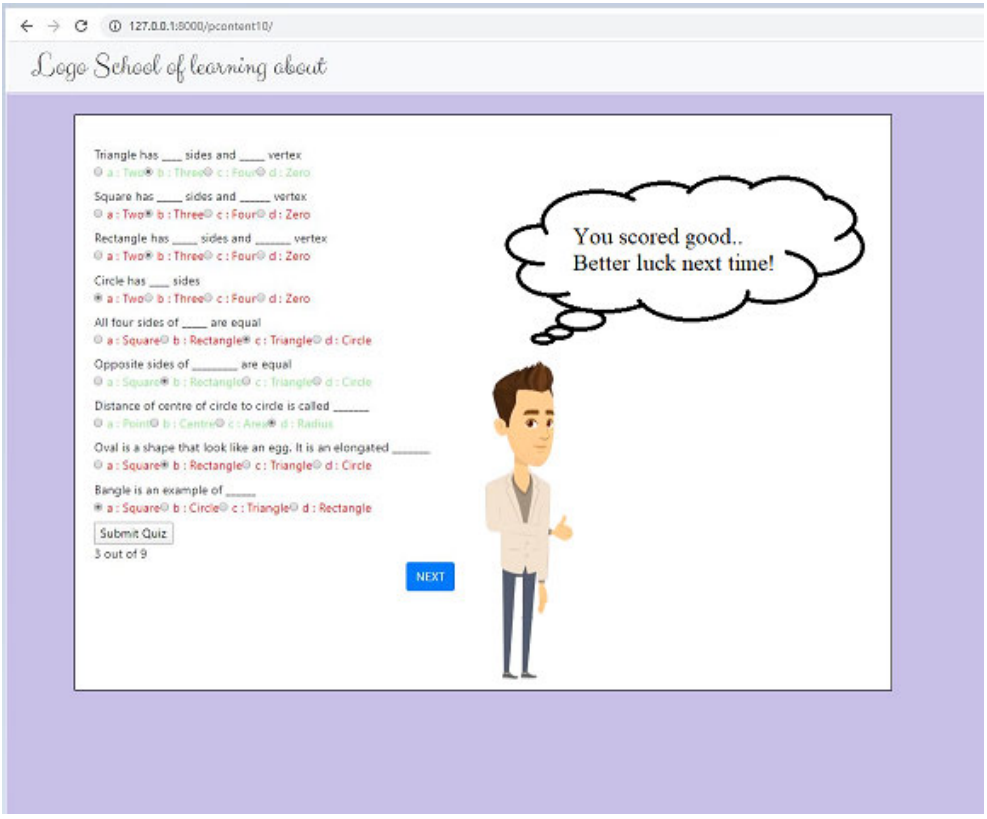


**FIGURE 9.** Preview of assessment for basic shapes (knowledge level).

difference in scores with and without the presence of Pedagogical Agent. Also p-values for column is 0.013 which is less than value of alpha 0.05. This shows the impact of Pedagogical Agent in providing learning for both Dyscalculia and Non-Dyscalculia learners is not similar and vary as per academic learning skill.

As compare to the previous test this test helps in elaborating the significance of the improvement in learning.

**TABLE 5.** t-Test paired sample for means score and intrinsic cognitive load.

| | Pre Assessment | Post Assessment |
|---|---|---|
| Mean | 18.90384615 | 22.32692308 |
| Variance | 7.892533937 | 5.596907994 |
| Observations | 82 | 82 |
| Pearson Correlation | | 0.054975343 |
| Hypothesized Mean Difference | | 0 |
| Df | | 81 |
| t Stat | | -6.910597238 |
| P(T<=t) one-tail | | 3.77E-09 |
| t Critical one-tail | | 1.67528495 |
| P(T<=t) two-tail | | 7.53E-09 |
| t Critical two-tail | | 2.00758377 |

**TABLE 6.** ANOVA two-factor without replication test to find the intrinsic load in learning.

| | | DC Mean | Non DC Mean | Variance | |
|---|---|---|---|---|---|
| Assessment with Agent | | 20.54 | 22 | 1.0658 | |
| Assessment Without Agent | | 20.4 | 21.8 | 0.98 | |
| Variance | | 0.0098 | 0.02 | | |
| SOV | SS | MS | F | P-value | F crit |
| Agents(w/wo) | 0.0289 | 0.0289 | 32.11111 | 0.1112 | 161.4476 |
| DC/Non-DC | 2.0449 | 2.0449 | 2272.111 | 0.013354 | 161.4476 |

Conducted test discloses the fact that the impact of Pedagogical Agent in providing learning for both Dyscalculia and Non-Dyscalculia learners is not similar. Learning implications and learning rate are different in both type of learner. Also, the learning vary as per academic learning skill. The rate of learning here is inversely proportional to the level of learning. For low level of learning, rate of learning is higher than corresponding higher level of learning.

The results from both tests provide the response to Research Question 1 and supports the fact that the presence of Pedagogical Agent does not affect the intrinsic cognitive load of a learner. Here in this study, presence of Pedagogical agent does not increase or decrease intrinsic cognitive load.

In addition, the results show negligible changes in learning gain with and without Pedagogical Agent in the form of mean scores Table 5Table 6. An average of (-)0.14 marks drop was reported. This supports the assumption of a well-designed instructional design Model and implies that the used instructional design Model is not exerting intrinsic cognitive load and supporting learning process of learners presenting Dyscalculia and Non-Dyscalculia.

### *B. RESEARCH QUESTION 2: IS THERE ANY INFLUENCE OF PEDAGOGICAL AGENTS ON THE EXTRANEOUS COGNITIVE LOAD OF LEARNERS WITH AND WITHOUT DYSCALCULIA?*

Extraneous load is related to learning experience and increases due to mental effort of poor learning material. The instructional design impacts the extraneous cognitive load. A poorly designed instructional design increases extraneous cognitive load on the learner and slows down the learning process, whereas a well – designed instructional design decreases extraneous cognitive load. To conclude the effectiveness of the present instructional design model, the assertion that 'a low extraneous cognitive load indicates a well – constructed instructional design', has been used in the present work. Hence, following two statistical tests are conducted to find the influence of extraneous cognitive load.

**TABLE 7.** Mean and Standard deviation of learner experience on different categories.

| Categories/Score | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Colour combination | 0% | 5% | 53% | 35% | 7% |
| Learning content | 2% | 13% | 8% | 46% | 31% |
| Agent features | 15% | 19% | 23% | 30% | 13% |
| Agent gestures | 12% | 11% | 27% | 26% | 24% |
| Questionnaire quality | 3% | 21% | 24% | 35% | 17% |
| Feedback quality | 20% | 14% | 15% | 28% | 23% |
| Learning environment | 20% | 17% | 15% | 30% | 18% |
| Mean | 10% | 14% | 24% | 33% | 19% |
| Standard deviation | 9% | 5% | 15% | 7% | 8% |

1) Learner's experience regarding various features of Pedagogical agent were recorded.
2) Examining Learner's activity during learning session to find out distraction and disinterest during learning in absence of pedagogical agent.

Learner Experience (for Pedagogical Agent features): For determining the extraneous load and learner experience, the sample learner population (82 learners) were presented a questionnaire where they had to rate their experience with presence of pedagogical agent in learning environment.The descriptive statistical report is presented in Table 7. Maximum 33% of learner's categorised features as 'Good' and 19% rated features as 'Best'. Overall, 76% learners expressed that, presence of Pedagogical Agent as good Learning Experience. Table 5 presents the significant improvement in mean scores and improvement in the learning. Hence, analysing, data from Table 5 to Table 7 together, supports concluding that, minimal extraneous load was exerted on learners due to the presence of Pedagogical agent that answers Research Question 2.

Learner Experience (For Instructional Design) - An increase in extraneous cognitive load distracts the learning activity and influences the attentiveness of learners. A well-structured instructional model can minimize the extraneous cognitive load. To monitor the attention and interest level of the learner, a learning session is recorded for each learner using Camtasia 2018 screen recorder and direct recording using a webcam. This monitoring of learning sessions is performed in the absence of a pedagogical agent to find the extraneous load due to Instructional Design. The respective special educators rate the learning experience of the students between Interested-Disinterested and Attentive-Distracted. This result is shown in the form of a chart in Figure 10. 23 out of 41 Dyscalculia learners and 35 out of 41 Non-Dyscalculia learners were rated interested and active throughout the learning process. This makes an overall 73% of learners fully attentive during the learning session. This implies low extraneous cognitive load. As this experiment was performed in the absence of a pedagogical agent, it can conclude that this low extraneous cognitive load is due to the proposed Instructional Design Model.

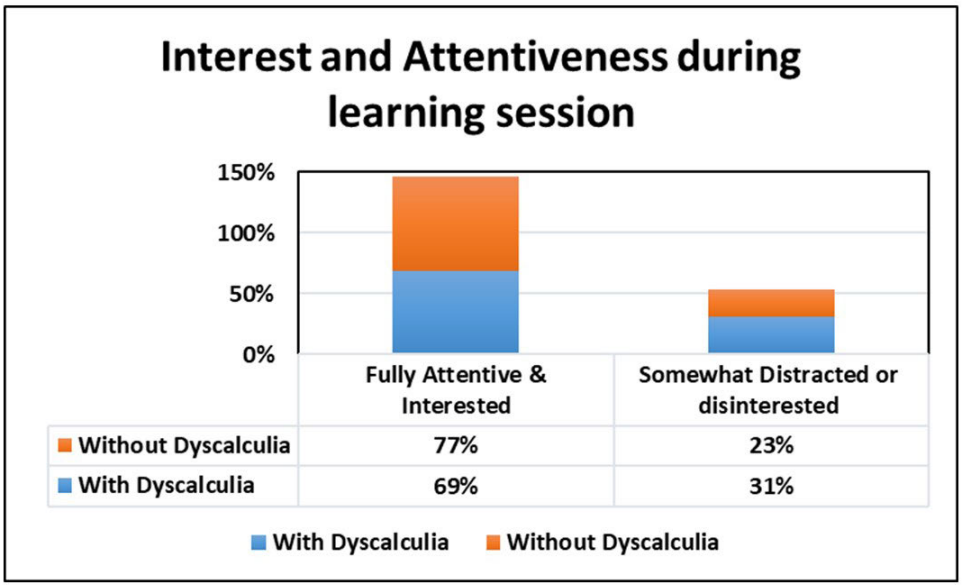


**FIGURE 10.** Interest and attentiveness in learners in absence of Pedagogical agent.

**TABLE 8.** F-test two sample for variance.

| | Variable 1 | Variable 2 |
|---|---|---|
| Mean | 24.26666667 | 23.33333333 |
| Variance | 1.71954023 | 1.195402299 |
| Observations | 35 | 35 |
| Df | 34 | 34 |
| F | 1.438461538 | |
| P(F<=f) one-tail | 0.166541607 | |
| F Critical one-tail | 1.860811435 | |

### C. RESEARCH QUESTION 3: IS THERE ANY INFLUENCE OF PEDAGOGICAL AGENTS ON THE GERMANE COGNITIVE LOAD OF DYSCALCULIA LEARNERS?

To assess the influence on germane processing retention test are used [21]. Germane cognitive load is the recalling and recognize memory of the learner. To assess the influence on germane processing retention test are used. Retention tests are conducted to find out the ability of learner to grasp the concepts and the retaining power of their knowledge. This knowledge retain test is conducted by a re-assessment test one week later. After one week of completion of tutoring session a re-assessment was taken for 35 top scorer learners, to find out whether there is retention of the learnt concept.

The f-Test Two Sample for Variance is performed on Assessment immediately after completion of teaching, and re-assessment, without considering equal variance to ascertain if null hypothesis which is a response to the Research Question 3. This test is used as we have same sample group and we are supposed to find out the significant differences in mean scores in learning during post and re-assessment test and impact on intrinsic cognitive load. *Hypothesis: There is no significant difference in variance and variance are equal* Table 8 represents F-value (1.438) is smaller in absolute value than the critical F-value (1.860). Since F-value is smaller than alpha 0.05, it does not reject the null hypothesis that there is no significant difference in mean of each sample. The test conducted supports the knowledge retention ability in learner. One week later, they remember the concepts and were able to recall the learned facts. It is concluded that the presence of Pedagogical Agent promotes and provides support in retention of knowledge and improves the learning.

### D. LEARNING IMPLICATION OF PROPOSED ITS FOR DYSCALCULIA LEARNERS

The generality of the proposed approach is regarding the impact of Pedagogical agents on learners with Dyscalculia and non-Dyscalculia. Through the study the generalized points are as follows: The impact of intrinsic cognitive load in the result concludes that the use of Intelligent Tutoring System as a teaching tool does not have any load on learners with and without Dyscalculia. During study, this was found to be true for all participants and during their division in group of Dyscalculia and non-Dyscalculia. The study for extraneous cognitive load implies that with a learner centric approach we can reduce the load in learners. The content Design and Instructional Design plays a significant role in this. The knowledge retention was visibly improved with use of pedagogical agent for the learners. The conducted tests confirms the improvement and learning gain between Dyscalculia and non-Dyscalculia learners.

The topic Shapes (solid and plane figures) was chosen during the field trial. Use of multisensory approach, tutor agents and learning companion maintains the learning curiosity throughout the learning. The proposed ITS has Individualized Educational Plan for various maths related problems which are selected by keeping focus on learning requirements of Dyscalculia learners. Like Counting, Place Values, Calculations, Comparison, Fractions, Word Problem etc.

**TABLE 9. Learning implications of proposed ITS.**

| Learner's Problem | Learning Requirements | Support provided to the learner | Learning Implications |
|---|---|---|---|
| Counting Numbers: Learners reverse or transpose numbers | Remembering the number series. Understanding the number sequence. Ability to use and apply numbers in daily life | Proposed ITS helps in assessing the knowledge level of learner about number system and provides the relative content. | The learner will be able to recognize the numbers and understand the number system. |
| Identify place value: Learners misread numbers | Remembering the place values of numbers Understanding the place value of numbers Ability to use the concept of place values in daily life | Proposed ITS helps the learner to visualize the numbers and differentiate the high and low values of numbers. | Learner will be able to identify the correct values of given number and differentiate the low and high values of numbers |
| Calculation Learners miscalculate. | Remembering and recognizing the symbols and their meanings Understanding the concept of calculation Application in solving word problems and using in daily life | Proposed ITS helps the learner to identify and understand their implied meaning. It helps learner to visualize the questions related to calculations and to understand the differences. | Learner will be able to recognize symbols, to calculate and to understand the concept of addition, subtraction, multiplication and division. |
| Compare and Measures: Learner misinterpret symbols (<, >, =) | Recognizing the comparison symbols Understanding the concept of comparison in numbers and fractions Ability to apply the concepts in daily life | Proposed ITS helps the learner to identify the symbols, to visualize the fractions and enable learners to differentiate the values of fractions. | Learner will be able to differentiate in number values and to visualize the fractions. |
| Spatial - Pattern recognition - Learners unable to identify shapes | Remembering the name of plane and solid figures Understanding the differences shapes Application of concepts | Proposed ITS helps in classifications and comparisons of various figures. It helps to visualize the concept of perimeter, are and volume in 2D and 3D figures. | Learner will be able to learn the facts, formulae and concepts of plane and solid figures. |
| Word problems | Understanding the problem stated in a question Ability to use in daily life | Proposed ITS helps learner to visualize the questions and to identify the given information and to understand the task. | Learner will be able to solve the word problems |
| Learning Attitude: Learners is fearful of mathematical concepts. | Curiosity generation Positive learning attitude | Proposed ITS introduce every concept by linking it with daily life to generate the curiosity. Learning companion and tutor make the positive learning environment | Learner will be able to have positive mindset. |
| Working Memory | Remembering Knowledge Retention | Proposed ITS uses multisensory approach in learning and introduced the learning companion and teaching agent to help learner | Learner will be able to memorize and visualize the mathematical concepts and will retain the knowledge. |

Table 9 shows the learning requirements, provided support and learning implications of the proposed ITS.

## VI. CONCLUSION

Pedagogical agents are not for entertainment purpose of learners. These agents can work as a tutor and a learning companion for learner. This study focused on the Dyscalculia learners and Non-Dyscalculia learners. The learning needs, support requirements of Dyscalculia learner are different than Non-dyscalculia learners. A well- designed instruction model, tutor agent and learning companion in an ITS were created for this study. The purpose of this experiment was to investigate the effects of pedagogical agents and well-designed instructional model on intrinsic, extraneous and germane cognitive load of learners with dyscalculia and without Dyscalculia. The study also explores the learning experience of these learner in learning environments with and without pedagogical agents.This analysis has following significant findings:

- The different learning requirements of learner with Dyscalculia can be assess using detailed assessment test to find the level of pre- knowledge. This will help in providing Individualised Educational Plan to the learners.
- A well-designed Instructional design reduces the cognitive load for the learners with and without Dyscalculia.
- There is no visible difference in intrinsic cognitive load after using pedagogical agent during overall learning process.
- Presence of pedagogical agent does not increase intrinsic cognitive load on Dyscalculia and Non-Dyscalculia learners.
- Minimal difference in extraneous cognitive load is visible after using pedagogical agent and a positive learning gain was recorded.
- Germane cognitive load is visibly improved when pedagogical agents are used and provides retention of learned facts and concepts.
- The constructed instructional design model does not contribute to exerting any intrinsic and extraneous cognitive load during learning process.
- 76% of the learners had good learning experience in the proposed system. These learners were attentive and interested throughout the learning.

## COMPLIANCE WITH ETHICAL STANDARDS

**Conflicts of Interest**: None.

**Ethical Approval**: Not required.

**Authors and Contributors**: This work was carried out in close collaboration between all co-authors. All authors have seen and approved the final version of the manuscript.

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