LEARNING BASIC ASTRONOMY THROUGH AN EMBODIED AND INTERACTIVE APPROACH

Rafikh Shaikh[1], Shamin Padalkar[2], Glenda Stump[3], Prayas Sutar[4] and Arunachal Kumar[5]
Tata Institute of Social Sciences, Mumbai[1,2,4,5],
Massachusetts Institute of Technology, MA[3]
rafikh.shaikh@tiss.edu[1], shamin.padalkar@tiss.edu[2], gsstump@mit.edu, prayas.sutar@tiss.edu, arunachal.kumar@tiss.edu

Students and adults struggle to understand the explanations of simple astronomical phenomena. Research has shown that much of the difficulty lies with students' difficulty to use visuospatial reasoning. Drawing on research on embodied cognition, multimodality and multimedia learning, a short pedagogic sequence called 'Basic Astronomy module' was designed around multiple external representations such as concrete models, gestures, role plays, animations, interactive digital games and diagrams. In the present study, we closely monitored the implementation of the module by seven teachers in government schools in Jaipur district of Rajasthan, India to study the teaching-learning process through the module and its effectiveness. In this paper, we will document the learning outcomes of the module in terms of conceptual understanding, attitudes and beliefs. Results show that students' understanding of basic astronomy concepts improved significantly after completion of the module; additionally, students' beliefs and attitudes towards science and specifically towards astronomy changed.

INTRODUCTION

Foundations of astronomy such as the model of the solar system and explanations of commonplace phenomena such as the occurrence of day and night, seasons, phases of the moon, solar and lunar eclipses are part of high school curricula in most Indian states. Earlier research in science education documents that alternate conceptions about the earth and astronomical phenomena are common among students (Vosniadou & Brewer, 1992, 1994; Padalkar & Ramadas, 2008). These alternative conceptions are often retained after instruction, or sometimes new alternative conceptions are developed (Bailey, Prather, & Slater, 2004; Lelliott & Rollnick, 2009). Thus many adults, including teachers, have alternative conceptions in the area of astronomy (Raza, 2002; Abell, 2007).

Models in astronomy, such as that of the solar system, include spatial information such as size, shape, distances, relative positions and trajectories of celestial bodies. Understanding models and explanations of commonplace phenomena such as the occurrence of day-night, seasons, phases of the moon and eclipses requires visuospatial thinking. For example, day and night are caused due to the rotation of the earth whereas the seasons are caused due to the revolution of the earth with its axis tilted. However, many students think that day and night occur due to the revolution of the earth (Vosniadou & Brewer, 1994) and seasons occur due to the change in the distance between the sun and the earth due to the earth's elliptical orbit (Lelliott & Rollnick, 2010). Thus, difficulty in visuospatial thinking is one of the main reasons for difficulty in understanding basic astronomy and emergence of alternative conceptions (Kikas, 2006; Subramaniam & Padalkar, 2009; Padalkar & Ramadas, 2010; Plummer, Kocarelli, & Slagle, 2013).

Our understanding of space is developed through the combination of visual, haptic, kinesthetic and vestibular perception. Hence, the corresponding external representations such as visual images (diagrams, photos, and animations), handling of concrete models, gestures and bodily actions should be used to teach content which requires spatial thinking. Diagrams play a crucial role in learning science and are commonly used as a pedagogic tool in textbooks and classrooms (Ainsworth, Prain & Tyler, 2011). However, diagrams are two dimensional, static and abstract (i.e. not realistic) and hence pose a difficulty to learners (Mishra, 1999). Drawing from the research on embodied cognition and multimodality, Padalkar and Ramadas (2008, 2010) proposed a pedagogic sequence of concrete models, gestures & actions (referred here as role-play) and diagrams to teach basic astronomy. Similar attempts to use the role-plays and gestures to teach astronomy are documented in Crowder (1996) and Venkateswaran & Gupta (2009). However, we adopted the sequence proposed by Padalkar and Ramadas since it weaved different spatial representations. Also, in previous research, this pedagogy was found to be effective in addressing alternative conceptions and developing a rich and accurate understanding of astronomy. Students who underwent this pedagogy also developed good representational competence (Padalkar, 2011).

The digital medium is another powerful medium which could be included in such pedagogy. Animations can overcome the limitations of diagrams to convey motion and to some extent three-dimensionality. The advantage of diagrams and gestures is that the learner can generate them. On the other hand, it is difficult to generate concrete models and animations for a learner. However, both afford a certain amount of interactivity. In addition, the digital medium can provide instant automated feedback and if the feedback is detailed and appropriate students can use it to learn. Keeping the general theme in mind, we selected some part of the pedagogic sequence proposed by Padalkar and Ramadas (2008, 2011) and added digital activities to the module. The activities suggested by Padalkar and Ramadas (2008, 2011) were appropriated in such a way that they complement the digital activities and the module was more suitable for large-scale implementation. The purpose of this paper is to describe an intervention that utilized a combination of technology and embodied pedagogic strategies to improve high school students' understanding of basic astronomy concepts. Additionally, we examined changes in students' attitudes and beliefs about astronomy. The intervention was implemented as part of a large-scale initiative targeted toward government schools in four states of India. This work is significant in that it strives not only to mitigate a problem common to high school students in general, but it seeks to do this in a population that is under-resourced and often under performing.

METHODOLOGICAL APPROACH/ MODULE DESIGN AND CONTENTS

The module was developed via iterative design and development phases. Several classroom and individual trials were done during the development phase of the module (Chopde & Padalkar, 2018). The first round of implementation took place in Grade 9 classrooms of government schools in Rajasthan (documented in

Shaikh, Chopde & Padalkar, 2018) based upon which we revised the module and finalized the support material for the teachers. Both the module and the support material for teachers are available in both English and Hindi. As shown in Figure 1, the module is divided into three units. Each unit contains four lessons that last approximately 40 minutes each. Thus there are twelve lessons, comprising eight hours in all. Three out of twelve lessons are digital lessons which are to be conducted in a computer lab. The remaining nine lessons contain hands-on activities and discussions which are to be conducted by the teacher in a regular classroom. All of the lessons can also be accessed via weblink. The module used free and open software and will soon be released as an Open Educational Resource (OER).

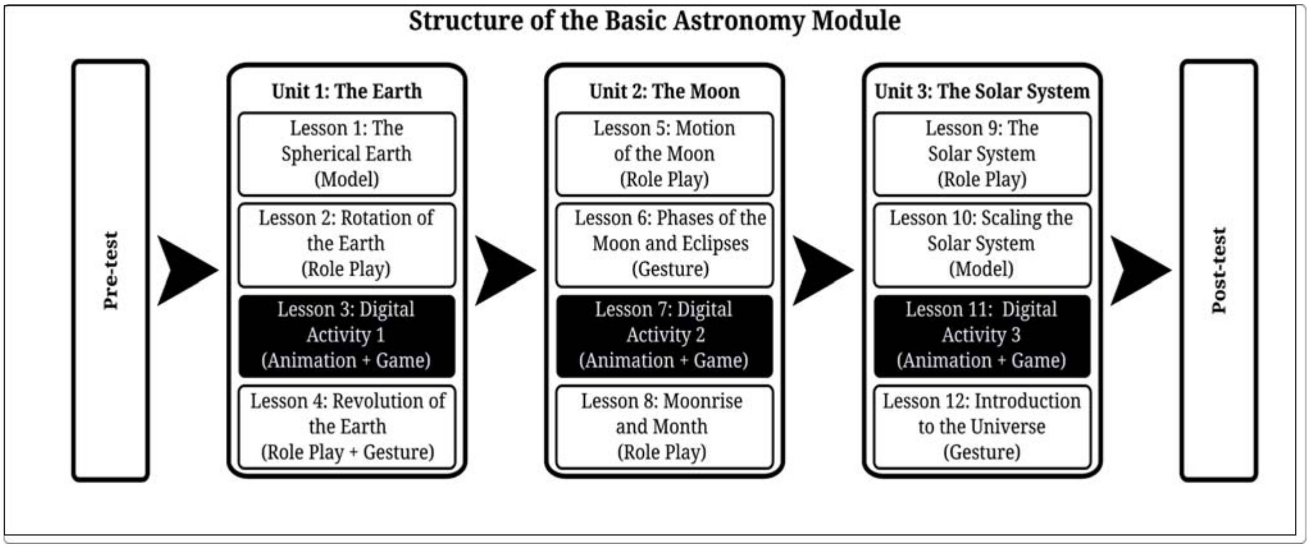

Figure 1: Structure of the 'Basic Astronomy' module

Classroom activities

As mentioned earlier, the classroom lessons consist of activities and related discussions. The number of activities focused on different kinds of spatial representations in each unit are shown in Table 1.

Unit No.	Concrete Models	Gestures	Role-plays	Diagrams (given + asked to draw)	Photos	Videos
1	3	2	5	17 + 7	0	0
2	1	1	5	11+6	8	0
3	1	1	1	3+1	23	2
Total	5	4	11	61+14	31	2

Table 1: No. of activities focused on different kinds of spatial representations

An example of use of a concrete model would be geosynchron (axis of the globe is parallel to the Earth's axis, pointing towards Pole Star). The lesson in which the geosynchron is used includes putting it in direct sunlight and observing the time of day at different locations. Examples of gestures used in the module include the right-hand thumb rule to determine the direction of the rotation and revolution of the earth and to trace the path of the sun at different latitudes and in different seasons. An example of role play is to mimic the motion of the moon to understand why we see phases of the moon. Note that different role plays were used to explain different phenomena. Most of the explanations are accompanied by diagrams, or students are required to draw a diagram after they complete the role-play activity. Photos of most of the celestial bodies which are discussed in the module are provided and two short videos on stars and galaxies are also included in the end. Teachers are expected to show the photos and videos in the classroom and to initiate appropriate discussions about them.

Digital activities

We used the multimedia principles of Mayer (2014) as guiding principles to design our digital content. All digital lessons are divided into two activities. In the first activity, students see animations. The animations include representations from different perspectives (to convey the three-dimensional nature of the systems) and mainly emphasize the motions of the celestial bodies. Some of the animations also morph into diagrams to help students see the correspondence between an animation and diagrams they regularly see in textbooks and classrooms. The second activity of the digital lesson includes a digital game called AstRoamer (divided into three parts, one part for each unit). The details of the digital activities are shown in Table 2.

Unit No.	Lesson No.	Activity 1: Animation	No. of Animations	Activity 2: Game	Astronomy Concept	No. of demos + No. of clues
1	3	Rotation of the earth	4	AstRoamer: What's the time	Rotation of the Earth and time of the day	1 + 7
2	7	The motion of the moon	3	AstRoamer: Moon Track	Phases of the moon	1 + 7
3	11	Solar System	4	AstRoamer: Planet Trek	characteristics of planets	0 + 10

Table 2: Details of the digital lessons

Apart from multimodality to facilitate the visuospatial thinking which is crucial in learning astronomy, three more guiding principles directed the design of the module: Collaborative Learning, Authentic learning and Learning from mistakes.

Collaborative Learning: Most activities in the module are to be done in pairs or groups. For example, in Roleplays students become different celestial bodies and mimic their motion. Given that the school labs have a limited number of computers (typically 10) and the number of students is at least 20, we expect that two students will use one computer when they are in the computer lab for the digital lessons. We have deliberately designed the first part of the digital game (AstRoamer: What Is the Time?) for two students to answer alternately so that students can discuss while solving the problems, and hope that it will set the trend for the rest of the activities.

Authentic Learning: India has a rich tradition of astronomy and has a variety of calendars (some are lunisolar some are lunar and some are solar). Since most of the festivals fall on a particular phase of the moon, students are well aware of the calendar used in their area. We tried to bring this aspect to the module by explaining terms used in the indigenous astronomy and designing the second part of the digital game (AstRoamer: Moon Track) around phases on different festivals. Incidentally, the terms used in indigenous astronomy and astrology are the same. We hoped that explaining them will demystify them and help students to think rationally about the astrological claims.

Learning from mistakes: In the digital game (AstRoamer), each trial has two chances. Case-specific feedback is designed which appears after the first wrong answer to help students find the correct answer. Teachers were also encouraged to ask open-ended questions to students and use their incorrect responses are resources to engage in the discussion rather than giving immediate feedback in terms of right or wrong.

STUDY PROCEDURE

For this study, we chose thirteen schools in Jaipur district with the following criteria of selection:

1. The number of students in the class was less than 40.
2. Computer lab had a minimum of 9 terminals working.
3. Schools were not too far from Jaipur to allow for classroom observations
4. Teachers were willing to participate: To ensure the authentic implementation of the module it was necessary that the teachers teach the module in their respective schools instead of allowing designers or experts to teach it.

The teachers from the selected treatment schools had access to the module on their school computers, and we also provided a hard copy of the support material two weeks before the study started. However, we anticipated that teachers would not be familiar with the module by the onset of the study and would also require on-site support. Prior to the study start date, we held a face to face workshop in which we took the teachers through half of the module in the same way the students would experience it. Out of 13 teachers who indicated interest in the study, only eight teachers attended this workshop, so we reduced our treatment sample to students in those eight schools.

Students completed a pre-test before the implementation of the module in their classes. The pre-test included 20 questions based on the content covered in the earlier grades or things that students would know from simple observations or social interactions (19 multiple choice questions, one question which required students to draw a diagram), 5 questions on attitudes towards science and astronomy and two questions related to beliefs regarding astronomy. In the next 6 working days, teachers were asked to teach the first six lessons of the module (approximately one each day). We held another workshop for teachers on the seventh working day to cover the remaining half of the module with them. We also shared pre-test results with the teachers and highlighted the major difficulties which their students faced. Seven out of the eight original teachers attended this workshop; thus we continued the study with those seven teachers and their respective schools, leaving data from seven participating schools for analysis. The study was concluded with the post-test and teacher interviews. The first 20 questions of the pre and post-test were equivalent; the post-test contained 5 extra questions on the content which was not taught in earlier grades but covered in the module. The study procedure is summarized in Table 3.

Teachers attended the first face-to-face workshop	
Student Pre-test	
* Teachers taught and students engaged in the Basic Astronomy module * Minimum two classes were observed by CLIx team member * Observed classes and teacher interviews were audio recorded	* A second face to face workshop for teachers was scheduled after half of the module was implemented (i.e. on the 7th working day). * The total number of working days between the pre and post-test (excluding the days of workshop) was 11 or 12 (typically included 12 lessons).
Student Post-test	

Table 3: Study Procedure

The study also included a control group but we have not included that part of the study considering the limited scope of this paper. The procedure and findings of the larger study are documented in more detail in TISS (2019).

SAMPLE

Grade 9 students of seven government schools from the Jaipur district of Rajasthan, India participated in the present study (school wise breakdown is displayed in Table 4). There were a total of 243 students, 106 boys and 137 girls, who participated in the study. The age of the students was between 13 to 15 years, and most of them came from low socio-economic areas. All participating schools were from rural areas of Rajasthan. The medium of instruction in all of the schools was Hindi. However, all students spoke a dialect of Hindi called Rajasthani when not in the classroom; inside the classroom most of the time they spoke in ‘standard’ Hindi.

School	Students		Total Number of Students	Teacher
School A	10 Boys	11 Girls	21	1 Female
School B	19 Boys	23 Girls	42	1 Male
School C	26 Boys	22 Girls	48	1 Male
School D	17 Boys	22 Girls	39	1 Female
School E	0 Boys	25 Girls	25	1 Female
School F	25 Boys	16 Girls	41	1 Male
School G	09 Boys	18 Girls	27	1 Female
Total	106 Boys	137 Girls	243	4 Female, 3 Male

Table 4: Sample details

A total of seven teachers, 4 females and 3 males, participated in the study. They all taught science subjects to grade 9 students. None of them had a physics background, some of them studied biology, and others studied chemistry during their graduation. Every year they were required to teach a chapter on basic astronomy to grade 9 students as it is part of their syllabus. Both students and teachers had rich cultural knowledge of several astronomical phenomena as there are many stories, rituals, and festivals around those phenomena.

Q. no.	Question
1	Every day at noon, the Sun is exactly overhead
2	The Moon does not rotate around its own axis
3	Saturn can be seen by the naked eye (without a telescope)
4	Planets which are closer to the Sun take more time to complete one revolution than the planets which are farther away from the Sun
5	Day and night occur because-
6	Seasons occur on the Earth because-
7	Which of these pictures is NOT a phase of the Moon?
8	The Moon rises from-
9	Mark the picture which shows the position of the sun, earth and moon at a full m oon
10	Which force is responsible for the Moon to revolve around the Earth?
11	The period from New Moon to Full Moon is called-
12	In what phase is the Moon on Diwali night?
13	Which is the brightest star in the night sky?
14	The asteroid belt is situated in between-
15	Which is the correct order from the smallest to the largest in size?
16	Which is the correct order from the nearest to the farthest from the Earth?
17	Which of the following objects produces its own light?
18	Which of the following is not part of our Solar System?
19	Which of the following is the name of a nakshatra (lunar mansion)?

Table 5: Details of questions used in figure 2

ANALYSIS AND RESULTS

This paper presents an analysis of students' pre and post-test data. Out of the 243 participating students, 169 students took both the pre and post-tests, so we included only 169 students in the statistical analysis. A dependent samples t-test was conducted to determine if students' understanding of astronomy improved after completing the module. We found that student performance on the basic astronomy test improved from pre-test (33.31%) to post-test (46.58%) and it was statistically significant ($p<.001$) with an effect size of 0.81.

A breakdown of the test questions that were similar showed that out of 20 questions, students' performance in 13 questions showed more than 10% improvement, performance in 5 questions showed no improvement (+ or - 5%), and performance in 2 questions showed negative improvement (approximately 10% or more). Figure 2 shows the change from pre to post-test for each question.

The pre and post-tests also had questions to probe students' attitudes and beliefs. As shown in Figure 3, students' attitudes toward science and specifically toward astronomy did change. Students reported slightly more positive views toward science after the intervention, in that fewer students strongly disagreed with the statement, "I enjoy learning science". Additionally, fewer students disagreed and more students agreed with the statement saying that science should be used when making decisions in everyday life, which suggests that students saw value in science even though some of them did not enjoy learning science. After completing the module, students indicated an increased interest in astronomy to the extent that some of them want to continue learning astronomy even after graduating from the school. More students said they would like to engage in astronomy related activities after completing the module (Figure 4). The number of students who said they did not like astronomy decreased slightly.

The module failed to have any impact on students' beliefs about the impact of astronomy on their life. At three different places, students reported that they think planets have an impact on their lives, eclipses are bad omens, or that they engage in making horoscopes and astrology (Figure 4, option D and Figure 5)

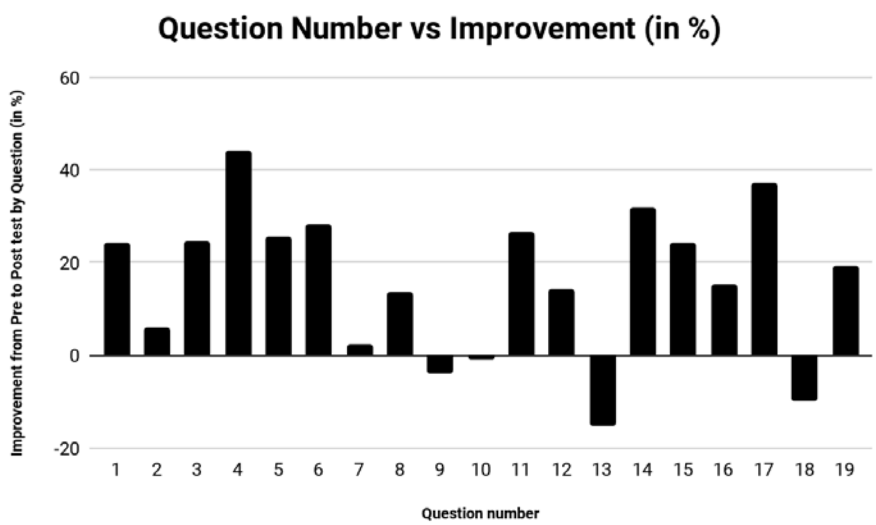

Figure 2: Question number vs Improvement from Pre to Post-test by Question. (Details of the questions are in table above)

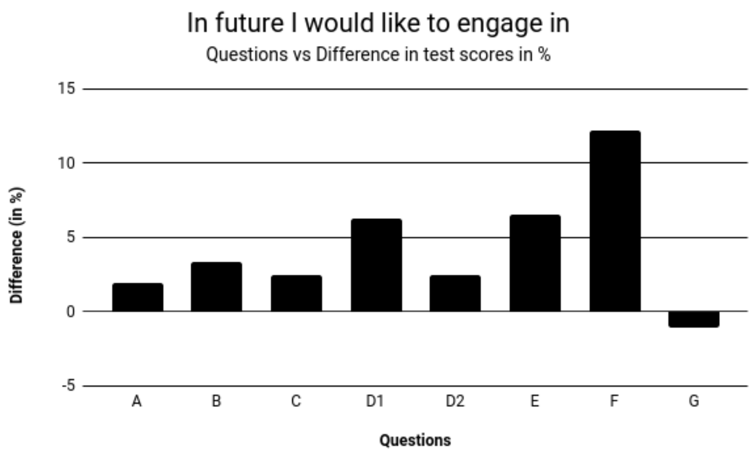

Figure 3: Students response to the following five questions regarding attitudes towards science and astronomy: A. I enjoy learning science, B. Scientific thinking should be used in taking decisions in everyday life, C. I find astronomy interesting, D. I would like to continue to learn astronomy in college (after 10th grade)

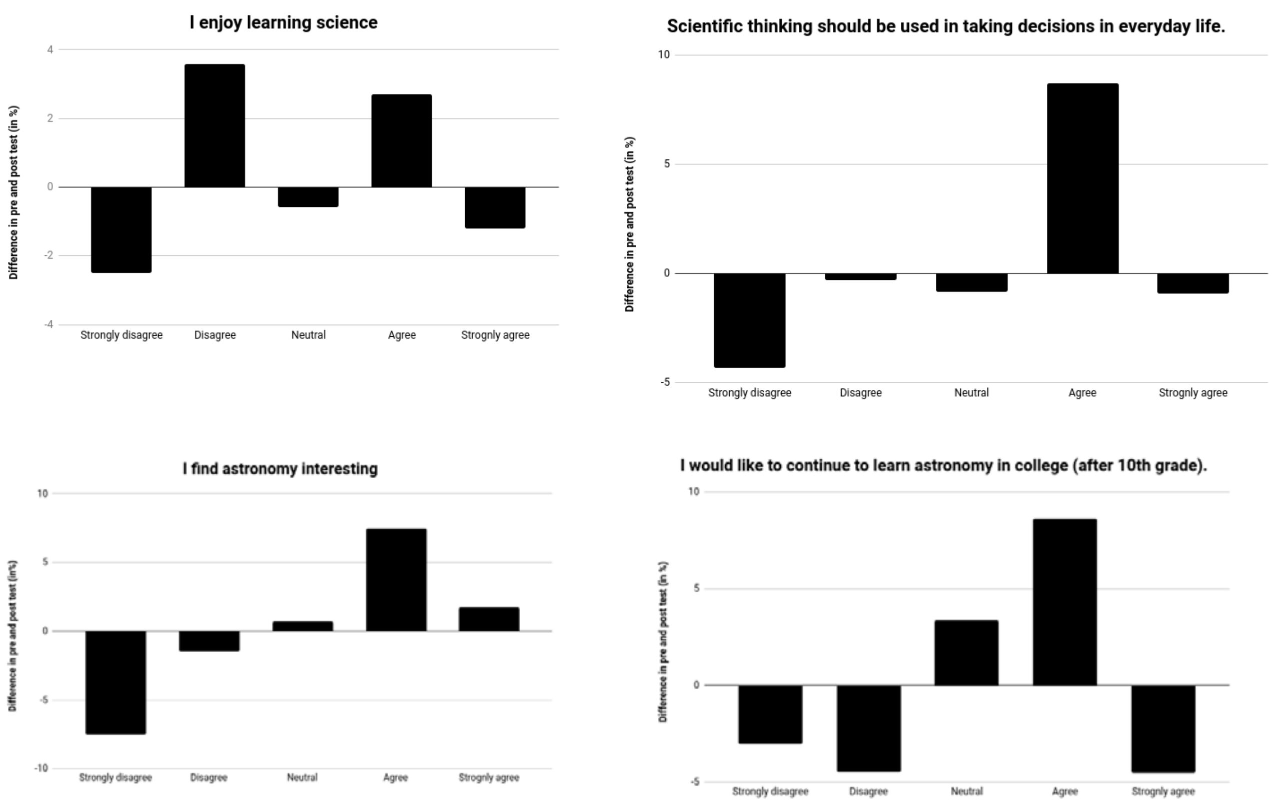

Figure 4: Students response to the question ‘ In future I would like to engage in:’. (Options: A. Observations of the moon, sun, stars and other astronomical objects, B. Learn more about different theories such as the formation of stars and solar system, C. Drawing pictures and making films about astronomy, D1. Preparing telescopes, satellites and other instruments, D2. Horoscopes and astrology, E. Doing calculations of orbits, energy etc, F. Studying how astronomy was developed in different parts of the world, G. Not interested in astronomy)

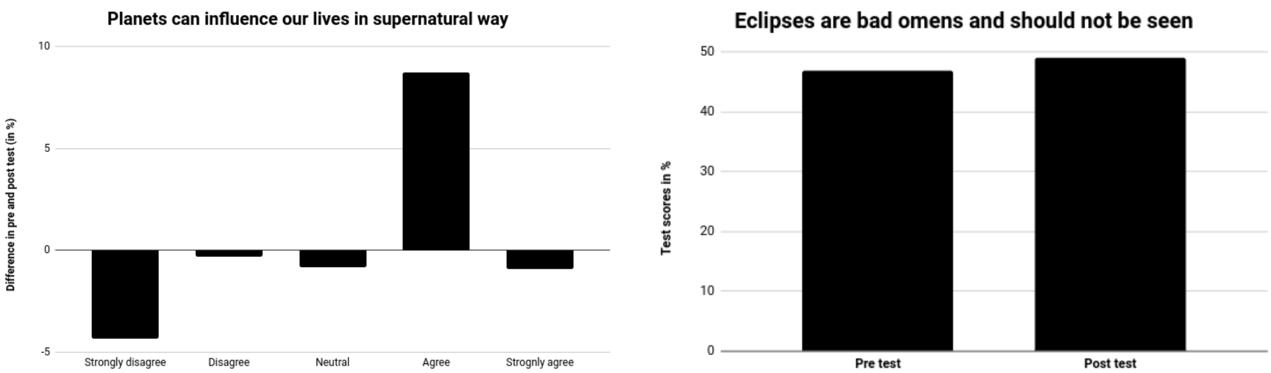

Figure 5: Students response to the following questions regarding beliefs: A. Planets can influence our lives in a supernatural way. B. Eclipses are bad omens and should not be seen

CONCLUSION AND DISCUSSION

A 'Basic Astronomy' module was designed to teach important astronomy concepts to students. The aim of this study was to investigate the impact of the module in changing students conceptual understanding, attitudes, and beliefs. A significant improvement in students' scores shows the module's effectiveness and robustness in the field. The module was also successful in changing some of the students' reported attitudes and beliefs towards science in general and astronomy. After engaging with the module, students reported positive changes in attitude toward science and astronomy, and reported increased interest in astronomy related activities. But such changes were not reported in the case of beliefs. More specifically, the beliefs which are part of the culture - the beliefs related to astrology— were not changed. It seems that such deeply held beliefs cannot be changed just by improved conceptual understanding, or change in another related belief. For example, after doing the module, more students believed that science should be used in everyday decision making but students did not view this as a conflict with making decisions related to astrology.

Lelliott & Rollnick (2010) mentioned in their extensive review that most studies in astronomy education do not refer to any particular framework. The study and other similar studies are significant because they systematically derive pedagogic ideas from an emerging framework such as embodied cognition and provide evidence of its effectiveness which in turn confirms the merit of an emerging cognitive theory. Furthermore, although many innovative pedagogies are effective in controlled settings, scaling them is challenging, particularly in disadvantaged settings. These results are important because they demonstrate that innovative pedagogies can be designed and implemented with the help of technology. It must be noted that four of the authors on this paper worked extensively with the teachers for more than three weeks to prepare them to implement this module and teachers spent considerable amount of time and efforts to improve their content and pedagogic content knowledge, but that will be the topic of another article. However, it is worth mentioning that the teachers who were initially skeptical about this new (and somewhat time consuming) pedagogy, were thrilled after going through the experience. We hope that both cognitive theories and educational technology will find practical applications through pedagogies designed for large scale implementation and the coming years will see more papers which document the challenges faced during implementation, their practical solutions and data from disadvantaged - or rather, differently advantaged - settings.

REFERENCES

Abell, S. K. (2007) Research on science teacher knowledge. *Handbook of Research on Science Education*. Abell, S. K and Lederman, N. G. (Eds.) 1105-1149.

Ainsworth, S., Prain, V., & Tyler, R. (2011). Drawing to learn in science. *Science, 333,* 1096-1097.

Bailey, J. M., Prather, E. E., and Slater, T. F. (2004). Reflecting on the summary of astronomy education research to plan for the future. *Advances in space research,* 34:2136 – 2144.

Chopde, S., Padalkar, S 2017. Astronomy Education: A Case for Blended Learning. *Paper presented at National Conference on ICT in Education Perspectives, Practices and Possibilities, Mysuru, Swami Vivekananda Youth Movement,* 11th-12th May 2017.

Crowder, E. M. (1996). Gestures at work in sense-making science talk. *Journal of the Learning Sciences, 5*(3), 173–208.

Kikas, E. (2006) The Effect of Verbal and Visuo-Spatial Abilities on the Development of Knowledge of the Earth. *Research in Science Education,* 36: 269–283.

Lelliott, A., & Rollnick, M. (2010). Big ideas: A review of astronomy education research 1974–2008. *International Journal of Science Education*, 32(13), 1771-1799.

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), Cambridge handbooks in psychology. *The Cambridge handbook of multimedia learning (pp. 43-71)*. New York, NY, US: Cambridge University Press.

Mishra, P. (1999). The role of abstraction in scientific illustration: Implications for pedagogy. *Journal of Visual Literacy*, 19 (2): 139-158.

Padalkar, S. and Ramadas, J. (2008). Indian students' understanding of astronomy. *In Electronic Proceedings of Conference of Asian Science Education (CASE2008),* Kaohsiung, Taiwan, February, 2008.

Padalkar, S. and Ramadas, J. (2010). Designed and spontaneous gestures in elementary astronomy education. *International Journal of Science Education.* 33(12), 1703-1739. DOI:10.1080/09500693.2010.520348

Padalkar, S. (2011). Visualization and Spatial Cognition in Elementary Astronomy Education. Unpublished Ph.D. Thesis.

Plummer, J. D., Kocareli A., & Slagle C. (2014) Learning to Explain Astronomy Across Moving Frames of Reference: Exploring the role of classroom and planetarium-based instructional contexts, *International Journal* *of Science Education*, 36:7, 1083-1106

Raza, G., Singh, S., and Dutt, B. (2002). Public science and cultural distance. *Science Communication*, 23(3):293 – 309.

Shaikh, R., Chopde, S., & Padalkar, S. (2018). Teaching and Learning Basic Astronomy Through a Blended Module. In Hye-Jung Lee ((Eds.), *Proceedings of the 8th Annual International Conference on Education and E-Learning (EeL) 2018*, *Singapore*, *127–133*. Singapore: Global Science and Technology Forum (GSTM).

Subramaniam, K. and Padalkar, S. (2009). Visualisation and reasoning in explaining the phases of the moon. *International Journal of Science Education*, 31 (3), 395-417.

TISS (2019) Unpublished Report on Learning Outcomes of CLIx Student Modules available at https://clix.tiss.edu/wp-content/uploads/2015/09/LO_Report-2019.pdf

Venkateswaran, T.V. and Gupta, A. (2009) *Basics of Astronomy through Role Play: Handbook for science activists and teachers.* Bharat Gyan Vigyan Samithi, New Delhi.

Vosniadou, S. and Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24:535–585.

Vosniadou, S. and Brewer, W. F. (1994). Mental models of the day/ night cycle. *Cognitive Science*, 18:123–183.