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Unpacking students' modelling behaviour in the Sun-Earth system: Use of digital media tool-based epistemological resources

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Abstract: Understanding scientific models described using external representations is an important objective of science education. However, modelling and reasoning using models are not easy for students due to inaccessible phenomena or abstracted/ idealized nature of the models. Learners rely on various epistemological resources to make sense and meaning of the models in any given context. However, the underlying processes and the interplay of these resources in the process of constructing and reasoning with these models are not completely understood. We use the case of the Sun-Earth system to unravel these dynamics, by a detailed study of 4 undergraduate (UG) science students, using questionnaires and interviews around interactions with a digital media tool (designed by us). The results throw some light on the dynamics of students' use of various epistemological resources (lived experiences, book-based, and tool-based experiences) in their process to construct models and reason with them. We also illustrate, in this process, a potential role of digital media interfaces in providing epistemic access to the inaccessible by being an epistemological resource of a new kind.

Keywords: modelling, digital media, sun-earth system, epistemological resources

1. Introduction

Models are used in science to describe or explain a physical phenomenon, by standing for relation with the phenomenon. They capture the structural relationship (five structure-types (Hestenes, 2010)) between the various components of the physical system. These components of a physical system (e.g. idealised moving mass) are abstracted or idealised features of the physical phenomenon (e.g. mass or acceleration as abstracted components of a real moving object, and the object idealised as a point mass) (Suppe, 1989; Suppes, 1960). These models take the form of external representations: physical models, spatial representations like diagrams, linguistic or mathematical formulations like statements or equations, simulations etc.

From a science education perspective, it is often difficult for learners to make sense of the epistemic role of the models and their relationship with the modelled. Furthermore, the process of systematic modelling (creating, testing and revising models as a community), a defining practice in science (Giere, 1988; Nersessian, 2002), does not reflect in the science learning (Lehrer & Schauble, 2010) in our current educational systems. Besides limited understanding of the nature of science among teachers, epistemic inaccessibility could be a key source of difficulties for the students in understanding and using the models effectively. The phenomena that are modelled in the science are often not immediately accessible to our sensorimotor system (e.g. phenomena at the subatomic level or cosmological level) (Pande, 2018) and the models themselves often represent abstracted or idealised components (minimised by removing non-relevant features e.g. texture or colour of the mass); hence they are not epistemically accessible.

Shifts in educational research from a deficit (like misconceptions) to a resources model (epistemological resources) (e.g. Hammer & Elby, 2003; Smith et al., 1994) acknowledges students' lived experiences of these phenomena, among others, as a valuable resource in their reasoning and learning. The experience of students with models of these phenomena through textbooks and classroom discourse can also be seen as a kind of epistemological resource. It is reasonable to assume that learners would deploy various epistemological resources at their disposal in the process of learning about or understanding a scientific model. However, there is very limited understanding of the underlying processes and the interplay of these resources in the process of constructing and reasoning with models. This study attempts to unpack these processes using a particular case of the Sun-Earth system (elaborated in section-2).

Towards this objective of unpacking the modelling behaviour and the interplay of various epistemological resources in the case of the Sun-Earth system, we use a digital media tool as a probe and as a *tool-based epistemological resource*. We take advantage of the potential of digital (or computational) media (Balacheff & Kaput, 1996; Papert, 1980) in enabling a better understanding of models by affording (Gibsonian sense (Heft, 1989)) novel sensorimotor interactions, thereby providing epistemic access (Karnam et al., 2019) to the models (epistemic availability (O'Donovan-Anderson, 1997)). We describe the digital media carefully designed to enrich experiences and trigger modelling behaviour in learners' about the Sun-Earth system in section-3. We report a study (in section-4) involving a detailed examination of the modelling behaviour (and use of various epistemological resources) in learners (UG Physics students) triggered by the digital media design. This examination would throw some light on the nuances of the underlying dynamics, possibly provide novel perspectives for learning scientists that have implications for future digital media designs.

2. Learning of Sun-Earth system

The Sun-Earth system provides an apt context to study modelling behaviour for at least 3 strong reasons. Firstly, astronomical phenomena have always fascinated the human mind and historically appears to have been among the first that humankind modelled in nature, as reflected in cultural narratives about astronomy across civilizations. For us, the Sun-Earth system provides a very rich context to unravel the modelling behaviour, because of its direct visuospatial and dynamic nature; the model of the Sun-Earth system is a model of the spatial and dynamic (moving) relation of the elements (the Sun, the Earth) in space. This direct one-to-one mapping between the elements of the model and the phenomenon significantly simplifies the complexity involved in unpacking the modelling processes in human minds.

Secondly, the elements of the Sun-Earth system have a strong real-world context to the learners and hence an attribute of concreteness. Learners across age groups, in their daily physical interactions, encounter and have meaningful relations with these elements. Further, the related phenomena of day-night and the seasons have direct and immediate salience and hence are perceptible to us. This is unlike other cases like atoms or plant/animal cells, which are epistemically distanced from the learner's lived experiences. We assume that it is more probable for a learner to have meaningful real-life encounters with at least the Sun (if not with the Earth) as an entity, than with, say plant cells or electrons in an atom of an object; even if they interact with objects and plants, the notion of an atom and cell as an entity, is still inaccessible. Thus, this topic is accessible and simple to study due to the lived experiences of the modelled phenomenon.

Lastly, from a more practical standpoint, the Sun-Earth and moon system is a topic well studied in education research (perhaps this was in turn because of the above two reasons). The studies range from those which highlight the alternate conceptions to those analysing the conceptual aspects of the system and those providing various interventions. The section-2.1 provides a quick review of the existing literature on the aspects explored about the Sun-Earth system and related phenomenon (like day-night and seasons) and the existing ways of teaching and learning this topic and the interventions. The moon could also have been incorporated in our study, but we chose to stick to the simplest model and simplest phenomenon to look at the process's underlying modelling behaviour and interaction between various aspects (formal representations, real-world experiences etc.) and creation of models.

2.1 A brief review of research related to the Sun-Earth like systems

Students are found to hold numerous models about the Earth (five mental models like being in the Earth, flat Earth, out of Earth etc.), Sun-Earth system (versions of geo-centricity) and related phenomena like day-night (Chiras, 2008; Samarapungavan et al., 1996; Vosniadou & Brewer, 1992, 1994) and seasons. The Sun-Earth-Moon system (Jones et al., 1987), Earth and space (Schoon, 1992) and overall astronomical understanding of children (Baxter, 1989; Schoultz et al., 2001; Trumper, 2001) have also been widely examined. Numerous interventions have been suggested in various forms such as (1) learner cognition driven ones like those based on inquiry-based learning (Salierno et al., 2005), mental model-based strategies (Taylor et al., 2003), gestural instruction (Padalkar & Ramadas, 2011); (2) technology-based ones like AR and VR interventions (Bakas & Mikropoulos, 2003; Shelton & Hedley, 2002); (3) pedagogical/ course interventions as diverse as conversation-based ones about the moon with Japanese teachers (Suzuki, 2003), engineering design-based engagement (Dankenbring & Capobianco, 2016) (given the recent push for engineering sciences in the US), among others. However, a careful and detailed explanation of students' current understanding from a modelling perspective is not satisfactorily provided. This study of unpacking modelling behaviour in the context of the Sun-Earth system could thus be a mutually useful and insightful exercise to the audience of astronomy education and audience interested in modelling in general.

3. The Digital Media tool

The standard Sun-Earth model geometrically captures the relative position and motion of a tilted Earth and the Sun. This models the movement of the Sun as observed from Earth and other phenomena like day-length, shadow and seasons. It is often difficult for learners to imagine the spatial dynamics and meaningfully linking the model with the observed phenomena using the static pictures in books. Digital media tools (hereafter referred to as just tools, unless specified otherwise) can address both the difficulties by dynamically linking multiple perspectives. They also afford experimentation and exploration of different scenarios, thus enriching their modelling experiences of phenomena, which are often epistemically inaccessible.

Different tools focus on different parts of the difficulty with understanding and reasoning about the Sun-Earth system. For example, 'Sun Position' app on Google Playstore shows the Sun's trajectory in Augmented Reality; '3D Sun-Path' shows the 3D trajectory of the Sun as viewed from different places on Earth (http://andrewmarsh.com/software/sunpath3d-web/). Both these systems allow exploring the phenomena but do not directly support developing an explanatory model. The Season's Simulator (NAAP) provides multiple perspectives of the Sun-Earth model; it supports basic causal reasoning but is not sufficient to build and explore the geometrical model. To suit our modelling requirements, we custom-designed a tool informed by design recommendations based on multiple external representations (e.g. Pande, 2018; Virk et al., 2015) trying to address the above shortcomings.

3.1 The Design

The design requirements were to provide affordances to explore phenomena in multiple perspectives, which are tightly interlinked. The design is broadly informed by the 4E models of cognition, which emphasize the 'constitutive' role of sensorimotor interactions between the body and the environment in shaping the cognition (and imagine using models in our case) (e.g. Glenberg, 2010; Hutchins, 1995; Sterelny, 2004; Thelen & Smith, 1996; Van Gelder, 1999). The design should be able to provide meaningful experiences of the usually inaccessible phenomena and the underlying abstract models. These experiences along with other experiences can thus trigger the imagination of the dynamics, and facilitate grounded conversations about the intricacies of the Sun-Earth system and the related phenomena.

The tool was built using the Unity Engine. The NREL's Solar Position Algorithm (SPA) was used to provide the values of azimuthal and incidence angles for a given position and time. It has 3 different interlinked views (see figure-1) presented in 3 view-panels.

- The first view or orbital view (top): This panel dynamically captures the geometric constraints of the model showcasing a tilted Earth rotating around its axis and simultaneously revolving around the Sun. The Sun is static and the Earth's axis and path are displayed. This perspective typically present in textbooks (as a picture) stands for the formal representation that learners could have experienced in their classrooms.

- The second view or out-of-Earth view (bottom left): This panel takes the position of an observer hovering just above the Earth, which was not present in the tools we came across. The Earth's axis, the normal at a given place, the sunrays and the geographical north are marked as arrows. This acts as a bridge between the faraway orbital (first) view, and the on-Earth (third) view, connecting which could be difficult due to the differences in the scale.
- The third view or on-Earth view (bottom right): This panel corresponds to the lived perceptual experience of seeing the Sun move across the sky. The geographical directions, the sunrays and the normal are displayed as arrows, and the Sun's trajectory is shown by a yellow arc across the sky. This view with a house and changing shadow could connect to the learners' lived experiences.

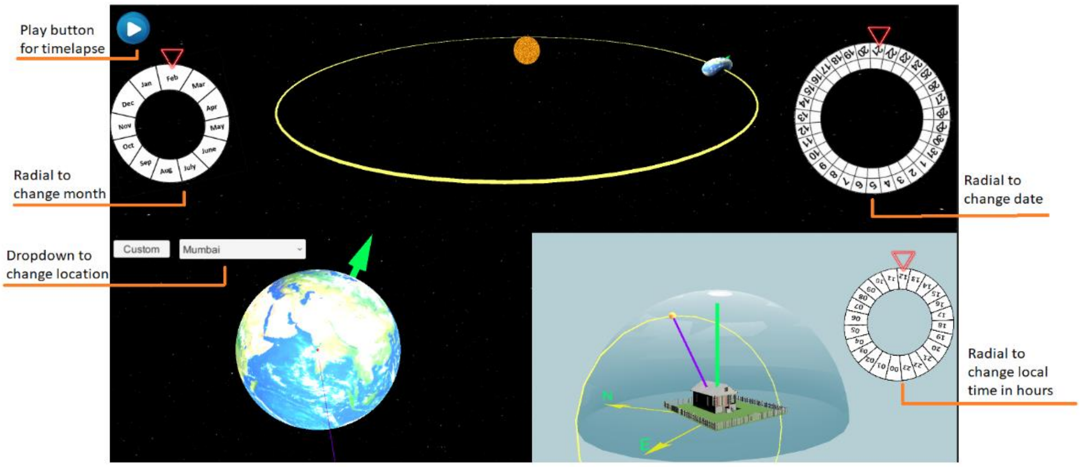

Figure 1. The three views: the first view or orbital view (top central), the second view or out-of-Earth view (bottom left), the third view or on-Earth view (bottom right); and the interaction affordances).

The interface has controls for changing the various parameters involved. Users can change the location on Earth for which the observations have to be made. The date and time can be changed to account for changes across the year. A play button was added to automatically increment the hour (Figure-1).

In the first view (top) the orbital position of Earth changes with a change in the day of the year. The axial tilt remains constant throughout; making it easy to observe that the northern and southern hemispheres are not equally lit throughout the year. This would be crucial for making sense of the differences in the Sun's trajectories and seasonal patterns in the northern and southern hemispheres. This view emphasizes that if the Sun is taken as the reference, the sunlight incident on Earth does not change its direction significantly in a day (24 hours). Therefore all the changes in the Sun's position during the day must be due to a change in Earth's rotation. Appropriate lighting effects ensure that half of the Earth facing the Sun is lit up while the other half is dark. The third view (bottom right) shows the position of the Sun in the sky at any given location, time, day of the year. The trajectory of the Sun for the entire day is also visible. This makes the change in the Sun's trajectory easier to observe. According to the change in position of the Sun, the shadow cast by the house also changes. This view supports panning, rotating and zooming to provide rich nuanced observations. The second view (bottom left) shows the corresponding location on Earth.

Transitioning between views happens via carefully designed inter-perspective elements. The part of the Earth lit in the top view is the same that is lit in the bottom left (second) view. The purple line shows the direction of the sunlight in second and third views. Two green arrows in the same view show the normal at that location and the north direction. These 3 lines are also provided in the bottom-right (third) view. Further, the Sun's position is seen from the on-Earth (i.e. third) view which also supports panning, zooming and rotating. These views and the inter-perspective elements change in real-time with the changes in the time, date and location, providing dynamically linked multiple perspectives.

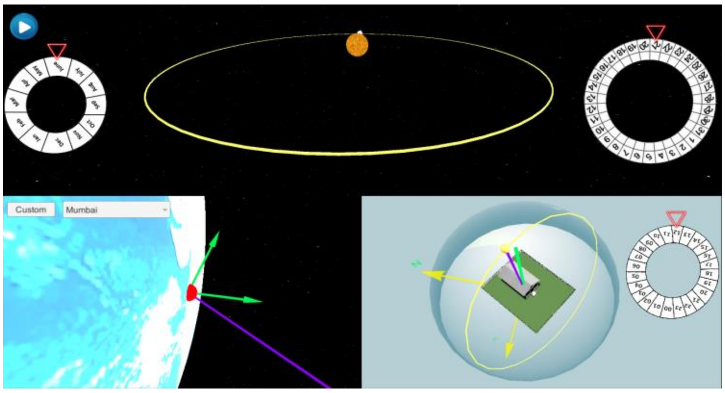

Figure 2. Exploring a scenario.

Further, the three views together provide powerful investigation (exploration and experimentation) opportunities for the learners. For example, figure 2 shows a scenario. On June 21 (summer solstice), at noon in Mumbai, the second view indicates the angle of sun rays (purple) with the normal (green). This angle is a direct result of the position of Earth in the orbit around the Sun and its rotation around itself. The time and date parameters in the first view determine the angle of the Sun's ray in the second view. As the time is changed, the Earth can be seen rotating in the first view, the direction of sun rays (purple arrow) can be seen changing in the second view. The third view extends the second view by providing the on-Earth perception of the above changes; the changing angles in the second view are directly reflected in the third view. Thus, the position of the Earth in its orbit and its angle of the rotation completely determine the Sun's position in the third view. This was one of the design requirements we started with.

These features of dynamically interlinked multiple perspectives affording powerful investigations can provide well-structured and rich modelling experiences to the learners. This thus can act as a new kind of epistemological resource, which we refer to as a *tool-based resource*, in this paper.

4. The study

The study aims to unpack the interplay of various epistemological resources in students' modelling behaviour. We used the above tool along with a set of questionnaires and interviews to trigger and examine modelling behaviour in students about the Sun-Earth system.

4.1 Methodology: Participants, Material and protocol

The participants were 4 UG Physics students (S1-S4). They were administered a written test (with an opportunity to describe their responses using text as well as diagrams). This was followed by a series of tasks with our tool and some conversations during the tasks. The participants worked in groups for these tasks. Each group spent about 1.5 hours interacting with the system. After 2 weeks, they were administered the same written test again. They were interviewed (students S1, S2, S3 together and, S4 one-to-one due to logistical constraints) in the context of their test responses to capture their modelling behaviour and the interplay of various epistemological resources. The usage of the pre and post-tests allowed us to capture changes in their modelling behaviour longitudinally and gave a better grasp on the dynamics in their reasoning supported by the tool, as an additional epistemological resource.

The tests had questions (they can explain using text and diagrams and later elaborate during the interviews) exploring their reasoning about the day-night lengths, seasons and the changes in them with time (of the year) and location on Earth. The tasks on the digital media tool were exploratory and open-ended and tried to put the students into situations that triggered their mental models about the motion of the Sun. Some of these tasks were: (a) observe if the direction of sunrise and sunset changes for a given location through the year; (b) is the Sun directly overhead at noon on all days? Create a directly overhead Sun for some locations; (c) look for patterns of change in the trajectory as we move from the equator to the poles.

4.2 Analysis Framework

The written scripts and the conversations recorded during interviews were analysed for the modelling behaviour and interplay of various epistemological resources. This involved tracking the usage of various epistemological resources in their reasoning through conversations. To do this, we sliced the data into streams of conversations called *lines of reasoning (LOR).* Any continuous flow of utterances anchored to a particular context or topic of conversation can become the unit of analysis, the LOR. These lines of reasoning (LORs) are dynamically constructed in real-time by an individual in the context of the conversation deploying various epistemological resources; these correspond to underlying processes of construction and manipulation of mental models (aspects of modelling behaviour). These dynamics are inferred from the sets of articulations (drawings and words) and gesticulations (gestures) as they reason and communicate. The epistemological resources for learners in our case could be broadly categorised as:

- *lived experiential resources:* from students' lived experiences with Sun-Earth - indicated by references to their experiences (e.g. observations of Sun, shadows while travelling or at their house or colleges etc.) and related extensions.
- *book-based resources:* from formal sources of science - indicated by references to textbooks, etc. (e.g. use of terminology or diagrams in their textbooks or scientific discourse etc.) and related extensions.
- *tool-based resources:* the experiences while doing tasks on the tool - indicated by references to the elements in the tool and the experiences with the tool and related extensions.

Different resources can play different kinds of roles in shaping their reasoning in a particular situation and reflect in their modelling behaviour. Here, we could operationalise desirable modelling behaviour as an ability to coherently use and apply different resources, and progressively create, test and revise one's mental models. This locally coherent integrated model is referred to as an epistemological frame (Elby & Hammer, 2010).

The quality of the students' modelling behaviour is tightly linked to the coherence of underlying mental models that are dynamically constructed, tested and manipulated as they reason. This is reflected in the coherence of LORs ─ the meaningfully connected streams of utterances in the conversations. Students put epistemic efforts to ensure this coherence, deploying multiple resources at their disposal, striving to resolve any inconsistency or cognitive conflicts. So, coherence of LORs can be a good indicator of the quality of modelling behaviour and any personal reconciliation can be a potential marker of meaningful learning.

5. Analysis, Findings and Discussion

We analysed the post-test interviews and the written scripts of the students for patterns in their modelling behaviour by transcribing the videos with descriptions of utterances (speech, gestures and drawings). These are iteratively organised into meaningful streams (series of episodes) of conversations as LORs. Then we reflected and inferred possible epistemological resources applied in this reasoning process based on the indicators previously outlined. There are certain situations, where the learners could engage in a conversation with coherent lines of reasoning. And there were certain other situations where they became less systematic and appear to lose track of a LOR; such situations had cases where they were throwing scientific terms (from book-based resources). We report some of such episodes, in detail, unpacking the dynamics below. In this paper, we confine to illustrating an initial application of the above analysis framework to some episodes, indicate some patterns of the interplay of various epistemological resources and highlight the usage of digital media interface as a tool-based epistemological resource; detailed analysis is in progress.

5.1 Deployment of various epistemological resources in Coherent Modelling Behaviour

While explaining the formation of zero-shadow (or overhead Sun position), S1 indicated the Sun rising and setting with his large semi-circular hand movements from one end to the other (indicating his current imagination) (see Figure 3). A corresponding explanation was also found when he drew the typical semi-circular figure from their textbook (see right of figure-4). S1’s gestures can be ascribed to interconnecting the book-based resources (diagram) as well as the lived experiential resources of typical Sun’s trajectory.

Both S1 and S4 used the angle between the normal and the sun rays (tool-based resources in the third view) in their reasoning, as indicated by gestures (palms orientated in a particular way corresponding to the arrows) as well as the drawings (Figure 4). These two arrows are found to provide them with very strong conceptual tools to reason about the formation of shadow (something to anchor upon similar to the attentional anchors (Abrahamson & Sánchez-García, 2016)). Here they could apply various epistemological resources (including tool-based ones) effectively. The LOR was coherent as long as they reasoned about the shadow in a given location.

Figure 3. S1 showing Sun’s movements- Sun at the top (left); Sun moving from East to West (his left to right) (mid); Sun setting (right).

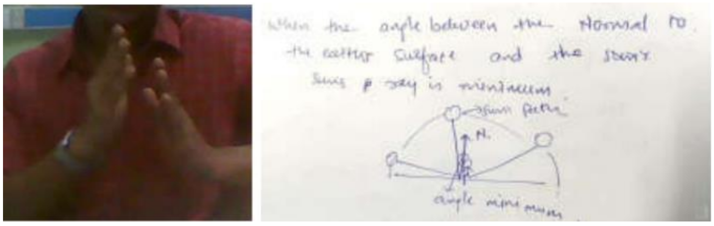

Figure 4. S4 showing using his palms (left) and S1’s response in the test (right) indicating using normal and the direction of Sun rays in their reasoning.

5.2 Deployment of various epistemological resources in Incoherent Modelling Behaviour

However, an extension of the above LOR — about zero-shadow in a given location — to different locations did not happen effectively. For example, S3 said zero-shadow will happen everywhere at least on one day in the year. When we pursued this LOR, it started getting incoherent. He then employed the conceptual tools of the normal and sun rays (tool-based resources, which has worked in the last situation) in an attempt to get a grip on it. S2 intervened and said ‘this does not happen everywhere, but only near the Tropic of Cancer’ (recollecting the experiences during the tasks hence as a tool-based resource as well as a possible book-based resource due to the reference to the Tropic of Cancer). This LOR is shaky and incoherent as reflected in S2’s tentative statements like ‘(near the tropic of cancer) the angle (between normal and Sun’s rays) is less and (hence) higher chances (for zero shadow)’. Here we can see the tool-based resources deployed to some effect, but the LOR is not very coherent yet, and nor is the underlying mental model.

Later, when they tried to resolve the confusion, S3 brought in the idea of equinoxes (book-based resources). He tried to make a connection between the longest day and the Sun being exactly overhead (or zero-shadow) and when asked, he was able to justify by gesturing and saying that the Sun rises exactly in the East and sets exactly in the West (his gestures indicated he was meaning the plane of the Sun’s trajectory does not tilt towards North or South directions). Here, he was deploying the tool-based resource – the visualisation of the Sun’s trajectory in the third view – in his LOR. But, he too could not coherently extend the reasoning to the shift with latitudes and used terms like ‘zenith’ incoherently. In a similar situation when LORs broke, S4 (interviewed one-to-one) too used terms like equinoxes and solstices (both of them are book-based resources).

Eventually, jumping some steps of reasoning, S2 and S3 concluded that the zero-shadow is possible only on the Tropic of Cancer and Tropic of Capricorn. A break in the LOR was evident when S1, who was there in the discussion but could not participate, said – “actually when there was the tool (earlier), I understood clearly. But now I am confused, as a lot of terms are used”. After some reflection, he attempted to reconcile the break in the LOR by recollecting the task using the tool: with Mumbai as the location, by changing the days, the plane of the Sun's trajectory was coming closer and farther from the normal, and they could not get an exact zero shadow. Here he could sense a broken LOR and when explicitly asked, tried to reconcile using tool-based resources. Though the tool helped in reconciling the broken LOR, the mental model is still incoherent; this indicates the way a digital media design could provide epistemic access by providing a new kind of epistemological resource and triggering imagination, especially useful for the learners.

To explain seasons, they continued the LOR from overhead shadow (with the Sun's trajectories) and connected it with the day-length (long days in summer and short days in winter-looking at the changing length of the Sun's trajectories: tool-based resources). S3 extended this by bringing in resources from the topic of heat and explained, the days are longer and hence more heat. However, when we asked S3 on how he connected this with the elliptical orbit (another representation used to model, that he drew in his written script), he drew the conventional Sun-Earth elliptical orbit diagram (book-based resource) and gave the distance-based explanation (Earth being close to the Sun in summer and farther away in winter). At this point, all of them were confused in explaining different seasons in the hemisphere at any given time and fell back on the Sun's trajectory-based description for explaining. This captures interesting friction in the process of testing and integration of resources from two different sources about the same physical phenomenon. They could not coherently construct the LOR starting from the changes in Sun's trajectory from the third view of the tool to the seasons interconnecting the tilt of Earth, and eventually fall-back on the distance-based explanation.

Figure 5. S1 and S2 explaining 6-month long day-night at poles.

5.3 Other observations

See Figure 5. In another conversation related to day and night at poles, S1 explained using a pen in a fist as Earth and its tilted axis and shows the way the North Pole receives sunlight for 6 months and then the South Pole (which was discussed while using the tool). S4 indicated the Sun's trajectory with his finger precisely explaining the 6 month-long daylight at the pole (North). This is something that they have tried on the tool (tool-based resources). Interestingly, the lived-experiential resources were not indicated much. So, when explicitly asked how much they used their lived experiential resources when answering these or during the 2-week break after their interaction with the tool, S1 and S4 said that they had observed the phenomena of shadow (overhead Sun) and sunrise time earlier too but never bothered to pursue them further and connect with what they were taught in their schools.

6. Conclusion

The above episodes of both coherent and incoherent LORs attempt to illustrate unpacking of the learners' modelling behaviour revealing the complex interplay of various epistemological resources to build coherent mental models to reason with. In the above processes, the episodes of confusion like the extension of the 'overhead shadow' LOR to different locations on the Earth or the friction integrating book-based resources and tool-based resources to explain seasons, needed more intervention beyond the limited conversations during the interviews. If interventions enhanced by the tool embedded in a continued discourse are ensured, the learner could test, revise their model or create an entirely new model for themselves, which can be considered as successful reconciliation and meaningful learning.

The paper also illustrates how digital media interfaces can be effectively used to provide epistemic access to – by providing conceptual tools (like the 2 arrows: normal and sun rays in 2nd and 3rd views of Figure-1) – and triggering imagination of otherwise inaccessible models. From the diverse deployment of tool-based resources in the above episodes, we illustrate the affordance of digital media interfaces providing new kinds of experiences and epistemic access to the inaccessible phenomena and models, and being a new kind of epistemological resource to the learners. Further, in a literal sense, the tool aligns with 'perspective-taking' involving the notions of 'diving-in' and 'stepping-out' (Ackermann 1996).

As we highlight the potential of digital media, we would also want to clarify the need for wider contexts integrating various epistemological resources. These contexts could emerge through more discourse in resolving the learners' confusions. This has practical implications to educational technology designers, to consider technological interventions as a part of a holistic intervention integrating other epistemological resources that learners already come with, and not be thought of as a one-pill solution for learning problems, akin to a technocentric critique (Papert, 1987). The study acknowledges that by being part of a community of peers (with diverse epistemological resources), a rich and meaningful discourse could emerge fostering the desired modelling behaviour with richer models, and digital media systems can be one among various epistemological resources. Furthermore, our study, in a way, helps deepen the existing descriptions of such reconciliations using various resources including cultural knowledge systems (e.g. Jegede & Aikenhead, 1999).

This paper, thus, in its limited scope, tries to illustrate unpacking of the modelling behaviour, using episodes of reasoning about the Sun-Earth system. This describes the underlying interplay between different epistemological resources in shaping the LORs based on models. For researchers in the learning sciences, this unpacking of the episodes could be insightful. We hope this paper could contribute to systematic conversations around learning dynamics and to the role of technological interventions in meaningfully supporting learning.

The tool as well as the study are preliminary and have certain limitations. Some reflection of this can be seen in student's post-questionnaire feedback to visually denote and mention numeric angular values (azimuth and incidence) in the out-of-Earth and on-Earth views. Also, the suitability of the design in connection to the existing formal school education is not accounted for in this paper. The study though gets sufficiently deep to deploy the analysis framework, a more rigorous data collection and application of the framework in future could give promising insights about the modelling behaviour, and the role of digital media tools in enriching learners' experiences. Also, more explorations of learners' modelling behaviour in spatial contexts with multiple perspectives other than the Sun-Earth system can strengthen the generalisability of the insights.

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