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Year 8 students' understanding of astronomy as a representational issue: Insights from a classroom video study

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Abstract
The research described in this paper argues that difficulties of learning science concepts such as those associated with processes involving the Sun, Moon and Earth, such as day and night, the seasons and phases of the moon, are fundamentally representational in nature. There is a need for learners to use their own representational, cultural and cognitive resources to engage with the subject-specific representational practices of science. From this perspective students need to understand and conceptually integrate different representational modalities or forms in learning science and reasoning in science. The researchers worked with two experienced teachers in planning a teaching sequence in astronomy using a teaching approach that highlight representational issues and options in helping students explore and develop key conceptual understandings. Classroom sequences involving the two teachers were videotaped using a combined focus on the teacher and groups of students. Video analysis software was used to capture the variety of representations used, and sequences of representational negotiation. From a pedagogical perspective the representational approach placed a significant agency in the hands of students which resulted in structured discussions around conceptual problems. Representations were used as tools for reasoning and communication to drive classroom discussions and develop higher levels of understanding in the students. The pre- and post-testing showed significant gains in students thinking from naïve to more scientific understandings of astronomy.

Introduction
The research literature that has focused on individual's understanding of astronomical phenomena is quite extensive (refer to bibliography by Duit, 2002) and has dealt with such astronomical behaviour as the day and night cycle (for example, Dunlop, 2000; Kikas, 1998); the seasons (for example, Danaia & McKinnon, 2008; Hsu, 2008); phases of the moon (for example, Danaia & McKinnon, 2008; Trundle, Atwood & Christopher, 2002) and gravity (for example, Agan & Schneider, 2004; Palmer, 2001). The main finding from this literature is that students at all levels of schooling and adults, including pre-service and in-service teachers, hold alternative conceptions about astronomical behaviour (Kalkan & Kiroglu, 2007; Parker & Heywood 1998; Trumper, 2001). Examples of such alternative conceptions include: day and night is caused by the motion of the Sun around the Earth; the phases of the moon are caused by the shadow cast on the Moon due to the Earth obstructing the light from the Sun; the seasons are caused by variations in distance between the observer on Earth and the Sun, and; gravity does not operate in the absence of air.

The prevalence of alternative conceptions across most age levels of individuals may suggest that school science has limited impact in resolving them. From this perspective Danaia and McKinnon (2008) suggest that teachers need to have some understanding of these misconceptions, including ways of dealing with the alternative conceptions their students bring to the classroom. Bakas and Mikropoulos (2003) point out that the sometimes limited success of conventional teaching methods in overcoming students’ alternative conceptions may be due to a lack of appropriate teaching aids in the form of representations that can intervene dynamically in the learning process and modify it.

There is general agreement that even the most elementary astronomical phenomena are difficult for students to understand since many of the ideas involve three dimensional spatial relationships and orientations between celestial objects (Hegarty & Waller 2004; Padalker & Ramadas, 2008; Yu, 2004). Within the classroom students are expected to deal with visual-
spatial representations through the application of reasoning skills that involve the ability to imagine spatial forms and movements, including translation and rotations, and perspective taking (Hegarty & Waller 2004; Padalker & Ramadas, 2008). The difficulty of learning three-dimensional perspectives of astronomical phenomena is compounded when one considers that most phenomena are time-dependent and that much of the teaching materials in astronomy education are two-dimensional in nature (Yu, 2008).

The difficulties encountered by individuals in learning astronomical phenomena point to the need for a very strong emphasis of the role of representations in learning. There is a need for learners to use their own representational, cultural and cognitive resources to engage with the subject-specific representational practices of science. From these perspectives students need to understand and conceptually integrate different representational modalities or forms in learning science and reasoning in science (Ainsworth, 1999; Lemke, 2004). These researchers argue that to learn science effectively students must understand different representations of science concepts and processes, and be able to translate these into one another, as well as understand their co-ordinated use in representing scientific knowledge and explanation-building. Classification categories of representations are generally held to include textual, visual, mathematical, figurative and gestural, or kinaesthetic, understandings.

In encapsulating the key features of adopting a teaching sequence with a representational focus and the roles played by representations in supporting reasoning and learning we are collaborating with other colleagues1 in developing a set of pedagogical principles. These principles draw on literature that emphasise the active role of representational work in supporting learning in science (Greeno & Hall, 1997; Ford & Forman, 2006) and formed the basis of advice to the teachers in this study concerning the nature of a representational focused approach to teaching astronomy. The principles are described as:

1. Teachers need to clearly identify big ideas, key concepts and their representations, at the planning stage of a topic.
2. There needs to be an explicit teacher focus on representational function and form, with timely clarification of parts and their purposes.
3. Representational generation and negotiation as the focus of teaching and learning:
   a. Students need to be active and exploratory in generating, manipulating and refining representations.
   b. Activity sequences need to have a strong experiential context and allow constant two-way mapping between objects and representations.
   c. Students need to be supported to develop explanations that involve coordinating and re-representing multiple modes.
   d. There needs to be a sequence of representational challenges which elicit student ideas, guide them to explore and explain representations, to extend to a range of situations, and allow opportunities to generate representations and integrate these meaningfully.
   e. Students need to understand that a single representation cannot cover all purposes, but needs to have a selective focus.
   f. There needs to be interplay between teacher-introduced and student-constructed representations where students are challenged and supported to refine and extend and coordinate their understandings.

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1 This study is part of a wider research project titled, The role of representation in learning science, conducted at three university sites.
There needs to be ongoing assessment (by teachers and students) of student representations. The adequacy of a representation depends on the particular purpose or purposes.

4. Activity sequences need to focus on engaging students in learning that is personally meaningful and challenging, through attending to students' interests, values and aesthetic preferences, and personal histories.

5. Formative and summative assessment needs to allow opportunities for students to generate and interpret representations.

In this project we worked closely and collaboratively with teachers to construct a teaching sequence in astronomy that validated the pedagogical principles. The topic's content was outside the teachers' discipline expertise of biology so the challenge for them was a combination of content knowledge and pedagogic content knowledge. This paper explores how the teachers and students responded to the new approach, implied by the principles above, and the role of representations in supporting learning and reasoning in astronomy.

**Approach & Methodology**

This study relates to a classroom study of an astronomy teaching sequence taught by two teachers, Lyn and Sally, to Year 8 students (13 years of age). The sequence content covered astronomical phenomena as it pertains to the Earth, Sun and Moon systems surrounded by planets and stars. These phenomena included: day and night cycle; the seasons; phases of the moon and tides; constellations; and gravity.

The research question is: What are the effects of an explicit representational focus on the teaching and learning of Year 8 astronomy?

**Approach to planning the astronomy teaching sequence**

In coming into this study Lyn and Sally were experienced practitioners who already had experience in a previous study (Hubber, Tytler & Haslam, in press) in the innovative use of strategies based on the development of students' representations. However, prior to the commencement of the teaching sequence both teachers expressed some reluctance to teaching it. This stemmed from a perceived lack of content knowledge about some aspects of the topic as well as a perceived lack of sufficient pedagogical content knowledge (Shulman, 1986) to effectively respond to the learning needs of the students. In the following transcript of a conversation had with Lyn and Sally the reasons behind their reluctance to teach the topic were expressed.

Researcher: last year you said that you really didn't want to teach this topic.
Sally: yes
R: So what was the main reason behind that? Was it a lack of content knowledge?
S: [yes] The content knowledge, the fact that I had never done it in school myself and I have never learnt the topic myself; only read it through books and watching movies and so on but it was the fact that it was the topic that was endless. I mean the kids could ask you lots and lots of questions and I was aware that half the time I may not have the answers straight away and would need to come back to them later. I mean that was the fear factor.

Whilst Lyn had taught the topic of astronomy before she commented that “... it was the one I was the least confident with and I have always avoided it because it has been difficult”.

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2 Pseudonyms have been given to teachers in this study. Where reference has been made to names of students pseudonyms have also been used.
Researcher: *What sort of approach did you have in that topic in the past? Did the topic have a lot of textbook orientated work?*

Lyn: *Yes, more delivery of facts rather than exploration of understanding.*

In planning the sequence with the teachers the adoption of a representational focus puts stringent demands on clarifying what knowledge was to be pursued. The teaching sequence therefore needed to be informed by a clear conceptual focus. At the planning stage, in order to refine the representational work, the research team collaborated with the teachers in identifying big ideas or key concepts of the topic in addition to the students’ alternative conceptions reported in the literature. The initial lessons in each teaching sequence focused on exploration of students’ prior views, generation of students’ representations, and introduction of the scientific conventions that underpinned the topic of astronomy.

The sequence sought to develop a model of classroom practice that foregrounds students’ negotiation of conceptual representations. The developed teaching and learning activities and sequences modelled pedagogies that take a representational focus to support student engagement and learning, but more importantly as a vehicle to explore the representational challenges and issues, the link between conceptual learning and representation, and the nature of effective teaching and learning focusing on representations, and effective assessment from this perspective.

The team workshopped activities that had a representational focus and discussed the implications of these for student learning bearing in mind possible alternative conceptions the students might have. This experience gave the teachers more confidence in tackling the teaching of astronomy. For example, when Sally was asked about her reported increased confidence following the workshop she commented:

*Sally: I think the role plays, how to actually go about teaching the topic and using ourselves, using the models, and understanding of relative distances, and I think the Power Points that showed the distances, and the size of the different stars and so on. I think that really was a wow factor and I put myself in the shoes of the kids and I thought, yes that would be something I could feel comfortable in teaching.*

Rather than dealing with an “endless” topic learning astronomy at a Year 8 level was now seen as a set of key ideas about astronomical phenomena that arise from simple dynamic systems such as the Earth, Moon and Sun connected by gravity. The representations of the key ideas associated with these systems gave the teachers the pedagogical tools they felt comfortable with in using in the classroom. The representations also gave the teachers the reasoning tools to enhance their own content knowledge. For example, Lyn commented:

*Lyn: ...I found the workshops that we had were really powerful ...I had a problem with the moon didn’t I. The rotation of the moon and the revolution of the moon around the earth and I couldn’t get it until I physically did it myself.*

**Teaching sequence**

The teaching sequence lasted 14 lessons varying between 45 minutes and 90 minutes of class time. The features of the sequence were:

1. Pre-test of key ideas associated with the astronomy topics to be taught. The test incorporated a slightly modified set of multiple choice questions used by Trumper (2001) and Kalkan and Kiroglu (2007). The pre-test also included short answer questions where students were to provide full explanations using text and/or drawings.

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3 Modified in language to support a perspective of observers in Australia
2. The students’ notebooks were different to their normal A4 lined notebooks but larger sized project type notebooks which, when opened out, had one line page on the left and an unlined page on the right. This encouraged the construction of multiple representations by the students.

3. Students were given representational challenges where they were to generate a representation with a particular purpose. For example,
   a. Explain to a 10 year old how it can be night in Melbourne the same time that it is daytime in LA.
   b. Explain what would be observed by an observer on the Moon in respect of the Earth and Sun over time.

4. Students were given representational challenges where they were to interpret a particular representation by generating a single or multiple representations in other forms and/or modes. For example,
   a. Explain through diagram/drawing the mutual revolution of two physical objects;
   b. Construct an observer’s view on Earth for summer and winter of the height of the midday Sun given a diagram showing these two seasons from the perspective of an observer in space.

5. Instances where representations where used in exploring astronomical behaviour. For example,
   a. Animations showing the motion of celestial bodies to explain such phenomena as the seasons, day and night, phases of the Moon and gravitational pull of objects near Earth;
   b. Role play of the dynamic system that involves the Zodiacal Constellations, Sun, Moon and Earth to explain the location of zodiacal constellations in the sky at certain times of the year, time periods of day, month and year, and eclipses;
   c. Scale models showing relative distances and sizes of the planets and the Sun; and

In most instances representations did not stand alone but were integrated with others. For example, gesture, everyday/science language and diagrams.

6. Classroom discussion generated by students’ questions. For example, ‘how come we can see the Southern Cross every night of the year?’

7. Inquiry-based investigations whereby student groups were to collect some data, represent it in a form of their choosing, analyse and interpret this data with the purpose of answering some questions. The students were to provide a written report as a summative assessment task and present their findings to the rest of the class in whatever form they chose. Examples of investigations involved:
   a. Finding directions using the Sun: investigating the length and direction of shadows over the period of a day.
   b. Tide Watch: students investigate tide heights and phases of the moon over time with accessing data from internet sources.

8. A Predict Observe Explain (POE, Gunstone & White, 1992) activity whereby students constructed plasticine scaled models of the Earth and Moon relative to their size and distance separation.

9. Post-test that included the same set of multiple choice questions given in the pre-test and also included some of the short answer questions. In addition, further short answer questions were given.

Data collection and analysis
Data collected included: (1) video recordings of most classroom sessions and of student interviews; (2) student workbooks; (4) pre- and post-tests; (5) transcripts of tape recordings of teacher and student interviews and (6) researchers’ field notes.

The video sequences used two cameras – one tracking the teacher and the main classroom interactions, and one focusing on a small group of students. The teacher and student group were radio miked. The student group’s microphone was transported with the group if it moved around. Most lessons in the unit sequence were videotaped as many of the lessons had some part or parts that had a representational focus. The videotaped lessons were coded using ‘studio code’ software which has been designed for this type of analysis, to allow quick reference to representational events and monitoring of classroom negotiation of representations. The analysis reported here included triangulation between video data, transcripts of student and teacher interviews, student work, pre and post tests and researcher field notes.

Findings

The sequence resulted in a number of insights into the efficacy of a representational focus in planning and implementing a lesson sequence in astronomy. During the lesson sequence representations were used by teachers and students in different ways. The findings described in this section are categorised as:

- The partial nature of representations means that the process of achieving full understanding is multi-representational;
- Representations can be used to challenge students thinking and facilitate reasoning;
- Formative and summative assessment are facilitated through representation; and
- Student learning in a lesson sequence focused on representations.

_The partial nature of representations means that the process of achieving full understanding is multi-representational_

The partial nature of representations was exemplified on many occasions during the teaching sequence. The students came to understand that a single representation cannot cover all purposes, but needs to have a selective focus. On most occasions when a teacher generated or student generated representation was introduced to the class there was a discussion as to the extent of the fit with the target phenomenon or process. For example, in the first lesson the teachers initiated a discussion of the globe as a representation of Earth. They asked the students what features of Earth are represented by the globe and what features are not represented by the globe. In Sally’s class the students quickly generated the following list of features (see Table 1).

<table>
<thead>
<tr>
<th>The Globe shows</th>
<th>The Globe does not show</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth is round</td>
<td>Day &amp; night</td>
</tr>
<tr>
<td>Earth has oceans</td>
<td>Gravity</td>
</tr>
<tr>
<td>Earth rotates about axis</td>
<td>Size</td>
</tr>
<tr>
<td>Earth is tilted</td>
<td>Mountains</td>
</tr>
<tr>
<td></td>
<td>Weight of Earth</td>
</tr>
</tbody>
</table>

The response by the students that the mountains were not represented by the globe opened up further discussion. Sally made explicit links between different modes of representation in generating the view that because of the scaled size of the globe the
mountains would not be able to be shown on Globe. She did this by getting the students to explore the Globe through sight and touch. This raised an issue of conflicting findings – by sight it didn’t appear that mountains were represented. However, by touch the students could feel slight bumps on the globe in the region of the Himalayas. This issue of whether the height of the bumps was accurately represented was then explored by the class.

Sally introduced the mathematical idea of diameter gesturing its meaning on the globe and illustrating this on the board (Fig. 1). She then explained the scaling process using hand gestures linking the numerical values for the Earth/globe diameters and height to the highest mountain Mount Everest written on the board to the actual globe.

The scaled globe height for Mount Everest was given by Sally as 0.01 cm, which the students converted to 0.1 mm. Finally, the students were asked to get out their rulers to then look at them to see what distance 0.1 mm might look like. The question “Can the globe represent mountains?”, was then emphatically answered by the students as no.

During class interactions the role of drawing out the specific purpose of a representation was undertaken by the teachers as well as the students. For example, when discussing the planetary status of Pluto the teachers presented the students with a diagrammatic representation of the planetary paths (Fig. 2) as well as images of the planets indicating their relative sizes. The students were expected to interrogate the representations in terms of their adequacy in providing evidence to differentiate Pluto from the planets.

The students were then able to successfully argue the non-planetary status of Pluto when presented with the criteria for assessing the status of a planet on the basis of evidence from different representations.

**Representations can be used to challenge students thinking and facilitate reasoning**

During the sequence both teachers regularly gave students representational challenges which elicited student ideas, guided them to explore and explain, to extend to a range of situations, and allowed opportunities to integrate their representations meaningfully. The students were given opportunities to re-represent to extend and demonstrate learning. They were challenged and supported to coordinate representations as a means to express coherent, defensible and flexible understandings. For example, during the first lesson in the teaching sequence both teachers gave the students a representational challenge to show, through the physical action of their bodies, the motions of rotation and revolution. This task elicited students’ understanding of these motions. From this initial challenge the teachers each set a further challenge for the students.
In Sally’s class the students were further challenged to show if it was possible to revolve around each other. She then asked two students:

Sally: How would you show what you did on the board? I want you to think about different ways of showing a representation of a concept or a phenomenon.

The students initially found this representational challenge difficult. In resolving this difficulty they partially acted out the motion and came up with the drawing on the left in Figure 3 after realising the need to have a central point of revolution. Sally then asked the boys to re-represent the diagram showing just the paths of the feet; this is shown by the drawing on the right in Figure 3. A realisation then came from the pair that the feet trace out intersecting circles.

This activity led to a discussion about binary star systems and their prevalence in the universe. In a post-topic interview Sally commented on one of the student’s effort with this challenge:

Sally: But I loved the fact that Henry was trying to press the pen hard on the board and going, “got to get that to move this way how do I do it. Coz it is 2-dimensional. It is not 3-dimensional.”

Throughout this activity the students created three different representations reasoning with one representation in constructing another in a process that was challenging for them.

In Lyn’s class the students were challenged to show if it was possible to pair up and to revolve and rotate simultaneously. She found two pairs of students who represented the task in two different ways. Each pair then demonstrated their motions to the rest of the class who evaluated each for the purpose underlying the role play – to represent rotation and revolution simultaneously.

For one pair, one student kept facing his partner whilst making one full revolution of him. Lyn asked the students, “I noticed two different styles...is John doing it right (rotating and revolving)? Most students were unsure which led Lyn setting the task for all students, in pairs, to role play this action whilst at the same time noticing which walls of the room were being looked at. By undertaking this activity the students found that for each revolution each wall was seen once and thus realised that they were rotating at the same rate as they were revolving.

Lyn then proposed some questions about what this representation might mean when mapped to celestial objects. This is illustrated in the following verbal exchange:

Lyn: if Shane was the Earth [central object] and John another object, what would be seen from Earth?
Student 1: you would only see one side.
Lyn: if Shane was the Sun and John the Earth, what would this mean?
Student 2: if the sun shines out of Shane this would mean only one country would see the sun.

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Pseudonyms are given for students who participated in the study.
Lyn then linked this motion to that of the Moon's motion about the Earth which resonated with the students some of whom knew about the observation that one can only see one side of the Moon from Earth. Evidence of learning through this role play is illustrated in the following post-topic interview transcript:

Researcher: did any of the role plays help you?
Student: I found the orbiting and noticing which wall you were looking at. If the moon was rotating, that helped, because up to that point I didn't think the moon was rotating. If you were looking at different walls then you knew it was rotating.

Rather than just being told that the moon rotates was not enough. The student recognised this through the actual action of a role play. The kinaesthetic experience of the role play gave him the reasoning tool to consolidate this idea.

These particular classroom scenarios illustrate two key roles for representations. There was an explicit teacher focus on representational function and form of the role play. Students then used the representation of role-play as a reasoning tool to explore, construct and consolidate ideas. The scenarios also highlight the manner in which the teaching approach can lead the class into different directions. From this perspective the teachers saw that they needed to be flexible and to plan accordingly. According to Sally "...you plan your lesson with a lot of possibilities. You think about okay what if the students ask me this question, what kind of activities can I have."

Another example of where the representation was used as a reasoning tool can be seen in the following verbal exchange between the researcher and a student in a post-topic interview.

Researcher: this is a globe. [refer to Fig. 4] What would it be representing?
Student: the globe represents the Earth
R: we have a little man there, he is an observer...If you wanted to look at a representation of day and night what other things do we need?
S: we would want the sun represented by some sort of flash light.
R: we haven't got a flashlight but we have got the tennis ball there...what time of the day is represented here for the man?
S: well it would be somewhere between 5 and 6 pm, I would say.
R: how did you work that out?
S: wait [Student looks at the globe and starts to rotate it with his hand, 10 seconds passes] R: tell me what you are thinking?
S: I want to change my mind, maybe it's a.m.
R: what made you change your mind there?
S: because I remembered in which direction the Earth spins. It generally likes to spin this way [demonstrating this with the globe].
R: how did you know that?
S: because what we learnt in class. We get the sunlight before Perth. If we are here [pointing to the man in Melbourne] Perth is that way so [point out Perth] so we turn this way [turning the globe].
R: so having the model here the representation helped you with that?
S: yeah
R: so you have worked out the day. Could you work out the season?

Fig. 4: representation of day and night
S: yes I could...let's see [Student looks at the globe and then the tennis ball and gestures the orbit of the globe] it's [5 seconds]...I'm going to say autumn.
R: where would I represent the globe in three months time?
S: um...I want to say over there. [globe is placed at that location] I know that's winter.

In this interview the student connected a known fact about Perth that he learned in class with the physical manipulation of the globe in reasoning about an astronomical behaviour from the perspective of an observer on Earth (time and season) and one in space (rotation and revolution).

**Formative and summative assessment are facilitated through representation**

The teachers saw benefit in the knowledge gained from the pre-test in terms of targeting the teaching in resolving misconceptions that arose and for the students to be made aware of their own thinking as an important part of the teaching sequence.

Lyn: Because we have more understanding of the misconceptions we can teach accordingly and we can single out misconceptions...we can tackle them straight away.. if you are aware of what the misconceptions could be, you are explicitly telling the students that you know some people think this is so, it has a huge impact because the kids will not then go along those lines...The pre-test was used as a basis to begin discussions, it gave kids a good reference point.

There were many instances during the teaching sequence whereby the students were given the opportunity to interpret and generate representations which gave the teachers a good sense of student learning from a formative and summative perspective.

Sally: It's good to give them a representation, but it's more powerful when they re-represent it...it helps in their reasoning.
Lyn: ...what you're seeing with representation is that you're seeing what's in their brain, not what they're regurgitating.

The teachers found that the representational focus placed more involvement by the students in the classroom interactions. This view is illustrated by the following comment by Sally.

Sally: I found most of the lessons were more student-driven...it was built up because of their questions. I think the kids appreciate the fact that they could openly discuss why they thought that was the answer and that discussion was really powerful ...they valued the fact that they wanted me to know what they were thinking.

For the astronomy topic there was a change in the type of notebook used by the students. In changing from an A4 lined page book to a larger than A4 project type book Sally commented that such a change was, “much better than what we used to do because the kids liked the fact that there were these blank pages where they knew, ah okay, I can draw this here and write what is on the other side.” It was in their project books where students often re-represented a particular situation. For example, in the diagram below (Fig. 5) the students were to re-represent the diagram on the left for a midday observer on Earth. This student’s re-representation, shown on the right hand side of Fig. 5, made explicit links between the original representation and her re-representation through numerical labels. The direction of sunlight is indicated through lines and use of shadows.
**Fig. 5** Student’s representations of midday Sun in winter and summer

In terms of summative assessment the provision of a space rather than lines for the students to respond to short answer questions in the post-test gave the opportunity, permission and authority to adopt a range of representational modes. This is illustrated by the sample of responses (see Fig. 6) made by students to a post-test question which asked: “An astronomer investigating the motion of Europa, which is a moon, or natural satellite, of the planet Jupiter, found that it revolved as well as rotated. Use the space below to clearly explain what each of these motions mean.”

<table>
<thead>
<tr>
<th>Revolve</th>
<th>Rotate</th>
</tr>
</thead>
<tbody>
<tr>
<td>To revolve is to move around another object in a consinished pattern</td>
<td>To rotate is to spin. Rotation is done on the spot. To revolve is to orbit or go around something. To revolve you need two objects: one to be revolved around and the other to revolve around the first object. So Europa must spin or rotate at the same time as it orbits or revolves around Jupiter.</td>
</tr>
</tbody>
</table>

**Fig. 6:** Four students’ responses to a post-test question about rotation and revolution

The representations in Figure 6 are scientifically correct and yet show a significant variation within and across different modes.

During the sequence there were many instances where students were expected to interpret a particular representation and generate others in explanation. The following example is taken from a question in the post-test (Fig. 7) with an example of one student’s responses.

**Q20.** The image opposite is a time-lapse photograph showing the position of the Sun on Antarctica’s horizon every hour for 8 hours. Use the space below to explain why the Sun doesn’t set below the horizon.

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5 The students’ written response was re-written to provide clarity

Fig. 7 Student response to post-test question

Student learning in a lesson sequence focused on representations

The pre-test that incorporated multiple choice and short-answer type questions elicited several alternative conceptions similar to those found by other researchers cited in the introduction. In evaluating student learning over the period of the teaching sequence the pre- and post-tests contained the same set of multiple choice questions which had previously been used in other studies (Trumper, 2001; Kalkan and Kiroglu, 2007). Table 2 indicates the students’ results to these questions and provides a comparison to results obtained by the Kalkan and Kiroglu (2007) study. These researchers pre- and post-tested 100 pre-service primary and secondary education teachers who participated in a semester length course in astronomy. A measure of comparison of pre- and post-test results is the normalized gain index, \( <g> \), the ratio of the actual average student gain to the maximum possible average gain: \( <g> = \frac{(\text{post\%} - \text{pre\%})}{(100 - \text{pre \%})} \), reported by Zeilik, Schau, and Mattern (1999). Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). The mean gain reported by Kalkan and Kiroglu (2007, p. 17) to be a “respectable 0.3”. In contrast the mean gain for this study was significantly higher as 0.65.

Table 2 Correct answer ratio and gain index \( <g> \) according to pre- and post-test results for two studies.

<table>
<thead>
<tr>
<th>Item</th>
<th>Year 8 Students N=40</th>
<th>Kalkan &amp; Kiroglu (2007) study N=100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Pre-test % correct</td>
<td>Post-test % correct</td>
</tr>
<tr>
<td>1 Day-night cycle</td>
<td>61</td>
<td>92</td>
</tr>
<tr>
<td>2 Moon phases</td>
<td>43</td>
<td>81</td>
</tr>
<tr>
<td>3 Sun Earth distance scale</td>
<td>9</td>
<td>49</td>
</tr>
<tr>
<td>4 Altitude of midday Sun</td>
<td>10</td>
<td>66</td>
</tr>
<tr>
<td>5 Earth dimensions</td>
<td>30</td>
<td>63</td>
</tr>
<tr>
<td>6 Seasons</td>
<td>13</td>
<td>63</td>
</tr>
<tr>
<td>7 Relative distances</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>8 Moon’s revolution</td>
<td>38</td>
<td>83</td>
</tr>
<tr>
<td>9 Sun’s revolution</td>
<td>86</td>
<td>97</td>
</tr>
<tr>
<td>10 Solar eclipse</td>
<td>31</td>
<td>86</td>
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Apart from the conceptual growth shown in the multiple choice questions there was also evidence of growth shown in the students’ responses to the short answer questions. For example, when asked, ‘If objects like apples fall to the ground then why do you think the moon doesn’t also fall to the ground? Explain why.’ One student responded:

Pre-test response: The moon is out of reach for the earth’s gravity to pull it to earth.
Post-test response: the moon is constantly falling but it is falling at a certain (sic) speed so it is orbiting the earth due to our gravity.

Post-test responses also showed evidence of students providing more representational modes (refer to Figs. 6 and 7 for examples of responses) than was shown in the pre-test.

In the following post-topic student interview transcript student 1 indicated that that models, the kinaesthetic action of role play and constructing/re-constructing the representations assisted her learning of ideas. For student 2 she made reference to diagrams and class discussion. Her last comment suggested that students were often asked to explain their thinking to the teacher and other students.

Student 1: [before the lesson sequence] I never knew how the moon kind of orbited the Earth.  
Researcher: what sort of things gave you a good understanding of moon?  
S1: like how my teacher made us actually stand up and act out the motions. It’s better than sitting down and trying to learn it by words on the board.  
S1: I learnt a lot when my teacher showed models and making us do the representations.  
R: what sort of things really helped you learn?  
Student 2: I like looking at diagrams I find they really help. I like it when we have class discussions... When the teacher says something you may not get it but when someone else asks a question and another kid answers it in a different way to how the teacher said it that helps. Then you get two different answers to a certain question.  
R: do you think it’s helpful if you have to explain something back to the teacher or other students?  
S2: yeah, you often have to do that.

Conclusions

In this study the teachers confirmed the efficacy of a representational focus in teaching and learning the key science concepts in astronomy. The conceptual focus in the planning of this topic gave the teachers a framework of concepts, alternative conceptions and simple dynamic systems with which to develop activities that had a representational focus; content was conceived of as an interconnected set of ideas linked and understood by representations. This focus reduced the teaching of the topic of astronomy from what Sally characterised as an “endless” one to a more manageable one. It also increased the teachers’ pedagogical content knowledge, in addition to their content knowledge, as they gained a greater understanding of what makes the learning of specific topics in astronomy easy or difficult.

The approach they adopted reflected the pedagogical principles listed in the introduction. Representations were generated by the teachers and students and played an active and central role in relation to thinking and learning. They were used as tools for thinking rather than as
summarised pieces of knowledge to be learned. Such a view is consistent with that held by Greeno and Hall (1997, p. 366) who suggest that representations are "essential tools for communicating and reasoning about concepts" and not "ends in themselves". By being challenged to coordinate and negotiate representations students came to refine and sharpen their understandings.

This approach was acknowledged to place much greater agency in the hands of students, and this brought a need to learn to run longer and more structured discussions around conceptual problems. The greater involvement of students in classroom interactions and the interconnectedness of ideas through representations mean the need for a greater flexibility in terms of what content is to be covered in teaching each lesson.

The teachers saw the knowledge gained from the pre-test results as beneficial in terms of targeting the teaching in resolving misconceptions and for the students to be made aware of their own thinking as an important part of the teaching sequence. The resolution to resolving the students’ naïve conceptions was perceived as very much a representational issue in terms of the use of representational challenges to drive classroom discussions. The students were given many opportunities to interpret and generate representations which gave the teachers a good sense of the students’ learning from a formative and summative perspective. The provision of spaces in the students’ workbooks and tests encouraged the generation of representations.

The study described in this paper supports the idea that learning is fundamentally a representational issue. The focus on representations opened up the pedagogy in classrooms where students readily responded to the invitation to refine and make coherent their representations. The pre- and post-testing of the students showed significant gains in understanding across the astronomical areas covered in the teaching sequence. The set of pedagogical principles given in the introduction provided a useful framework for the teachers to use and in doing so enhanced their confidence in teaching the topic. This greater confidence was generated by the high levels of student engagement in using representations to construct high levels of understanding the key ideas of astronomy that formed the basis of the topic.

Given current concerns about the engagement of students in meaningful science learning, and the relatively limited success of pedagogical approaches based on cognitive views of learning, we would argue that the approach adopted in this study is worthy of adopting in other science topics.

References


