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Multimodal Modeling Activities with Special Needs Students in an Informal Learning Context: Vygotsky Revisited

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ABSTRACT

In light of the challenges facing science educators and special education teachers in Singapore, this study entails design-based research to develop participatory learning environments. Drawing upon Vygotskian perspectives, this case study was situated in an informal workshop around the theme of "day and night" working for Special Needs Students in Singapore. Moving away from traditional astronomy teaching, we aim to explore interdisciplinary multimodal modeling activities towards developing a participatory learning environment. As the main finings of this case study, the central benefits of interdisciplinary multimodal modeling activities are twofold: (1) promoting multiliteracies development using digital and multimodal resources for supporting the emotional and social experiences in developing learners' astronomical understanding; and (2) integrating learners' everyday experiences with scientific astronomical understanding for the development of higher cognitive functions. These findings emphasize the need for the cultural development of Special Needs Students.

Keywords: special needs students, multimodality, multiliteracies, Vygotsky, informal learning

INTRODUCTION

Since the Thinking School, Learning Nation (TSLN) educational reform in 1998 (Goh, 1998), the Singapore government has stressed the importance of self-directed and inquiry-based learning to change and improve the educational system that has focused on getting good grades or achieving positive outcomes by students who memorize decontextualized facts. In other words, to promote learner-centered and active learning, such a government-initiated educational reform aims to encourage teachers to employ more engaging and innovative instructional methods such as inquiry-based learning (IBL). IBL aims to engage students in designing their investigations through hands-on activities and problem solving (Little, 2008). However, in the actual implementation of IBL, Singapore students often follow their teacher's instruction to solve problems that are given by prescribed procedures within highly organized instructional structures. Thus, although there is an increased amount of hands-on

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State of the literature

- Although it has been suggested that modeling-based inquiry learning is fundamental in learners' conceptual development, little attention has been paid to the benefits of modeling for Special Needs Students.
- Science literacy has expanded to include and emphasize various forms of multimodal tools such as speech, image, gesture and sound beyond reading and writing print-based, unimodal scientific texts.
- Special education research has addressed the instructional principles of inquiry based learning from socio-constructivist perspectives while many special education educators still have focused mainly on a remedial aspect of special education.

Contribution of this paper to the literature

- Through the lens of activity theory, this study shows the benefits of interdisciplinary multimodal modeling activities for Special Needs Students.
- Our findings support Vygotsky's social constructionist views on disability addressing the importance of understanding the disability in terms of a socio-cultural developmental phenomenon rather than a biological impairment.
- An interdisciplinary multimodal modeling approach to astronomy needs to develop shared/joint learning activities to promote the cultural processes of Special Needs Students as well as strengthening their higher psychological functions.

activities and collaborative tasks, students tend to spend less time generating their own questions or problems (Chin & Chia, 2006). Furthermore, there is a lack of research in science education how to foster students with special needs (Melber, 2004) although some scholars "have found benefits to using inquiry-based instruction to educate students with special needs" (Easterly & Myers, 2011, p. 37).

To cope with this concern, drawing on Vygotskian perspectives (Kim, 2013), this study sought to develop an authentic, rich and participatory learning environment whereby learners (as active agents of their learning) acquired motivation, values, and knowledge by interacting with their social environment for the development of their own meanings and senses. The study was situated in teaching and learning 'day and night' as one of astronomy thematic units within a Singapore informal learning context working with Special Needs Students (aged from 8 to 15 years old). Although there is no specific formal learning curriculum about astronomy in Singapore, astronomy has been recognized as an interesting subject both in and out of school contexts. For instance, there have been astronomy co-curricular activities or astronomy clubs of amateur astronomers to share their passion with others and further promote an interest in astronomy for others. To sustain their personal interests and encourage them to generate their own questions about astronomy phenomena across contexts, this design-based study employed an interdisciplinary approach to astronomy by using multimodal modeling activities in an informal learning context, aiming at a participatory learning environment.

Although scholars have shown that modeling is fundamental in learners' conceptual development (Schwarz et al., 2009; Windschitl, Thompson, & Braaten, 2008), little attention has been paid to Special Needs Students involving multimodal models in informal learning contexts. This case study seeks to unpack the lived experiences of Special Needs Students involving multimodal models in the context of technology-rich informal learning toward understanding the concepts of day and night.

Interdisciplinary Multimodal Modeling Activities

Astronomy has developed inherently interdisciplinary links with scientific fields as well as other content domains. Historically, many of ancient astronomers were skilled and renowned mathematicians, artists or writers. Furthermore, while disciplinary perspectives have been highly productive during the 20th century, given the integrated nature of complex tasks or problems in the 21st century, it is essential that an interdisciplinary approach be taken. Although developing an interdisciplinary science course originated in supporting non-science majors in higher education, there is a growing interest at all levels of education.

Lake (1994) summarized all of the definitions of interdisciplinary or integrated curriculum as including the following aspects beyond the linking of subject areas: an emphasis on projects, sources that go beyond textbooks, a relationship among concepts, thematic units as organizing principles, flexible schedules, and flexible student groupings. The integration of diverse disciplinary content and skills often occurs through a theme-based approach to the curriculum. The greater the level of integration desired, the higher the level of collaboration required. Despite these challenges, an interdisciplinary, research-based science program has been receiving growing attention (Lancor, 2015) as interdisciplinary perspectives address the importance of the authentic, experiential and reflective nature of problem solving.

This call for authentic participation is also consistent with the purpose of modeling-based inquiry learning. The approach of modeling-based inquiry, allowing students to construct models can keep them anchored so that students can engage in the problem situation. The definitions of "model" vary in different research, based on how models were employed in the studies. It can be simply an analogy of the understanding, simulation of process, or visualization and representation of a system (Kuhn, Hoppe, Lingnau, & Wichmann, 2006). Kuhn et al. (2006) noted that "[modeling] is therefore more than reproduction: the whole process is a reflected transformation in which students actively organize their own learning" (p. 185).

Attention should also focus on the modeling process, which involves the process of describing, explaining, representing, modifying and developing the conceptual understanding of learners and demonstrating the development in their learning (Shen & Confrey, 2007). Hence, formulating and refining inquires around the models students construct in a group or individually lies at the heart of modeling-based inquiry (Kim & Lee, 2013; Kim & Ye, 2013).

Drawing upon a constructivist learning perspective, recent research in science teaching and learning has recognized the importance of various modes (e.g., movement, sound, music, animation, gesture) in terms of multimodality in students' development of conceptual understanding (Kim & Lee, 2013). Scientific meanings cannot be communicated only by scientific terms and the names of new discoveries, but through common words, diagrams, pictures, graphs, charts and other forms of visual and mathematical expression (Márquez, Izquierdo, & Espinet, 2006). Science literacy in education, thus, has expanded to include and emphasize such various forms of multimodal tools as speech, image, gesture and sound beyond reading and writing print-based, unimodal scientific texts. Doing and understanding science is not simply a matter of individual rational decision-making, but an active bodily engagement (so-called embodied engagement) in a meaning-making process using various forms of representation and learners' logical, linguistic and semiotic resources, reflecting social and cultural contexts and consequences (Lemke, 2004; Prain & Waldrip, 2006; White & Pea, 2011). There are various ways to classify models in science learning. In this paper, the models are classified based on the media they utilize: graphical, textual or verbal modeling (2-D modeling), 3-D physical modeling, and 3-D computer modeling.

Technology-Rich Science Education for Special Needs Students

From socioconstructivist perspectives, special education research has addressed the instructional principles of inquiry based learning, ICT-mediated learning and problem-based learning with an emphasis on authentic contexts, social interaction and collaboration (Grumbine & Alden, 2006; Jimenez et al., 2012; Mechling & Bishop, 2011). For instance, Melber and Brown (2008) explored the learning of students with special needs in informal learning environments, which were voluntary, student centered, non-assessed and out of school. They summarized that the informal and inquiry-based learning experiences assisted students with special needs with researching on task and staying cognitively engaged, where they were more motivated in the authentic and engaging context. Hence, their science field course was specially designed for college-bound high school students with special needs. All activities include opportunities for written description, scientific diagramming, group discussion, specimen investigation, and communication of discoveries. Based on their explorative study, they suggested several methods for successful implementation in informal environments for Special Needs Students: providing alternative assessment strategies; incorporating objects and specimens; planning for durability; getting out of the classroom; and empowering the learner.

Growing attention has been drawn to the role of technology in special education to apply inquiry-based instruction and project-based instruction with Special Needs Students (Courduff, Szapkiw, & Wendt, 2016; Courtade, Spooner, & Browder, 2007; Ke et al., 2015; Regan et al., 2014). The Journal of Learning Disabilities had a special issue (1998, vol. 31, issue 1) discussing the effectiveness of assistive technology on students with learning disabilities. Various barriers could be addressed by technology by replacing an ability that is impaired or providing the support needed to accomplish a task. Lewis (1998) summarized the current technologies used for meeting the needs of Special Needs Students such as interactive videodisc interventions for math, and technologies for daily life.

Drawing upon this view, Olsen and Slater (2008) studied the impact of modifying activity-based instructional materials, which integrated the use of technology, for Special Needs Students in middle school Astronomy. They modified the curriculum of a space science package for the Special Needs Students. The modifications were literature-informed and strategically targeted to address the issues presented in astronomy education. The assistive technology was applied to lessen cognitive load for Special Needs Students, such as voice descriptors and visual cues. The software designed for problem-based learning also created powerful instructional affordances so that Special Needs Students were actively engaged in authentic learning opportunities.

Vygotskian Perspectives on Special Education

However, many special education educators, specifically in Singapore, have focused mainly on a remedial aspect of special education by addressing biological needs of Special Needs Students – what Vygotsky (1993) called primary disability. Rather than focusing exclusively on primary disabilities (e.g., visual and hearing, language-related impairment, motor-related impairment), Vygotskian perspectives imply that educators and researchers need to draw a distinction between primary disabilities and secondary disabilities to understand the interrelationships among them.

In accordance with his emphasis on the social origins of an individual's higher cognitive functions, Vygotsky (1978) noted that primary disabilities led to the Special Needs Students' exclusion from the sociocultural environment – this is what he called a secondary (sociocultural) disability. In other words, primary disabilities have significant negative impacts on not only the development of lower cognitive functions but also the development of higher cognitive functions in Special Needs Students. Hence, he stressed the importance of social learning for Special Needs Students by taking into account the sociocultural developmental process influenced by social interactions situated in particular sociocultural contexts in terms of the dynamic, sociocultural nature of disability (Hudson et al., 2016; Rodina, 2007).

Vygotskian perspectives therefore indicate that both general and special education need to support the social and cultural aspects of general and special education students' development, in particular the development of higher cognitive functions (Gindis, 1999, 2003). Special Needs Students need to still develop similar ways using compensatory strategies, which mediate lower cognitive functions so that they can collaborate with others until they are eventually able to do so independently, leading to the emergence of higher cognitive functions. That is what Vygotsky (1978) meant by the Zone of Proximal Development (ZPD) defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). However, educators and researchers often recognize Special Needs Students to be deficient within a limited area rather than exploring the ways in which students with special needs collaborate with others using alternate methods.

Based on the theory of dysontogenesis, Vygotsky (1993) argued that students with disabilities communicate with others using different ways of communication and interactions with others by addressing Special Needs Students' strengths rather than focusing on their weaknesses. Vygotsky stressed the importance of empowering students with special needs to explore alternate ways to compensate for their functional disabilities. Therefore, it is important that educators and researchers explore unique ways of interacting with others, which could be different from typically developing peers.

THE STUDY

The research team was invited by the Singapore Spastic Children Association to organize and conduct a one-day astronomy workshop as part of their scout galaxy night program. There were fifteen Singaporean students from the association aged from 8 to 15 years old. Students had difficulty in motor functions as a result of intellectual disability. Students' behavior ranged from extreme difficulty in controlling muscles to slight speech impairments. The school developed a specialized curriculum to meet students' needs in both academic skills and independent living skills. According to their teachers, students who participated in the Scout Club had relatively good motor and cognitive abilities. They did not have prior experience with inquiry-based learning. In this paper, all participants were given pseudonyms to protect confidentiality.

The workshop was designed with their teachers including our research collaborator, who had been teaching physics and organizing an astronomy club and astronomy camps both in and out of the school setting for more than 10 years. Through the adoption of the interdisciplinary multimodality modeling approach, the first step in a project was for the research team to come up with an authentic theme for the workshop with respect to the Special Needs Students' expectations, experiences, challenges, and abilities related to astronomical objects that could be observed by the naked eye or telescopes. The theme of "Day and Night" was selected because these are the daily astronomical phenomena that all students could have experiences with across different ages and abilities. The idea of the day/night cycle is recognized as a familiar astronomical event and a big idea that is commonly taught at school and intensively researched over the past 30 years (Lelliott & Rollnick, 2010). Research has showed that it is not easy for children and even adolescents to give scientifically correct responses about the day/night concept (Chiara & Valandides, 2008; Plummer, 2014).

This case study employed a qualitative research methodology to explore participants' understanding of astronomical phenomena. In other words, the focus was not on investigating possible cause-and-effect relationships using different variations and control groups in regard to Special Needs Students' understanding of the day/night concept.

Instead, this study aimed to explicate how students constructed and appropriated multimodal models to develop a deeper understanding of the day/night concept. As described above, there are few studies on exploring the in-depth analysis of Special Needs Students' learning involving multimodal models in the literature. Hence, this case study sought to unpack the lived experiences of a small number of Special Needs Students involving multimodal models in Singapore toward understanding the day/night concept. The small number of research participants facilitated the researcher's close relationship with them, and enhanced the validity of in-depth inquiry in naturalistic settings (Creswell, 2013; Kim, 2014). Unlike quantitative research that uses a random sample generalizable to a larger population, this qualitative study used a purposive sampling method.

Data Collection and Analysis

In order to clarify the meaning of an observation by viewing a phenomenon from multiple perspectives and to achieve triangulation to increase the validity of the results, this study involved multiple interconnected interpretive sources such as surveys, participants' artifacts, videotaped or audio taped observations in the workshop, field notes, and transcriptions of semistructured interviews with one teacher. Therefore, throughout this study, the researcher continued annotation and a recursive analysis of emerging data, triangulating different data types and sources to identify salient themes relevant to the participants' understanding about the day/night cycle.

In addition to this constant comparative method (Creswell, 2013), activity theory was used to analyze participation by the target students working with their teachers and research members as facilitators, illuminating the activities that characterized the workshop dynamics. Activity theory is a psychological and multi-disciplinary theory with a naturalistic emphasis that offers a framework for describing activities and provides a set of perspectives on practices that bring together individual and social levels (Engeström, 197; Kim, 2012). In the system, the relations between 'subjects' and 'objects' are mediated by various mediators, including tools, community, rules, and division of labor (see **Figure 1**).

Rather than focusing mainly on the mind or intellectual abilities of the individual, activity theory concerns how the actions and understandings of human agents are constructed across multiple resources (mediators) and extended time frames. In other words, activity theory conceives 'activity' as the unit of analysis with the goal of capturing and analyzing the process of learning in situ. In this light, activity theory has been recognized as a useful analytical lens (Engeström, 2007) "for understanding and representing dialectical transformations that occur between and within activity systems in which individuals or groups (defined as *subjects*) and their *goals* or *objects* are mediated by conceptual and physical *tools* developed within a *community* and mediated by shared *rules* and *divisions of labor*" (Kim, 2012, p. 437).

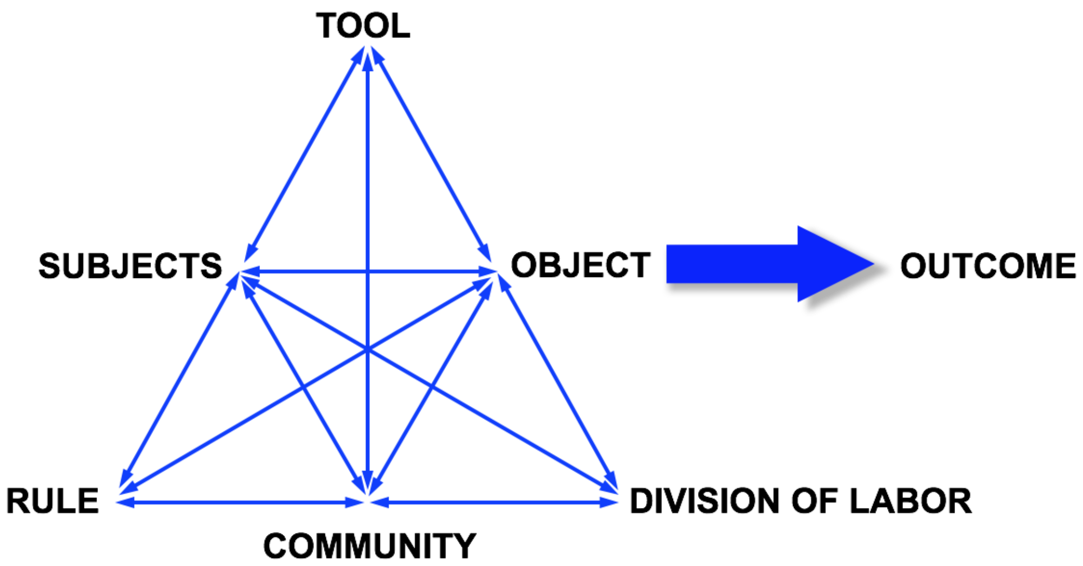


Figure 1. The Structure of an Activity Theory (Engeström, 1987)

RESULTS AND DISCUSSION

Through the lens of activity theory, I was not simply concerned with "doing" as a disembodied action but focused on "doing in order to transform something," with the focus on the contextualized activity of the system as a whole (Engeström, 2008). In this respect, there were two major emerging activities of the Special Needs Students' understanding of the day/night cycle: (1) communicating with others through multimodal modeling; and (2) communicating with themselves through multimodal modeling.

Communicating with Others through Multimodal Modeling

With an emphasis on contextualization and visualization of astronomical phenomena so as to connect with the target students' prior knowledge and experiences, storytelling activities were designed and implemented (see **Figure 2**).

While participating in this ICT integrated storytelling activity, students had a chance to have shared experiences, feelings and challenges around the story events, in particular why the Moon is visible at night. Rather than sharing simply a scientific explanation about the cause of day and night such as the Earth's rotation causing the cycle of day and night, facilitators helped the students experience a variety of stories with respect to the cause of day and night across different cultures. Many researchers, in particular in the area of misconception research, argue that astronomy misconceptions are often acquired from informal sources such as students' literature, television, media and newspapers as well as some 2D diagrams in textbooks. For instance, illustrations representing the sun setting behind a hill might mislead learners to believe that the sun moves and goes behind the hill or

Figure 2. Storytelling Activity using ICT Tools

other objects (Baxter, 1989). However, it was useful for the students to have diverse experiences, feelings, ideas, beliefs and attitudes of day and night by collaborating with the book authors, facilitators or teachers as well as their peers because diverse ways of interpretation motivated students to compare and contrast them to rethink both others' perspectives and their own understanding.

Following the storytelling activity, the students were grouped for communicating and sharing their ideas about day and night using drawings and verbal expressions. Their facilitators, who included both their own teachers and the research team members were part

Figure 3. Drawing Activity

Figure 4. Tuck's Drawing about the Day/Night Cycle

of these groups (see **Figure 3**).

Volunteers from regular schools also helped students move their hands to draw and articulate their feelings, ideas and thoughts about day and night. Initially they were reluctant to draw but due to their teachers' guidance and encouragement, they became quite motivated.

For example, seven-year-old Tuck was excited to show his drawing (see **Figure 4**) about day and night to his teacher (T) and the facilitator (F). His drawing and related verbal communication with his teacher and his facilitator indicated that on the left side of his drawing, Tuck drew the pink crescent Moon while Tuck was sleeping with his air conditioner and fan at night. On the right side, Tuck drew the Sun in yellow with his writing of "Day". Tuck also represented his favorite activities during the day such as playing computer games through drawing his computer in blue.

Tuck also drew his basketball and stand in pink as well as a TV program written as 'wwe'. As shown in the following excerpt, his conversation with his teacher and facilitator indicated that playing basketball and watching a wrestling TV program were also his favorite daytime activities.

01	Tuck	Teacher, look at mine!
02	Teacher	Yeah, so what is that?
03	Tuck	The wrestler in the wrestling.
04	Teacher	The wrestler ah..
05	Teacher	You never put WWE, people don't know, I thought it's your star, oh, that's WWE. And then you never put John Cena's name ah? ((laugh, looking at the facilitator)), he LOVEs wrestling, when he grows up, he wants to be a basketball player or a wrestler, that's why you see the basketball, and the WWE ((laugh))
06	Facilitator	Oh!
07	Teacher	He's always thinking about these things
08	Facilitator	What is the WWE?
09	Teacher	Ah, it's wrestling. Wrestling show on the TV, World Wrestling …?
10	Tuck	Way
11	Teacher	Way or Weight?
12	Tuck	Way, John Way.
13	Teacher	Ray ah? R or?
14	Facilitator	Weight? Do you mean the weight?
15	Teacher	Weight or Way? W, a, y? Or which way? John ray? John way or John weight?
16	Tuck	w, a, y
17	Teacher	Oh, way, I don't know wrestler lah. I don't know wrestling. I don't know, ((laugh))
18	Facilitator	So he is your favorite wrestler?
19	Teacher	Is he your favorite wrestler? John Way? Tuck!
20	Tuck	No such thing, this is the bad wrestler.
21	Teacher	Oh… what's that, how you spell?
22	Tuck	Baron
23	Teacher	b, a, r, o, n

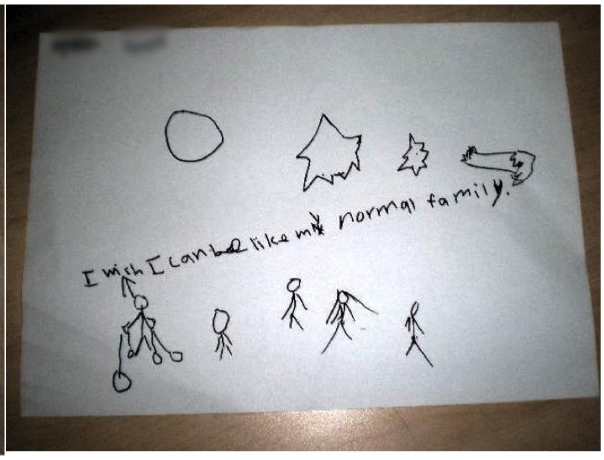
24	Facilitator	Is he a good wrestler?
25	Tuck	No!
26	Teacher	He is a bad one. So who is the good one?
27	Tuck	John Cena.
28	Teacher	You see, he knows all the wrestlers ((laugh)) John Cena is the good one.
29	Teacher	What do you think the moon will look like, Tuck?
30	Tuck	This time?
31	Teacher	Yes, what do you think it looks like?
32	Tuck	Like the sun!
33	Teacher	Like a sun?
34	Facilitator	Okay, is this your sun?
35	Tuck	And I see the alien!
36	Teacher	Eh, I don't know whether there's alien.
37	Tuck	How they know what the planets name?
38	Teacher	Oh, then you ask, you ask!
39	Teacher	Tuck asked a question, how do you know the names of the planets?

After carefully listening to what Tuck said and expressed in his drawing, his teacher often asked (lines 02, 11, 13, 21, 26, 29, 31), elaborated (lines 05, 07, 28, 31, 33, 36, 39) and confirmed (lines 05, 26, 28, 33) Tuck's experiences and ideas and even responded (line 09) to a facilitator question as well as restating, clarifying or elaborating questions (lines 19) the facilitator asked (line 18) beyond simply asking questions. Further the facilitator encouraged Tuck to ask his own question about who named the planets and who decided what to name the planets (line 38). Her communication with Tuck indicated her excellent rapport with Tuck. This led the facilitator to revisit her own experiences with Tuck and to make emotional connections with him, from which the facilitator further restated, clarified and elaborated Tuck's own interests (line 03), feelings (lines 20, 25), knowledge (lines 10, 12, 16, 22), thoughts (lines 27, 32, 35), and questions (line 37).

As shown in **Figures 4 and 5**, apparently the drawing skills of Tuck and other students with special needs were relatively simple. However, such a drawing activity, which was supported and mediated by Tuck's teacher, facilitated and enhanced Tuck's ability to verbalize his experiences and encouraged the expression of his thoughts, beliefs, feelings and perceptions. Similarly, it was not easy for other students to express their thoughts and feelings through drawings without social interactions with their teachers and facilitators.

Hence, by considering the whole process of drawing and working with others such as their teachers, peers, and facilitators, drawing was an important tool for students not only to communicate and interact with others but also to reflect on their experiences and ideas situated in a particular sociocultural context (e.g., favorite wrestling TV program). Although they had difficulty performing fine motor tasks and controlling their movements, students' dedicated teachers' intentions, motives and interests to communicate with them as well as

(a)



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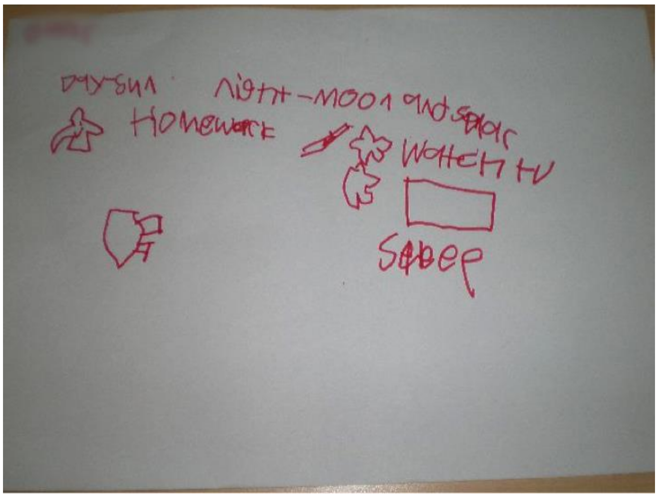

(c)

Figure 5. (a) Drawing about the Day/Night Cycle **(b)** Drawing about the Day/Night Cycle **(c)** Drawing about the Day/Night Cycle

collaborative learning activities designed by the research team supported and mediated the students' communicative intentions and emotional experiences.

The drawing activity provided the students, their teachers and facilitators with time and a place to interact with others whereby they felt more comfortable and had a chance to

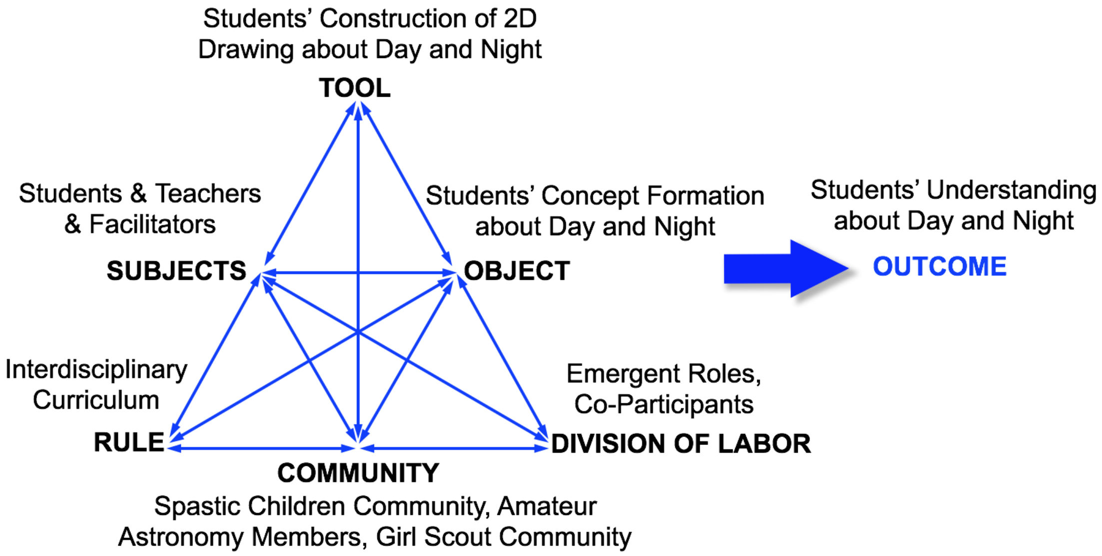

Figure 6. Activity Theory Analysis of the Students' Drawing Activity

listen, ask, elaborate, clarify, understand and extend the students' experiences, thoughts, and voices as well as inquiries. Also the students became motivated in sharing their own experiences and ideas related to the topic of "day and night." Hence, as indicated in **Figure 6**, their drawings led to restructuring of social relationships towards becoming collaborators or co-participants (division of labor) who co-constructed meanings.

In this process, their drawings were also used as effective communicative tools to connect the students and their social environment as well as to reflect their inner voices and emotions.

Following the drawing activity, the students were encouraged to think about the cause of day and night by considering such guided questions as 'Why do we have day and night?', 'How do day and night occur?', 'What causes day and night?', 'What do you see during day time or night time?', 'Does your moon/sun/earth move?', 'How does the moon/sun/earth move?', 'Where is the sun at night?', or 'Where is the moon during the day?'. Particularly, such inquiry questions were situated in 3D modeling activities. Given limited time for the workshop and the students' difficulty to control their motor skills, the students manipulated the researcher-created physical modeling materials such as the Sun, the Moon and the Earth (see **Figure 7**) to make sense of their own drawings about the cycle of day and night.

Although they did not construct their own 3D physical models, the students had a chance to consider how to position three celestial objects (i.e., the sun, the moon and the earth) for representing the phenomenon of day and night. For instance, the research team gave the students a 'person clip' and asked them to show where the person would be when it was night or day time (Vosniadou & Brewer, 1994).

Figure 7. 3D Physical Modeling Activity

Whereas creating a 2D drawing was related to their everyday experiences, involving a 3D physical model required the students to put attention to not only particular properties of each celestial object but also certain relationships (so-called astrophysical relationships) among those celestial objects. For instance, it was necessary for them to consider whether such celestial objects were moving around or not, which directions each object rotates on its axis, how far the Earth is from the sun or the moon, and how far apart the Sun, Moon and Earth are during day and night. With respect to the movement of sun or moon, there were much more diverse ideas such as 'sun and moon do not move', and 'earth and moon was moving' compared to students' two-dimensional drawing models in which they did not show the movement of the moon, earth, sun, stars or other astronomical objects. Hence, the 3D physical modeling activity not only drew the participants' attention to the relationship among the celestial objects but also challenged their prior understanding. Compared to the previous drawing activity in which there was no significant internal contradictions (see **Figure 7**), in such a three-dimensional physical modeling activity, there appeared to have the increasing frustration expressed by the students (indicated by the red arrows in **Figure 8**).

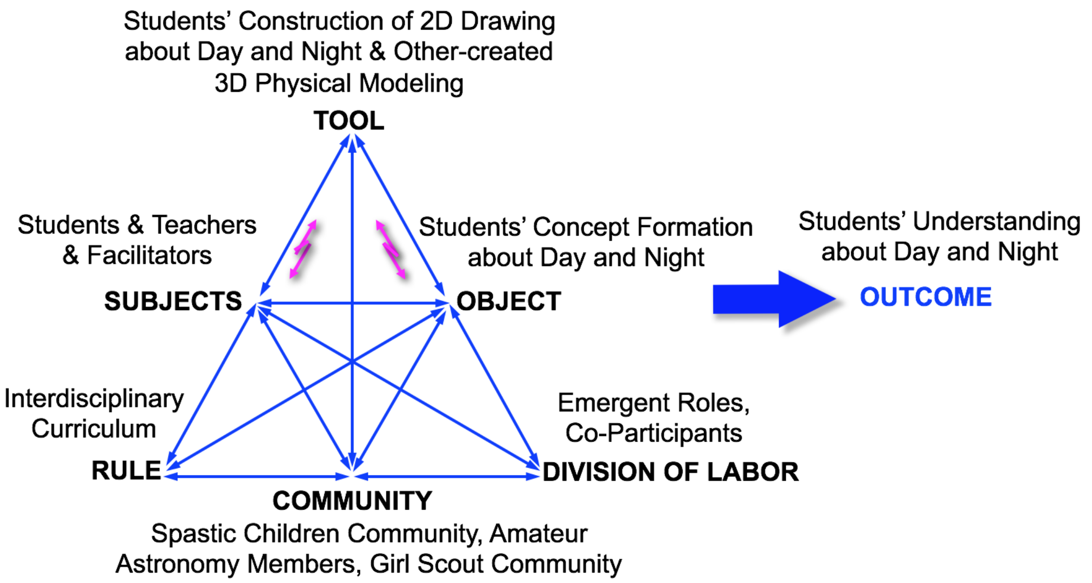

Figure 8. Activity Theory Analysis for Other-constructed 3D Physical Model Activity

Communicating with Themselves through Multimodal Modeling

Referring to their drawings (see **Figure 5**), the students often related the concept of day with (a) concrete objects which they saw during the day time such as the sun, clouds, birds, trees, house, rain, kites and people, (b) concrete actions which they liked to do such as playing, doing Facebook, taking a ride, doing homework, playing on the computer, playing games, playing basketball, watching their favorite TV programs (e.g., wrestling), wearing hats, singing songs and eating. Similarly, they associated the concept of night with (a) concrete objects such as the moon (crescent and full), shooting stars, owls, lights, ghosts, monsters, and cars with lights, and (b) concrete actions such as sleeping, watching TV, turning on a fan, or an air-conditioner. Some of their drawings also indicated the spatial orientation of the objects. For example, **Figure 5** shows that they often drew the moon, sun, clouds, stars and birds on the top and humans, cars, buildings and trees at the bottom of the page.

This 2D paper drawing activity therefore indicates that most of the students only made connections with concrete objects and related actions, so it was crucial for them to further explore the cycle of day and night on Earth. In that respect, 3D physical scale modeling (see **Figure 7**) was implemented to invite the students with special needs to have an opportunity not only to think about the question, "why does Earth have day and night?" but also to experience the process of planetary motions and lights using Sun-Earth-Moon Styrofoam physical models. Interestingly, one participant even mentioned confidently that "the moon reflected the light, so we can see the moon". Also some of them indicated that the celestial objects were moving although their celestial objects were static in their 2D drawing because

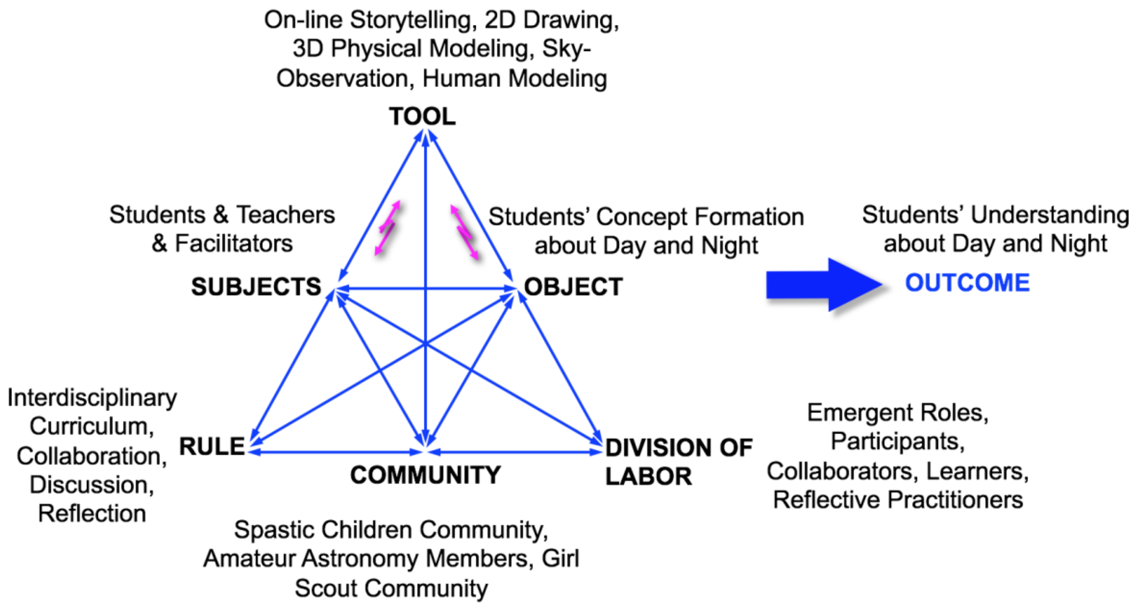

Figure 9. Activity Theory Analysis for an Interdisciplinary Multimodal Modeling

they did not or could not show the movement in their 2D paper drawings. Therefore, such a multimodal modeling activity provided the students with a means of mutual engagement for understanding and representing the relationships among celestial objects.

To support their ideas and understanding about the cycle of day and night, a human model was also developed to model the astronomical phenomena (see **Figure 9**). This activity was aimed to help students have embodied experiences related to the key concept of rotation of Earth causing the cycle of day and night. Kinesthetic modality and a participatory learning approach were applied in this activity. Facilitators explained how the Earth rotates counterclockwise (from west to east) on its own axis (as seen from above with north being up), causing the cycle of day and night (rising in east and setting in west). Such a demonstration required three students to take roles of the Moon, Sun and Earth respectively while wearing a paper-made hat representing their roles. After observing how other peers took a role to represent day and night, the other students also took certain roles to participate in a modeling activity using their body movements. This role-playing activity provided an opportunity for them to experience the rotation of the Earth on its axis. According to their feedback on the workshop, however, such a human modeling activity about moon-sun-earth received less positive feedback from them although most perceived that they learned something about day and night. This may be due to their lack of motor function and they were too tired during the session because the activity was the last one during the workshop.

The availability of volunteers from amateur astronomy clubs gave the students a chance to observe the moon and Jupiter clearly using professional telescopes. This sky-gazing activity was beneficial for the students to be motivated in reflecting on their daily experiences and exploring new scientific knowledge. Their feedback on the workshop showed that the level of engagement in the sky-gazing activity was remarkable. Drawing on above findings, it is obvious that each modeling activity provided different affordances and challenges for the students to construct their own meaning and sense. Most importantly, for the students, it was essential to involve multimodal models to interact and communicate with others. Such social interactions enabled them to use appropriate scientific words (e.g., rotation, axis, cycling) and to further develop the concepts of day and night.

Hence, rather than considering drawings and other multimodal tools as a set of individually acquired skills, we should view them as social practice situated in a particular sociocultural context.

CONCLUSIONS AND IMPLICATIONS

Participation of students with special needs in interdisciplinary multimodal modeling activities resulted in (1) promoting multiliteracies development using multimodality for supporting the emotional and social experiences in developing students' astronomical understanding; and (2) integrating students' everyday experiences with scientific and astronomical understanding for the development of higher cognitive functions. However, the multiple forms of representation constructed by the students has shown that they were faced with the challenge of communicating their spatial concepts and ideas to others including themselves about astronomical phenomena, the day and the night. First of all, because of their limited motor skills, it took a long time for them to complete a drawing activity as well as 3D physical and human models. Secondly, they did not have enough prior learning activities related to targeted multimodal activities. The follow-up teacher interviews indicated that their teachers tended to be very supportive and friendly while implementing lots of hands-on activities (e.g., field trip), but they did not provide enough challenging learning activities to construct the ZPD (Vygotsky, 1978) towards the development of their higher cognitive functions.

These findings support Vygotsky's ideas which argued that the secondary disability caused by insufficient and inefficient social interactions is a much more severe problem than the first disability resulting from the physical disabilities. Thus, we need to understand the disability in terms of a socio-cultural developmental phenomenon rather than a biological impairment having psychological consequences. In that sense, caregivers of the students (e.g., teachers, researchers, parents) need to deal with not only a biological disability (e.g., the sensory or neurological impairment) but also their social consequences, what Vygotsky called secondary disability. The interdisciplinary approach to astronomy teaching and learning involving inquiry-based multimodal modeling activities in this study also addressed a favorable and positive societal outlook on Special Needs Students through identifying levels of overall independence and needs for support. Specifically, this study aimed to foster multiliteracies development using multimodality functioning as a mediator for the students to interact with others by communicating their experiences, ideas, feelings, thoughts and questions about astronomical phenomena.

Most importantly, it is essential to consider positive qualitative differences between a child with special needs and his/her normal peer. This is different from a traditional view on special education in which the difference among them is predominantly quantitative. Special education should not be just a diminished version of regular education. Instead, according to Vygotsky (1993), students with special needs develop differently. Thus, it is essential for educators and researchers working with Special Needs Students to create a learning environment in which alternative means of communication and development need to be considered for students to appropriate and internalize tools or mediators leading to acquiring cultural forms of behavior and developing their higher or cultural development. Hence, the main objects of developing an interdisciplinary approach to astronomy teaching and learning involving inquiry-based multimodal modeling activities are developing shared/joint learning activities to promote the cultural processes of Special Needs Students as well as strengthening their higher psychological functions.

Consequently, moving away from traditional astronomy teaching and learning, this interdisciplinary multimodal modeling approach to astronomy indicates two main benefits for the students: (a) promoting multiliteracies development using multimodality for supporting the emotional and social experiences in developing their astronomical understanding beyond fostering their cognitive development; and (b) integrating learners' everyday concrete experiences with scientific abstract astronomical understanding for the development of higher cognitive functions.

What are the implications to astronomy educational theory and practice using this study? These findings highlight the importance of differentiation between lower cognitive functions and higher cognitive functions for supporting the social and cultural processes of Special Needs Students. Despite their physical impairments, students with disabilities should interact with others to develop higher cognitive functions. An interdisciplinary and multimodal modeling approach could provide such an alternative learning environment in which teachers and researchers need to explore specific complementary strategies to recognize their strengths and to support their difficulties. Another aspect of this research was to explore the ways in which learner-created models represent their ideas in astronomy meaning-making. Further research needs to consider developing technological tools whereby Special Needs Students could overcome their physical impairments and manipulate their ideas to create certain models. Also it is important to integrate diverse tools simultaneously for learners to synthesize and analyze them. This could support the generation of questions and challenges. For this reason, it seems necessary to introduce various ways of modeling and representing students' ideas, which would provide different kinds of affordances for understanding and exploring astronomical concepts.

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