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Slowmation: Preservice Elementary Teachers Representing Science Knowledge Through Creating Multimodal Digital Animations

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Abstract: Research has identified the value of learners using technology to construct their own representations of science concepts. In this study, we investigate how learners, such as preservice elementary teachers, design and make a narrated animation to represent their science knowledge. The type of animation exemplified is called a "Slowmation" (abbreviated from "Slow Animation"), which is a simplified way for preservice teachers to make an animation that integrates features from claymation, object animation, and digital storytelling. Drawing on semiotic theory, a case study of three preservice elementary teachers, who were audio and video recorded as they created a slowmation, illustrates how the construction process enabled them to engage with a science concept in multiple ways. Findings suggest that when preservice teachers create a slowmation, they design and make a sequence of five representations, each being a semiotic system with particular affordances that link as a *semiotic progression*: (i) research notes; (ii) storyboard; (iii) models; and (iv) digital photographs, which culminate in (v) a narrated animation. In this study, the authors present their theoretical framework, explain how the preservice teachers created a slowmation using a sequence of representations to show their science knowledge and discuss the implications of these findings for learners in universities and schools.

Keywords: slowmation; technology; animation; semiotics; multimodal representation

The education literature has repeatedly highlighted concerns about the nature of science learning in schools and universities (Bennett, 2001; Committee for the Review of Teaching and Teacher Education, 2003; Lee, Wu, & Tsai, 2009; National Academy of Sciences, 2006; Tytler, 2008). Despite some notable exceptions, there is a persistent view that science learning is more often about learners' memorization of content as propositional knowledge rather than their development of deep conceptual understanding; at least, that is how many preservice teachers perceive their own school science experiences (Davis, Petish, & Smithey, 2006; Goodrum, Hackling, & Rennie, 2001). What is needed is the introduction of new ways of representing content that motivate students to take an interest in interpreting information, transforming this knowledge, and developing richer links between science concepts and their everyday experiences of the real world (Loughran, 2010).

If teachers are to become more skilled at using approaches that encourage students to engage with content, an obvious place to begin is in their own teacher preparation programs

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by enabling them to experience new ways of learning that may be different from how they learned science when they were at school. One such way is to get preservice teachers to create their own representations of science knowledge. This approach is consistent with current views on learning in science education; ''we conceptualize learning in science as the process and outcomes whereby students come to understand how to interpret and construct scientific meanings, processes and reasoning procedures using the representational conventions of this subject'' (Waldrip, Prain, & Carolan, 2010, p. 69).

This is especially needed for preservice elementary teachers whose limited content knowledge is one reason why they often avoid teaching science (Davis et al., 2006). For example, elementary teachers sometimes have difficulty understanding scientific concepts such as day and night (Atwood & Atwood, 1997), phases of the moon (Trundle, Atwood, & Christopher, 2002), the water cycle (Stoddart, Connell, Stofflett, & Peck, 1993), and energy (Trumper, Raviolo, & Shnersch, 2000). Even in secondary schools, a lack of content knowledge is sometimes a concern for teachers especially if they teach outside their specialization (e.g., a physics teacher teaching biology; Nielsen & Nashon, 2007). Our challenge as instructors in science teacher education is to encourage our preservice teachers to experience for themselves new ways to represent science knowledge. Using technology can sometimes provide such encouragement, especially if the tools help preservice teachers to engage with knowledge and transform it in multiple ways (Jonassen, Myers, & McKillip, 1996; Kim & Reeves, 2007; Lee, Linn, Varma, & Liu, 2010). As Kozma (2000) notes, ''technology can augment the cognitive and social processes of scientific understanding and learning'' (p. 13).

There are several reasons why technology can be such a catalyst. First, it has been argued that learners need to become immersed in ways of thinking and use of technology that are commonly used in scientific communities (Lemke, 1998, 2004). Second, the worldwide explosion in personal digital technologies offers increasing opportunities for learners in universities and schools to use their own technologies to represent content (Kim & Reeves, 2007; Traxler, 2010). For example, nearly all preservice teachers and school children have the capacity to create their own digital media because of their access to digital cameras (still or movie cameras), iPods™ for playing and storing sound tracks, and computers preloaded with free movie-making software. It is not surprising, therefore, that the most popular web sites in the world—Facebook, Wikipedia, MySpace, Twitter, and YouTube—are all driven by user-generated content, which will only expand with the additional affordances of Web 2.0 technologies. Third, there is a growing body of research suggests that getting learners to create their own representations of a science concept using technology is a way to engage them with science content (Hand, Gunel, & Ulu, 2009; Prain & Waldrip, 2006; Tytler & Prain, 2010).

We believe that creating opportunities where our preservice teachers use their own personal digital technologies to design and integrate different modes of representation could be a suitable means to foster such engagement with science content. A mode is a ''meaning-making system in order to articulate the meanings demanded by the social requirements of particular communities'' (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001, p. 43). Examples of modes for expressing meaning include writing, diagrams, graphs, gestures, music, layout, images (still and moving), 2D and 3D models as well as voice. According to Prain (2006), technology can be used to integrate these modes as ''student manipulation of computer-generated texts, where students integrate imagery, sound, mathematical symbols, diagrams, and writing, alters the role of written language as the major or dominant medium of learning'' (p. 180).

Literature suggests that it is relatively common in schools and universities to have learners use various modes to make representations of their science knowledge (e.g., Danish & Phelps, 2010; Mammino, 2008; Prain, Tytler, & Peterson, 2009). In the process of making a representation, learners can translate meaning from one mode to another (Ainsworth, 2008; Van Meter & Garner, 2005). If the representations involve interpreting different modes or media, then there is potential for developing understanding (Eilam & Poyas, 2010). But as Ainsworth suggests, there are challenges in making connections between representations and modes, since learners need to understand how a representation encodes information with particular modes. Ainsworth also notes that making multiple representations of the same concept can also be beneficial for learning. Digital technology has been particularly useful for integrating a range of modes in visualizations of science concepts (Chin & Wu, 2009; Gilbert, Reimer, & Nakhleh, 2008; Tasker & Dalton, 2008). These can take many forms including models, simulations, or games, however, most often these representational forms are expert-generated for learners to interpret the information presented (Gilbert, 2007; Phillips, Norris, & Macnab, 2010). In particular, visualizations in the form of animations can provide new and exciting opportunities to use various modes of representation to facilitate science learning.

Animations in Science Education

Many computer-based environments have been developed by experts to assist learners in working with symbolic representations of various science processes. For example, ThinkerTools (White & Frederickson, 1998) used symbolic elements to represent both real-world objects and abstract concepts allowing middle school learners of varying ability levels to explore Newtonian mechanics. Elliot Soloway's group at the University of Michigan developed a series of computer-based tools to support phases of scientific investigation. One of these, Model-It (Metcalf, Krajcik, & Soloway, 2000; Soloway et al., 1997), is a specially designed software program that enables middle and high school students to build qualitative models to explore dynamic phenomena, such as water quality in a stream or the effects of different drugs on the human body. Other topics that have specially designed animations targeting a range of school and university learners include the mathematics of change and variation (Roschelle, Kaput, & Stroup, 2000), infectious diseases (Colella, 2000), astronomy (Sadler, Gould, Brecher, & Hoffman, 2000) as well as other scientific visualizations (Clark & Jorde, 2004; DeJong et al., 1999; Edelson, 2001).

However, studies on student learning using computer-generated animations have produced mixed results. For example, some studies have shown that watching animations to explain science concepts has improved the knowledge of both high school students (Marbach-Ad, Rotbain, & Stavy, 2008) and college students (Williamson & Abraham, 1995), especially with regard to learning about challenging concepts such as molecular genetics and college level chemistry. In contrast, other studies have found that there has been little improvement in learning when students in introductory college chemistry courses watch animations that are intended to explain science concepts (Sanger & Greenbowe, 2000; Yang, Andre, Greenbowe, & Tibell, 2003). For example, reviews of literature involving over 100 studies found mixed results regarding the relationship between use of animation and student learning across many contexts (Berney & Betrancourt, 2009; Rapp, 2007; Sperling, Seyedmonir, Aleksic, & Meadows, 2003). A common finding was that animations often present key concepts too quickly and do not explain concepts well, largely because they are designed to demonstrate educational concepts in real time (Tversky, Morrison, & Betrancourt, 2002). One suggestion is that the educational value of animations could be improved if the key features to be learned were highlighted and if they were played slower to enable learners to follow the movements in the objects being animated:

> Animations must be slow and clear enough for observers to perceive movements, changes, and their timing, and to understand the changes in relations between the parts and the sequence of events. This means that animations should lean toward the schematic and away from the realistic... It also may mean annotation, using arrows or highlighting or other devices to direct attention to the critical changes and relations. (Tversky et al., 2002, p. 258)

One salient point, however, is that nearly all animations intended to promote student learning have been designed by experts. If there was a change in the role of who makes the animation and for what purpose, it might provide a different way for learners to use animations to engage with science knowledge.

Learner-Generated Animations

It is possible that animations could carry new meaning if learners themselves (preservice teachers or school students) became the designers and creators rather than consumers of knowledge presented in expert-generated animations (Chan & Black, 2005). In accord with this view, Bransford, Brown, and Cocking (2000) argued that making and manipulating science models is valuable because learners "develop a deeper understanding of phenomena in the physical and social worlds if they build and manipulate models of these phenomena" (p. 215). However, the possibility of learners designing and creating their own animations has been limited because the process of making an animation is usually too complex and time consuming. The significant challenge of learners creating animations of science concepts is clear from the paucity of research in this area.

To gauge the extent of research, the following string was used to search across six educational databases (Proquest Educational Journals, ERIC, EdITLibrary, Scopus, ISI Web of Knowledge, and Science Direct): "student generated or learner generated or student created or learner created and animation and science." The search revealed a small number of research publications involving learners creating animations about science. One learner-centered animation software, called *Chemation*, was specially designed to enable 7th grade school students ($N = 271$) to design and evaluate simple flip-book like animations about the particulate nature of matter (Chang, Quintana, & Krajcik, 2010). Pre- and post-test results revealed that there was a significant effect on the learning of student participants, especially if they also peer-evaluated the animations produced. Students needed access to hand-held Palm computers to help them design the animations to represent chemical reactions. Other studies have been conducted using another specially designed software, *ChemSense*, which enabled high school students to construct their own representations of molecular level animations in chemical systems by viewing, manipulating, and interpreting visualizations in chemistry (Schank & Kozma, 2002; Stieff & Wilensky, 2003; Wilder & Brinkerhoff, 2007; Wu, Krajcik, & Soloway, 2001). A third specially designed software, *Carousel*, enabled 12 computer science undergraduates to design their own animations of three different mathematical algorithms involving text, pictures, video, animations, and speech, which could also be shared with other students on a web site (Hubscher-Younger & Hari Narayanan, 2008). Pre- and post-tests suggested that authoring and evaluating animations was a positive learning experience for most of these students. A common feature of these studies involving either *Chemation*, *ChemSense*, or *Carousel* was that the animations produced were peer reviewed, which also enhanced student learning.

Although the number of research studies on learner-generated animations is small, their educational value was noted: "encouraging students to create their own animations (which are not found in textbooks or commonly employed by teachers) of complex procedural concepts may enhance learning in an otherwise traditionally delivered course'' (Hubscher-Younger & Hari Narayanan, 2008, p. 258). However, in each study a specially designed software package needed to be programmed in order for the students to generate their own animations. It seems reasonable to suggest that a simpler way to make animations without requiring subject specific software would enable learners to create animations across a range of concepts and possibly provide a new way to represent their science knowledge.

Slowmation: A Simplified Way to Make Stop-Motion Animations

Because of advances in personal digital technologies, it is now becoming easier for learners such as preservice teachers to make animations to explain their interpretation of a science concept. But even with access to portable technologies, making an animated mini-movie to explain a science concept could still be difficult for them because science objects do not move by themselves unless they are motorized. However, using a traditional stop-motion animation technique is feasible because it is the creator who manually moves the objects whilst taking a digital still photograph, thus eliminating the need for complex mechanisms to provide movement. Yore and Hand (2010) also contend that getting students to make stop-motion animations is a good way for teachers to introduce content as ''students take a series of still photographs and produce a time-series or time lapse collection or a flipbook to illustrate relative motion'' (p. 99). However, traditional approaches to stop-motion animation, such as claymation are still very tedious and challenging to implement in the confines of a science methods class.

Slowmation (abbreviated from ''Slow Animation'') is a simplified way for preservice teachers to make a narrated stop-motion animation as an instructional resource to explain a science concept (Hoban, 2005, 2007, 2009). They can learn the process in 1–2 hours using models made out of everyday materials, such as plasticine, cardboard, or paper, or use existing plastic models and take digital still photos of the models as they are moved manually. Creating a slowmation integrates features of clay animation, object animation, and digital storytelling (Lambert, 2002) with the product being similar to a narrated flip-book. It involves the preservice teachers designing a sequence of five representations using a range of modalities (Hoban & Nielsen, 2010, 2011): (i) research notes; (ii) storyboard; (iii) models; (iv) digital photographs; and (v) the narrated animation. In short, a slowmation displays the following features:

purpose. The intention of a making slowmation is for preservice teachers to engage with science content by making a 1–2 minute narrated animation as an instructional resource to explain a science concept. According to Jonassen et al. (1996), when students design multimedia to explain content ''they reflect on that knowledge in new and meaningful ways'' (p. 95). Its design can include a range of enhancements such as narration, music, and static images.

timing. Slowmations are usually played slowly at 2 fps, not the usual animation speed of 20–24 fps, thus need 10 times fewer photos than in clay or computer animation, hence the name ''Slow Animation'' or ''Slowmation.'' This slow speed is suitable for a narration to explain the science.

orientation. Models are made in 2D and/or 3D and usually manipulated in the horizontal plane (lying flat on a table or the floor) and photographed by a digital still camera mounted on a tripod looking down or across at the models, which makes them easier to make, move, and photograph.

materials. Because models do not have to stand up, many different materials can be used such as soft play-dough, plasticine, 2D pictures, drawings, written text, existing 3D models, felt, cardboard cut-outs, and natural materials such as leaves, rocks, or fruit.

technology. Students use their own digital still camera or a hand-held mobile phone camera (with photo quality set on low resolution) and free movie-making software available on their computers (e.g., iMovie or SAM Animation on a Mac or Windows Movie Maker on a PC).

In summary, slowmation greatly simplifies the process of creating an animation enabling preservice teachers to: (i) make or use existing 2D or 3D models that may lie flat on a table or the floor; (ii) play the animation slowly at 2 fps requiring 10 times fewer photos than normal animation; and (iii) use widely available technology such as a digital still camera, a tripod, and free movie-making computer software. Whilst previous research on learner-generated animations (Chang et al., 2010; Hubscher-Younger & Hari Narayanan, 2008; Schank & Kozma, 2002), has identified their value, the research area could benefit from the development of a simpler way for learners such as preservice teachers to make them. The purpose of the present study, therefore, is to investigate how preservice teachers create a slowmation to represent their science knowledge. To address this purpose, the following research question was posed:

> How did the preservice teachers represent their science knowledge by making a slowmation and what were their reflections on the construction process?

Whereas most research studies on animations have used either cognitive or situative theories as their focus (Russell & Kozma, 2007), our theoretical framework for the study draws on a language-based theory, semiotics, because it focuses on the representations produced to help explain the slowmation construction process and the preservice teachers' reflections on their meaning making.

Theoretical Framework

The theoretical framework selected to study slowmation construction is semiotics—the study of signs and their relationship to meaning making. In semiotics, a sign is something that stands for something else, such as the sign H stands for Hydrogen in the Periodic Table. Peirce (1931/1955) was one of the pioneers in the field and identified three terms that help explain how meaning is made when a sign represents an object: (i) a "referent" or "object" is the concept or content being represented; (ii) the sign created is called a "representamen" or more recently a "representation"; and (iii) the meaning generated from the sign is called an "interpretant." This is how he explained the relationship between the three terms:

> A sign or *representamen*, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the *interpretant* of the first sign. The sign stands for something, its *object*. . .that is to have a like content. (Peirce, 1931/1955, pp. 99–100) [italics in original]

As Peirce noted, these three influences on meaning making—the referent, the representation, and interpretant—do not act independently, but instead form an interrelated whole as a "semiotic system." This dynamic relationship is shown in Peirce's (1931/1955) triadic model

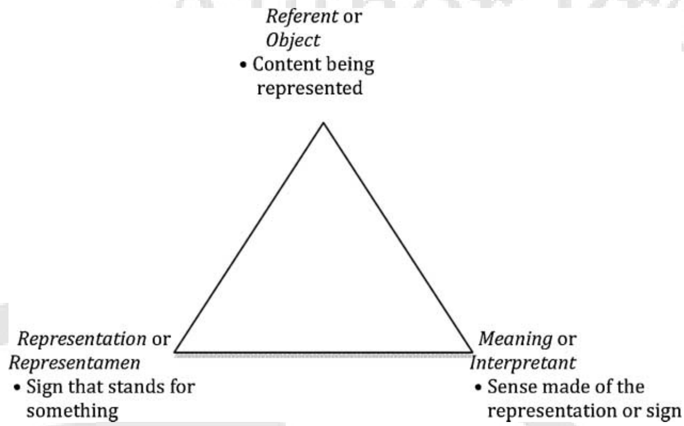

Figure 1. Peirce's (1931/1955) triadic model of a semiotic system.

of a semiotic system in Figure 1. For example, a high school student who wants to learn about the solar system may read about the content from a reputable source (the referent or object) and as a consequence sketch a 2D diagram of the planets positioned in orbits around the sun (the representation), thus making meaning about the order of the planets (the interpretant). Clearly, this is not a linear process. Rather, the process is dynamic as the student makes meaning by iteratively checking the content whilst creating the diagram, which is consistent with the semiotic system shown in Peirce's triad.

More recently, Lemke (1998) also explained how a semiotic system involves a connection between related elements using a range of modes to construct meaning:

> I believe that all meaning-making, whatever semiotic resource systems are deployed, singly or jointly, has become organized around three generalized semiotic functions[Q2] (Lemke, 1989, 1990, 1992, 1995). When we construct meaning we always simultaneously construct a 'presentation' of some state-of-affairs, orient to this presentation and orient it to others and in doing so create an organized structure of related elements. (p. 91)

Both Peirce's (1931/1955) and Lemke's (1998) explanation of a semiotic system, however, usually refer to a representation that has been constructed by experts for learners to interpret. Although from early last century, the theory of semiotics explaining how learners make meaning by interpreting representations still has currency in science education research (Gilbert, 2007; Prain, 2006; Prain & Waldrip, 2006; Tytler & Prain, 2010; Tytler, Prain, & Peterson, 2007). According to Waldrip et al., (2010), "with any topic in science, students' understandings will change as they seek to clarify relationships between their intended meanings, key conceptual meanings within the subject matter, their referents to the world, and ways to express these meanings" (p. 67).

Another feature of making representations is that signs can form a "semiotic chain" whereby one sign or representation is converted into another sign or representation and so "yield chains of signs from a single object, where the first sign stands for an object and a related sign comes to stand for the first sign, and so on" (Driscoll, 2000, p. 170). For example, the gears on a bicycle can be counted and the ratios between them represented in a table, and then re-represented into a line graph and then a column graph, thus creating multiple representations of the same concept. Science education researchers claim that meaning-making is enhanced when learners create more than one representation of a concept; ‘‘multiple representations refers to the practice of re-representing the same concept through different forms, including verbal, graphic, and numerical modes, as well as repeated student exposures to the same concept’’ (Prain & Waldrip, 2006, p. 1844). When students create one representation from another it is called a translation task. According to Loughran (2010):

> *Translation* occurs when ideas and information presented in one way are processed and then used in another form. It requires cognitive manipulation as the ideas and information being worked will need to be well understood in order for them to be applied in a different way in a different setting. Being able to translate information is one way for students to demonstrate understanding of a subject because the work of translation depends on much more than just restating facts and information. (p. 104) [italics in original]

In agreement, Yore and Hand (2010) claim that ‘‘the transformation among multimodal representations has the greatest potential in promoting learning and depth of processing’’ (p. 96). Other researchers have also argued for the value of learners creating multiple representations of the same concept as a semiotic chain (Bezemer & Kress, 2008; Hand & Choi, 2010; Kozma, 2003; Kress et al., 2001; Lemke, 1998; Waldrip et al., 2010). How preservice elementary teachers represent their science knowledge by making a slowmation, as well as their reflections on the construction process, is now demonstrated in a case study of three preservice teachers, which was preceded by pilot studies.

Methodology

Pilot Studies

Two pilot studies preceded the case study reported in this article because to the best of our knowledge, getting preservice teachers to use their own technology to create animations to represent science knowledge is a relatively new field of research and the pilot studies helped us to refine the methodology. In both studies, the participants were preservice elementary teachers at a university in a 4-year Bachelor of Education program in New South Wales, Australia. During that period of time, all the elementary preservice teachers in three cohorts (over 600 in total) in a core science methods course successfully made a slowmation as one assignment to explain a science concept although only a small number were selected to be participants in the two pilot studies.

In both pilot studies, preservice teachers were allocated typical elementary science topics at the beginning of a science method course (e.g., weather patterns, life cycles, floating and sinking, habitats, day and night, phases of the moon, earthquakes, forces, animal adaptations, seasons, motion, or kitchen chemistry) and participated in a 1-hour workshop on how to create a slowmation. They were expected to create a 1–2 minute narrated slowmation as one assessment task to explain a science concept from their allocated topic as an instructional resource for children in elementary schools. The preservice teachers in both pilot studies were interviewed as soon as they were allocated a topic and asked to sketch a concept map, which was used to help identify their prior knowledge about the concept. They were then interviewed 4 weeks later when they had submitted their slowmations. During the interviews, participants modified the concept maps that they had previously sketched. Data suggested that the preservice teachers ($N = 15$ in 2007 and $N = 14$ in 2008) designed a slowmation to represent science knowledge as a multimodal representation (Hoban, McDonald, & Ferry, 2009; Hoban, McDonald, Ferry, & Hoban, 2009). However, data from these studies did not allow us to draw conclusions as to how they actually created the slowmation. We felt that we needed to design a more focused study in which data were collected during the actual construction process to understand how the preservice students created a narrated animation, which is the aim of this study. An overview of the two pilot studies and the case study is summarized in Table 1.

Case Study

In order to address our research question, we used a case study design (Merriam, 1998; Stake, 1995; Yin, 2003) to study the construction process as a group of three preservice teachers actually designed and made a slowmation. The narrated animations that our preservice teachers made are instructional resources in content areas consistent with the K-6 Science and Technology Curriculum (New South Wales Board of Studies, 1991). The process for creating a slowmation has developed over several years and we now explicate our data collection procedures for the study.

Data Collection. The study was conducted based on the assumptions of a constructivist–interpretivist paradigm (Gallagher and Tobin, 1991; Schwandt, 2003) that guided how data were collected, analyzed, and interpreted. To research the actual creation process of making a slowmation, a case study was conducted in November 2009 in which three elementary preservice teachers, Jackie, Elettra, and Alyce, constructed a slowmation from start to finish. The study took 3 hours including the time for pre- and post-data collection (the actual construction time was under 2 hours). The three preservice teachers were assigned the topic at the beginning of the 3-hour study, ‘‘Life Cycle of a Ladybird Beetle,’’ a topic that was only revealed to them at this time and asked to create a 1–2 minute slowmation as an instructional resource for elementary children. The preservice teachers were interviewed individually before and after the study including constructing and later modifying a concept map. As they

Table 1
Overview of two pilot studies and case study

Time Frame	Participants	Research Approach	Data Collection Methods
Pilot study 1: July to October 2007	Preservice elementary teachers, $N = 15$	Individual studies of preservice teachers	Pre- and post-creation interviews, animations as artifacts, pre- and post-concept maps
Pilot study 2: July to Octobe 2008	Preservice elementary teachers, $N = 14$	Individual studies of preservice teachers	Pre- and post-creation interviews, animations as artifacts, pre- and post-concept maps
Case study: November 2009	Small group of preservice elementary teachers, $N = 3$	Case study over 3 hours as three preservice teachers created an animation about a topic about which they were unfamiliar	Video and audio data collected during the construction of the animation, pre- and post-interviews and concept maps, individual and group field notes during the construction process

jointly constructed their slowmation, they were audio and video recorded and the artifacts produced were also collected.

It should be noted that there was some previous preparation for the study: (i) the three preservice teachers were in the third year of a 4-year Bachelor of Primary Education degree program and had previously made a slowmation in a first year course, so they were familiar with the construction process and use of the technology; and (ii) a week before the study the students completed 1-hour workshop in which they were encouraged to "think-aloud" and verbalize their thinking as they made a slowmation. It should be noted that in order for the case study to finish within 3 hours (including the pre- and post-interviews), the preservice teachers were given a plastic model set of the four stages in the life cycle of a ladybird beetle, but no other information was provided. They were also provided with assorted colors of plasticine and construction paper to make any other models. Data from the transcript of the construction were selected to illustrate how the preservice teachers represented their content knowledge during the study. Data are also included that were collected after making each representation, whereby the three preservice teachers held a "reflective discussion" in which they articulated influences on their thinking consistent with their "think aloud" workshop.

It is beyond the scope of this study to make claims about the preservice teachers' learning through making a slowmation, which is documented in a separate paper (and includes data from the pre- and post-interviews, the concept maps, and a discourse analysis). Instead, the purpose of the current study is to investigate how the preservice teachers made a slowmation to represent their science knowledge and their reflections on this process as elaborated in the case study. An overview of the creation process is shown in Figure 2 which illustrates the five representations that were constructed by the three preservice teachers resulting in a

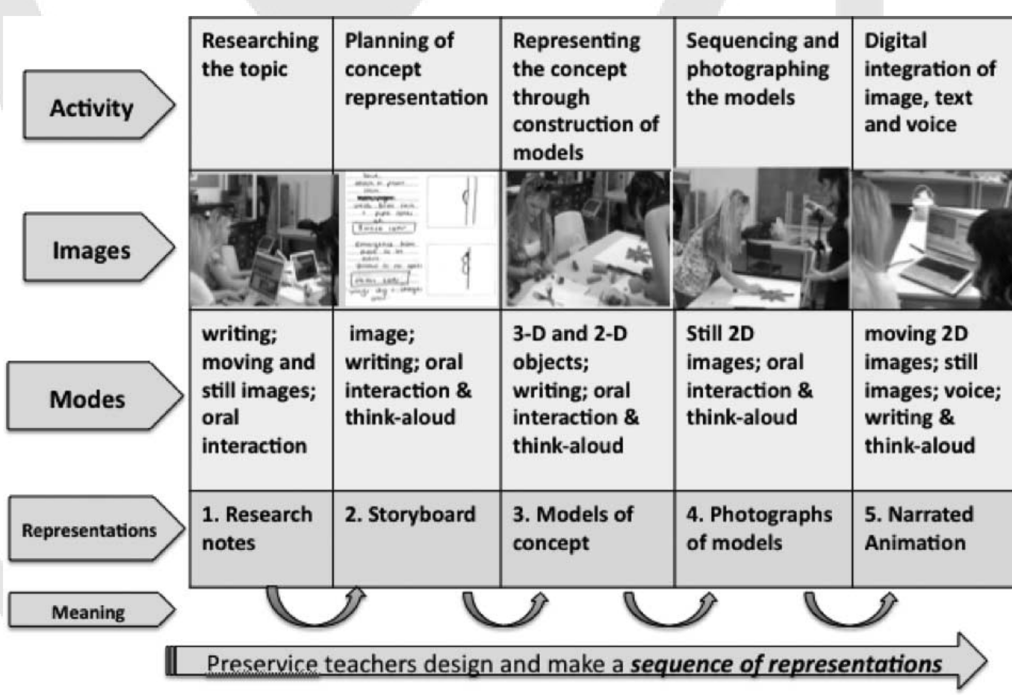

Figure 2. Overview of the slowmation construction process.

slowmation: (i) research notes; (ii) storyboard; (iii) models; (iv) digital photographs; and (v) the narrated animation.

The next section presents data collected during the construction of each representation along with our interpretive analysis. To address the first part of the research question concerning how the preservice teachers represented their science knowledge, a general description of the making process is provided followed by excerpts from the case study collected from video and audio recordings as they constructed each representation. To address the second part of the research question concerning the preservice teachers' reflections on the construction process, we present data from the reflective discussions held immediately after each representation was completed.

Findings

Representation 1: Research Notes

Some background knowledge is required before preservice teachers can begin to think about designing and making an animation as an instructional resource to explain a science concept. As a starting point, preservice teachers are usually allocated a topic and then conduct research in order to be cognizant of salient information that they can use to represent a concept. From observations of and interviews with preservice teachers from the two pilot studies and the follow-up case study, preservice teachers mainly gather information through an internet search using the Google search engine and/or by watching videos on YouTube.

The following excerpts from the case study illustrate discussions about the science content as the preservice teachers gathered initial information from the internet about the topic of the "Life Cycle of the Ladybird Beetle" allocated to them at the beginning of the study. The three elementary preservice teachers (Jackie, Elettra, and Alyce) were sitting around a desk, each with their laptop computers open using a wireless connection to the internet as shown in Figure 2. They were all gathering information by reading Wikipedia and watching a video from YouTube, discussing what they found and writing notes. As they were doing their research, the preservice teachers clarified two points of confusion. The first was shared between Jackie and Elettra as they clarified the differences between an egg, larvae, and pupae:

> Jackie: So the larvae are the eggs, yeah?
> Elettra: No, the larvae is the pupa thing, and there's one of them there. [points to the internet]. I'm pretty sure that just moves around and then the thing comes out of it, but I don't know, like there must be a phase.
> Jackie: [reading from the internet] 'So there are four stages—egg, larvae, pupa, and adult'. That's what it says here. Yes look, the larvae hatches from the tiny eggs. I thought larvae were eggs, but I guess not, that's confusing.
> Elettra: That's a pupa. . .this would be the larvae [pointing to the screen]. So this is what I thought the mating was [from YouTube video]. See how it looks like two bugs, it's coming out of it and then it turns into that [points to the screen].

The preservice teachers' second point of confusion concerned what ladybird beetles eat (aphids), and whether an aphid was a plant or animal:

> Jackie: What's an aphid, did we say that?
> Alyce: Oh, and they eat aphids.

Jackie: Yeah, that's why she lays the eggs there, the female lays the cluster of eggs near an aphid colony.
Elettra: Sorry, aphids are plants aren't they?
Alyce: Some sort of flower?
Elettra: What's an aphid, OK?
Alyce: It's like a little, yeah, we need more information than what I'm saying about aphids.
Jackie: Are you saying it's an animal or a plant?
Alyce: No, it's a little bug.
Elettra: "also known as plant lice. Small plant-eating insects" [reading from Wikipedia]

During this time the preservice teachers summarized their research using the internet in nine dot points, which took 20 minutes. Then they had a reflective discussion for a few minutes about creating this first representation. They discussed how they were processing information in a multimodal way by reading text, viewing still images and the video as well as looking at the models. Interpreting this information challenged some of their prior knowledge and clarified two points of confusion:

Jackie: My previous ideas were challenged because I didn't know what an aphid was and I actually thought larvae were eggs, but in fact these are the eggs and the larvae comes out of the eggs. So I didn't realize that.
Elettra: I was confused with that as well.
Jackie: So I guess as I was reading, my ideas were conflicting, so I had to change my understanding of what larvae was.
Alyce: So it was like from the reading of the material on our search engines and the pictures have helped us see and understand. . .so models have helped us, the internet has helped us, speaking to each other about what we know, like sharing things.
Jackie: Yeah, rephrasing our ideas.
Elettra: So first of all we read information so we were like reading.
Alyce: So you were imagining it in your own head from what you're reading.
Elettra: We looked at the words, then looked at the pictures, like the photos of a life cycle and then we actually watched the video.
Jackie: It confirms what knowledge was gained, like confirmed the knowledge gained was correct.

In relation to Peirce's triad in Figure 1, the preservice teachers generated nine dot points using the mode of writing (the representation) to summarize features of the ladybird lifecycle (the referent), which was a semiotic system. The meaning generated (the interpretant) was then transferred and used in designing the next representation.

Representation 2: Storyboard

There are two aspects when creating a storyboard as the second representation in a slowmation—chunking and sequencing. First, making a storyboard encourages preservice teachers to break a target concept down into its constituent elements or "chunks." Each chunk then needs to be placed in a sequence to bring the anticipated actions and explanations into a coherent order. In addition to storyboarding, a narration is usually scripted because thinking about a narration is likely to inform other parts of the storyboard such as sketches and labels. In this study, however, the preservice teachers discussed the narration at the end of the storyboarding but did not script it until the final representation. Data collected illustrates how the preservice teachers designed their storyboard by contracting the nine dot points from the research notes into six chunks, each represented in the mode of a sketch with a label as shown in Figure 2: (i) ladybird beetles mating in spring; (ii) laying eggs next to aphid colony; (iii) larvae crawls out of eggs and eats aphids; (iv) larvae attaches to plant stem and pupae comes out; (v) emergence from pupae as an adult; and (vi) color develops, eats aphids, looks for mate straight away. As they did this they checked their information by referring back to the text they read from Wikipedia and the YouTube video. An excerpt of the dialog is provided showing how the preservice teachers made decisions about the design and modes to use based on what they had read and viewed on the internet:

Jackie: So the first slide will be about mating in the spring and then summer. . .and the next sequence will be laying the eggs.
Elettra: What do they lay them on? It [the internet] says near aphids.
Jackie: Well it'd be near the aphid colony, so I guess it would be on some part of a plant.
Elettra: But they [YouTube video] show the aphids on a stem didn't they?
Jackie: All right, so put them right near a stem.
Elettra: There's the little aphids. [as she sketches them]
Jackie: Yes, so we can draw a little plant stem if you want and have the ladybird just come and lay the eggs there.
Elettra: So laying the eggs next to aphids, then the eggs hatch. [sketches]
Jackie: Yes, into the larva. So we have this larva crawling out of the eggs and then the eggs disappear.
Elettra: I've got the pupa attaches itself to a stem. Oh sorry, the larvae attaches itself to the stem, sheds a final skin and the pupa comes out. How long is it in the pupae phase?
Jackie: One week and then it goes to the next phase.

In the reflective discussion held immediately after designing the storyboard, the preservice teachers stated that constructing a storyboard helped them to break down the information and provided them with a chance to "check" their information and think about the simplest way to explain it to elementary children:

Jackie: It's helping us to clarify the sequence of the life cycle.
Alyce: So we did a sequence before we put it onto the storyboard. Because we're learning such new information, we needed to break it down so we'd remember it for a start.
Jackie: And we're trying to plan, we are learning new information so we're breaking it down.
Elettra: And then we're just transferring it but simplifying it for children, so we've gathered our information, we've written down the main points, now we're going, like re-collaborating on our information like I guess putting it into our brain.
Alyce: So before putting all our information into the storyboard, we've decided to make sure it's right, check it's right and add to it before we transfer it.

In relation to Figure 1, the process of creating the storyboard using the modes of sketches and writing (the representation) to explain phases of the ladybird lifecycle (the referent) was a semiotic system with the meaning (interpretant) generated being transferred to guide the design of the next representation of modeling. It is worth noting that the process is not linear, but is recursive like a system with the preservice teachers moving back and forth between sketching and writing the storyboard as they checked their information from the internet and from YouTube (both were used as sources for the referent) to clarify the length of each phase of the life cycle and the role of the aphids as food.

Representation 3: Models

The third representation involves preservice teachers thinking about each chunk of the storyboard in concrete ways and how to best represent it through constructing models. Because the models in a slowmation are often layed down flat on a table or a floor, many different types of materials can be used to express the particular features of the concept. In the case study, the preservice teachers were given a plastic model for each of the four life-cycle phases. The prefabricated models helped to limit the time required for the construction to under 2 hours, however, the preservice teachers decided to make other models to complement the ones provided. They made another model of a ladybird beetle (as a partner) out of plasticine, as well as models of the aphids. They also collected a real plant stem and leaves from the garden as props as shown in Figure 2. Making the models made the preservice teachers think about the relative size of aphids compared to the ladybird beetle as they again checked their knowledge using the internet:

Elettra: We're ready to start making.
Alyce: What's that coming out there? [pointing to the model of the emerging adult]
Jackie: They're the wings, that's the wings while drying.
Elettra: That's what I got from it, I'm pretty sure that's what it says in here. [reading from the internet] "Emergence." Here we go..."Twenty-four hours after emergence from the pupa case the rear shell changes from yellow to red. The spots will appear while the wings are drying."
Elettra: Look, here is our stem and the leaves. Well, we have no little aphids, what can we have for little aphids? Let's make them...oh, but the paper is yellow. Aphids can be orange.

In the reflective discussion immediately after model construction, the preservice teachers noted that as they were making models, they were again discussing and checking information from the internet about features such as emergence and the actual appearance of the ladybird beetle and the aphids. Interestingly, they discussed that although being presented with pre-made models did limit construction time, it also meant that they did not check the details of these models, which limited their thinking. In contrast, making models caused them to check their information to ensure that their models were accurate with an appropriate relative size:

Alyce: I think being given the models is in many ways responsible for the way that we're doing it. Because in a way we're limited because we can't make the model.
Elettra: Whereas if you are making it yourself, you're constructing it yourself and you need to go into more information and look for actual visual images of what it would look like.
Alyce: So you are learning more.

Referring back to Peirce's (1931/1955) triadic model in Figure 1, a semiotic system was established by the preservice teachers trying to represent features of the ladybird beetle and aphids (the referent) through making the aphids and the ladybird beetle partner out of plasticine as well as the props (the representation). The meaning generated (interpretant) was then transferred and used in the next representation as they photographed the manual movements of the models.

Representation 4: Photographs

The next step involves taking digital still images of the models as they are manually moved in small increments consistent with a stop-motion animation technique. Photos can be taken with a digital still camera mounted on a tripod looking down at the models or using a camera in a hand-held mobile phone. The preservice teachers in our study placed a yellow piece of project cardboard flat on a table and mounted a digital still camera on a tripod next to the table looking down at the cardboard sheet as shown in Figure 2. They placed a plant stem, collected from the garden, flat on the cardboard, and then arranged models of the aphids in a fork on the stem. The ladybird models were manually moved step-by-step to approach the aphids as photographs were taken of each movement. As the preservice teachers were taking photographs, they were able to stop after each one to discuss any points of confusion and when needed, recheck their information in order to correctly label the duration of each life cycle stage. Only one photo was taken of the title page and labels as these are copied several times as a ''static image'' in the final representation. In double-checking the content with the internet, they realized they had made an error with regard to labeling the time for the stages and were able to correct it and take another still photo:

Elettra: How long do they stay eggs? How much did we say?
Jackie: Eggs hatch into a larvae stage. It [internet] says it stays like this for 10–15 days.
Alyce: We should quickly find out, because we're saying how long everything else is.
Alyce: How long until the eggs hatch, is it 7 days or something? Ah, ''egg stage, 2–5 days.'' [reading from the internet]
Elettra: How long did we say the larvae stage was?
Jackie: 10–15 days.
Elettra: Because here [internet] it says 21 days. Three weeks, that'd be right, 3 more days. . .we need to double-check the information. [on the internet]
Alyce: OK, well that's like conflicting what we just wrote.
Elettra: No, because the egg stage is 21 days.
Alyce: The egg stage is 21 days?
Jackie: Yeah, because we've said the larvae stage.
Elettra: Oh sorry, I got totally confused. [reading from the internet] 'Egg stage is 2–5 days, larvae stage is 21 days' which is 3 weeks, ''pupae stage is 7 days.''

In the reflective discussion after taking the photos, the preservice teachers acknowledged that they confused some information about one of the stages. As a result, they stopped and checked their information with the internet about the length of each stage. As they took the photos they were visualizing the video they had seen on YouTube:

Elettra: Well, with taking the photos we had to double confirm our information.
Alyce: Oh, that's right because we found that we were missing some information.
Jackie: I think its also helping to clarify it as well, because as I'm making this [model of a ladybird beetle], I am imagining it like a movie in my head. So I can see the animation like moving through the life cycle stages.

Alyce: I'm thinking of the video when we're doing it as well, that we saw on YouTube. That's what's in my head, stuck in my head the most probably.

In relation to Peirce's (1931/1955) model in Figure 1, the process of moving the models and taking the digital photographs (the representation) to represent phases of the ladybird life cycle (the referent) was another semiotic system with the meaning (interpretant) generated being transferred and used in the design of the final representation.

Representation 5: The Narrated Animation

The final step of the construction process involves downloading the images onto the desktop of a computer and uploading them into any movie-making software on a computer. This is an important aspect of thinking because it offers a meta-level of analysis whereby the synthesized explanation of the concept can be viewed as a whole and altered accordingly. During this editing, refinements can be made to enhance it as an instructional resource by ''copying and pasting'' key images such as labels and important still images as many times as necessary to be ''static images'' to suit the narration.

When the preservice teachers finished taking their photographs, they sat down at Alyce's computer and downloaded the photographs onto her desktop. The photographs were then uploaded into a movie-making program on her laptop computer. Importantly, the animation speed was set at 2 fps to provide the slow-moving images enabling the preservice teachers to provide a narration. Also, the preservice teachers made decisions about which photographs should be ''copy and pasted'' to stay on the screen longer than the predetermined half-second as a ''static image.'' Although it is suggested that the narration be written during the storyboarding, in this study the preservice teachers wrote it in this last phase. Interestingly, it was whilst writing the narration that the preservice teachers stopped and had a discussion about another point of confusion regarding what ladybird beetles eat. Up until making this last representation, Jackie thought that ladybird beetles ate plants, but she was corrected by Elettra as they suddenly realized that ladybird beetles were carnivores:

Jackie: As we are preparing the narration, we're recasting one another's ideas to formulate what we are going to say.
Alyce: Stuff is sinking in better I think, like I just realized that ladybirds are carnivores.
Elettra: I was just saying then, ladybirds eat aphids and Jackie said, ''and other small plants'' and I went, ''no, other small insects.'' And they were like, ''oh, that's right, they don't eat plants.''

Finalizing the slowmation construction involves recording the narration to explain the slow-moving images supported by the static images as labels and key still photos. Below is a script of the co-constructed narration that was recorded by Elettra to explain the ladybird beetle life cycle in the 1 minute and 9 second animation:

''The Life Cycle of the Ladybird Beetle''
Ladybirds mate in spring and summer.
The female lays a cluster of eggs of up to 300 near an aphid colony.
After 2–5 days the eggs hatch into a larvae state. This state lasts up to 3 weeks.
The larvae eat aphids and grows rapidly shedding its skin several times.
When the larvae is full size, it attaches itself to a plant stem.
The larvae splits and exposes the pupae stage which lasts for 1 week.

After this week the ladybird emerges as an adult.
It is a pale yellow color with no spots.
But over 24 hours the wings dry and its color darkens to become red with black spots.
Adult ladybirds eat aphids and other small insects and quickly search for a mate.
The Life Cycle continues.

When the preservice teachers held their final reflective discussion immediately after finishing the slowmation, Alyce used the term ''foreign'' to describe information written in their first representation as research notes, but this ''started to sink in'' as they made the other representations:

Alyce: It started off foreign, it was foreign information to us; we didn't know anything. Then as you started to see the pictures [on the internet], we could link the information with the pictures. And then as you saw the video we could think and string it all together and say, ''Oh, so that and that work together to make this.'' And then let's try and make that ourselves and then it started to sink in through the actual making of it. Even though the information is there, you can read something, but you do not necessarily take it in. These steps have helped us, you know, to take it in.
Int: What do you mean take it in?
Elettra: Gain the knowledge.
Alyce: Observe it, you can read a book and not be concentrating, so to actually take it in and apply it to yourself and store it in your head.
Jackie: I think that's because we had to represent it in multiple ways. Like we had to represent it visually, had to represent it orally, written and then orally as well, yeah, in the different ways.
Elettra: The three aspects or modes of learning are there. You've got your visual learners, your verbal learners and your kinesthetic in the doing, like they are all there.

In sum, the preservice teachers created a 1 minute and 9 second narrated animation to explain the life cycle of a ladybird beetle, which was a topic introduced to them only 2 hours earlier (See Animation S1 for the slowmation created by the preservice teachers available as Supplementary Material accompanying the online article).

Discussion

The need to find new ways for elementary preservice teachers to represent science knowledge is well documented (Bennett, 2001; Committee for the Review of Teaching and Teacher Education, 2003; Davis et al., 2006; Goodrum et al., 2001; Lee et al., 2009; National Academy of Sciences, 2006; Tytler, 2008). With regard to the first part of the research question concerning how the preservice teachers made a slowmation to represent their science knowledge, they re-represented text, still images, and video they had seen on the internet by designing and making a sequence of representations culminating in a narrated animation as an instructional resource for elementary children. Furthermore, each representation was a semiotic system (Lemke, 1998; Peirce, 1931/1955) because the preservice teachers were making meaning (the interpretant) as they made decisions about which modes to use (the representation), as well as thinking about how to integrate them to best explain the life cycle of the ladybird beetle (the referent). Furthermore, the final semiotic system is a multimodal digital animation that the preservice teachers designed by aligning the modes of slow moving images, still images, text, and narration to complement each other (Jewitt, 2009; Kress et al., 2001). A key feature of this process is that it did not involve the use of any topic-specific software as in other learner-generated animations such as *Chemation* (Chang et al., 2010), *Carousel* (Hubscher-Younger & Hari Narayanan, 2008), or *ChemSense* (Schank & Kozma, 2002).

Another feature of the making process that distinguishes it from topic-specific software, is that the creation process involves the preservice teachers in "translating" (Loughran, 2010) the content five times through a progression of representations. To make the first representation of research notes, the preservice teachers translated information presented in text, still images and video from the internet into nine summary points. These points were then translated to make the second representation of a storyboard, whereby the preservice teachers synthesized the nine points into six chunks (sketches with a label), and then sequenced them in a way that best explains the concept. Each chunk or panel in the storyboard was then translated into models in the third representation by using existing plastic models and making new ones. The fourth translation involved manually moving these models in order to take the digital still photographs. The fifth and final translation involved uploading the digital photographs into the movie-making software on a computer and using technology to edit and integrate the modes of narration, writing, still, and moving images to explain the concept.

This sequence of interrelated semiotic systems, involving a transfer of meaning from one representation to the next culminating in the final narrated animation, we call a *semiotic progression*. This is different from a semiotic chain (Driscoll, 1990[Q3]), which involves changing one representation into another complete representation, such as changing a table into a graph, because each representation in a slowmation transfers meaning to be a part of the subsequent one rather than being a finished representation, except for the final narrated animation. It needs to be noted, however, that this progression of meaning is not strictly linear, because in the construction of each representation, there was a good deal of recursive checking of information with the internet and with previous representations.

With regard to the second part of the research question concerning the preservice teachers' reflections on the construction process, they shared reflections immediately after making each representation, which provided some interesting insights. One finding is that each representation had a role or affordance that focused the preservice teachers' thinking about the concept in a particular way. For example, in constructing the first representation of research notes, the preservice teachers engaged in multimodal learning by summarizing information presented in the modes of writing and still images on Wikipedia as well as from video from YouTube. The storyboard then has the affordance of making the preservice teachers "break down" the content into several "chunks" and place them in a logical sequence. The chunks are then used as the basis of modeling, which has the affordance of causing the preservice teachers to closely examine features of the model they are making thus motivating them to check details of the content. Taking the digital photographs as the models are moved manually using a stop-motion technique has the affordance of focusing the preservice teachers on aspects of relative size and visualizing how the models move in relation to each other, "like a movie in my head" (Jackie). Importantly, this stop-motion technique enables the preservice teachers to stop, discuss and check their information whilst taking each photo, which is different from making a video in which the filming is usually continuous. Finally, the affordance of the final representation is that the preservice teachers use technology to integrate the four modes of writing, moving, and still images and narration. Constructing each representation therefore allows the preservice teachers to revisit the content for different purposes and "the three aspects or modes of learning are there" (Elettra).

A useful feature of making a slowmation is that the preservice teachers used their own technology to create their digital artifact to represent their knowledge. This includes using their own digital still camera mounted on a tripod and using the generic movie-making software existing on their own computer. Although not a part of this study, another use of technology could be sharing and critiquing a learner-generated animation. This is similar to what previous researchers (Chang et al., 2010; Hubscher-Younger & Hari Narayanan, 2008; Schank & Kozma, 2002) noted, whereby learners were involved in reviewing and critiquing each other's animations, so that the public display of the created representations could be a further enhancement to student engagement. This is an important step because any representation, especially created by learners, is an approximation to the referent or content it is representing. Public display of a slowmation may provide an opportunity to become aware of and discuss preservice teachers' alternative conceptions, which may be revealed in a representation that they create (Keast & Cooper, 2011). The important point being that creating a slowmation to explain a science concept produces a digital artifact that can be shown publically, which may illuminate preservice teachers' alternative conceptions and in so doing, the conception may be modified in light of discussion or further research.

A limitation of the study is that there were only three preservice teachers involved and they were self-selected when we asked for volunteers. Also not providing the existing plastic models would have enabled the participants to investigate particular features of each life cycle phase in more detail, but the construction process would likely to have taken longer than 2 hours. Repeating the study with a range of learners such as other preservice teachers and school students and using a range of topics would confirm the findings of this study. Moreover, conducting additional studies using a quasi-experimental design with groups that use different forms of representation such as expert-generated animations would be a useful comparison.

Implications for Science Education

There are several implications for the use of slowmation in the science education community. First, the simplicity of the construction technique and accessibility of the technology suggest that slowmation may provide opportunities for widespread use by a variety of learners as a new way of representing science knowledge. There is already evidence for this on the internet. A Google search on the word *Slowmation* provides several hundred URLs showing examples created by elementary, secondary, and university students from different countries and there are over 100 examples already uploaded to YouTube. The use of mobile phone cameras creates additional possibilities for using stop-motion animation in different locations.

It does not surprise us, however, that we have not been able to find other examples in the research literature of preservice teachers creating animations to explain science concepts. We attribute this to the crowded curriculum in a science methods course and time consuming nature of making animations in a traditional way. However, because of the simplicity of the slowmation technique, preservice teachers can learn how to make one in a 1–2 hour class, and then create their own at home using their own technology as an assignment or a home project. The number of plastic models in school and university science laboratories may also provide opportunities for creating a slowmation, for example, models of atoms for organic and inorganic Chemistry, models of cells and human organs in Biology, models of land forms in Geology as well as a range of equipment in Physics. Other specific models exist in laboratories in a Faculty of Science (even in Medicine and Dentistry), enabling science university students to animate them using a stop-motion technique to explain the concepts as instructional resources.

In a school context, our preservice teachers have shown the slowmation they made to primary children whilst on practicum and some have encouraged the children to create their own by making or using existing models. The most common use appears to be encouraging school children to make a slowmation towards the end of a science topic as an assessment task to represent what they have learned about the topic. In some school classes, these have been shown to the rest of the class to discuss if the science concepts were represented accurately and evaluated in terms of how they could be improved. Uploading these to the internet on YouTube or TeacherTube makes collaborations between classes in different schools possible.

A second implication is that getting learners (university students or school children) to create slowmations as instructional resources may be a new way for them to learn science content or at least provide a motivation to learn it. Current literature in science education has emphasized the value of learners constructing their own representations of a science concept and re-representing these ideas to enhance understanding (Anthony, Tippett, & Yore, 2010; Hand & Choi, 2010; Hand et al., 2009; Prain & Waldrip, 2006; Tytler & Prain, 2010; Waldrip, Prain, & Carolan, 2006; Yore & Hand, 2010). To justify this inference, however, is beyond the scope of this study and would require analyzing the pre- and post-knowledge of the preservice teachers as well as conducting a discourse analysis of the discussion whilst they created their slowmation. It would also mean repeating the case study using a range of concepts and a range of preservice teachers. A third implication is that whilst this study focuses on how preservice teachers design and make a progression of representations when creating their slowmation, the research studies conducted so far have not focused on the decisions learners make regarding the relationship between the different modes and representations. Yore and Treagust (2006) emphasized that there have been few studies to investigate ‘‘the enhanced cognition that occurs during the transformation from one representation to another representation or one mode to another’’ (p. 208).

It is clear that further research is needed to study how learners in different contexts use their own technology to design and make multimodal animations to represent science concepts. This would include studies to develop insights into how preservice teachers and school students might build understanding of science concepts through the creation process. We are hoping that this study may provide an impetus for further studies to investigate how, why, and when preservice teachers or school children use different modes to represent their ideas and the possible consequences for their learning. With the inevitable rapid advances in personal digital technologies and Web 2.0 capacities, we anticipate that learner-generated digital animations such as slowmation may have an increasing presence in university and school science courses.

Free examples, instructions and resources for making Slowmations can be accessed at the project web site www.slowmation.com. The authors would like to thank the three preservice teachers who participated in this study as well as the anonymous reviewers and colleagues who provided insightful feedback on drafts of the article.

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Name ________ **Purchase Order No.** ________

Institution ________ Phone ________

Address ________

________ Fax ________

________ E-mail ________