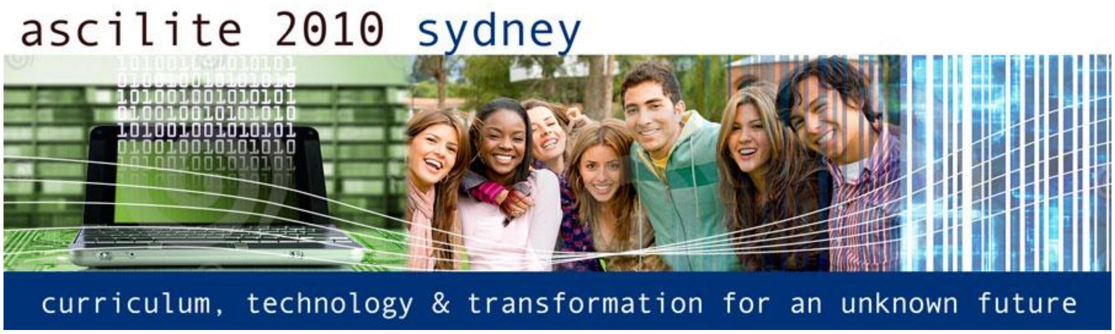

Articulating constructionism: Learning science though designing and making "slowmations" (student-generated animations)

Garry Hoban, Wendy Nielsen & Charles Carceller
Faculty of Education
University of Wollongong

This conceptual paper analyses several theoretical frameworks for "learning through making" using technology. First, the theoretical framework of Constructionism, which was proposed by Seymour Papert (1987), is discussed which is based on an integration of constructivist views of learning and social views of learning. Second, several instructional design frameworks are analysed and finally a theoretical framework based on Peirce's (1931) Semiotic Triad is explained. An example of learning through making is provided in the form of a "Slowmation" (abbreviated from "Slow Animation"), which is a new way for preservice teachers to learn science by making a narrated animation. It is a simplified form of stop-motion animation that integrates features of clay animation, object animation and digital storytelling. A theoretical framework then evolves that guides students in learning by creating a sequence of five multimodal representations (the 5 Rs): Representation 1 — research being written notes from summarising a topic; Representation 2 — a storyboard to plan the design of the animation; Representation 3 — making 2D or 3D models; Representation 4 — taking digital still photographs of the models as they are moved manually; and Representation 5 — creating the animation which can include text and a narration. Each of the theoretical frameworks help to explain the learning involved when students design and make an artefact using technology but the most relevant one is Peirce's (1931) Semiotic Triad. Theoretical frameworks help to explain student learning that occurs through "designing and making" but some have limitations and their use depends on the purpose and context.

Keywords: constructionism, student-generated animations, slowmations, semiotics

Background

The world-wide explosion in personal digital technologies offers increasing opportunities for students in universities to learn by making their own digital media. Twenty years ago, getting preservice teachers to make a mini-movie about a science concept was unheard of because of the expense of acquiring a movie camera and a video player. Also, digital still cameras for personal use were science fiction. But times have changed. Nearly all university students now have access to digital cameras (still or movie cameras), iPods for playing and recording sound tracks, and computers preloaded with free movie making software. It is therefore not surprising that the most popular web sites in the world, Facebook, Wikipedia, MySpace and YouTube, are all driven by user-generated content because of this widespread accessibility to media making technology. With this access to new technologies, therefore, it is becoming easier for students to design and make their own multimedia. Consequently, it is becoming commonplace for students to upload their multimedia products to YouTube, Facebook and MySpace. Although many of these artefacts are for entertainment value only, increasingly students are using technology to make artefacts as representations of their content knowledge. It is therefore timely to discuss the theoretical frameworks that underpin 'learning through making" especially for knowledge representations. The remaining parts of this paper discuss three such theoretical frameworks: (i) Constructionism; (ii) instructional design frameworks; and (iii) Semiotics using Peirce's (1931) Semiotic Triad.

Theoretical frameworks: learning through making

1. Constructionism

This view of encouraging students to learn by making artefacts or representations with technology was first proposed in the theory of "constructionism", which was originally proposed for science teacher education. Seymour Papert introduced the term in his 1987 National Science Foundation grant application entitled, *A New Opportunity for Elementary Science Education*. He defined the term in the grant abstract:

> The word constructionism is a mnemonic for two aspects of the theory of science education underlying this project. From constructivist theories of psychology we take a view of learning as reconstruction rather than as a transmission of knowledge. Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences is constructing a meaningful artefact. (Papert, 1987, p. 2)

Papert contended that students engage in deep learning when they research, design and construct an artefact or model as a representation of their knowledge. He later explained how constructionism links personal and social influences on learning because the artefact produced is an output of the interaction of personal and social knowledge construction that needs to be meaningful and made public:

> Constructionism—the N word as opposed to the V word—shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (Papert, 1991, p.1)

In reviewing the history of constructionism, Kafai (2006) recently noted that although constructionism has its roots in Piagetian theory, it is not the same theory. This is because Piaget placed an emphasis on individual knowledge structures whereas constructivism focused on the connection of both individual *and* social influences on learning. Most research studies that have used constructionism as their theoretical framework have involved students using computers to design various motorised models using the "digital manipulatives" of LEGO™/Logo building blocks and digital beads (Harel & Papert, 1991; Kafai & Resnick, 1996). Resnick (1998) stated that these design activities encourage active participation, interdisciplinary knowledge, pluralistic thinking, reflection and social engagement. In his studies, children as young as 10 years old constructed robotic creatures such as dinosaurs and other moving animals and objects. Other studies have moved beyond programmable LEGO™ robots to involve young children designing software (Kafai & Ching, 2001; Kafai, Franke, Ching, & Shih, 1998; Kafai & Roberts, 2002). An important insight from these studies was that young children can learn to become software designers when they work in partnership with more experienced software designers to develop a "culture" of collaboration in the planning and construction phases of designing and making.

However, reviewing the literature on constructionism has indicated that it is more of a "meta-theory" than an explicit learning theory per se. It does not go beyond the proposition of highlighting the importance of the interaction of personal and social influences on learning and is not explicit about how this occurs.

Furthermore, there appears to be few articles, which use constructionism as a theoretical framework, that articulate the process of designing and making artefacts and justify why this process is beneficial for student learning. This is not surprising considering that Papert himself did not restrict himself to encouraging students to making artefacts with technology, and he often talked about the value of students designing other artefacts such as “sandcastles”, “soap sculptures”, “art projects” and “”build-an-animal-kit” (Papert, 1991). Moreover, he often emphasized that constructionism has a much broader application beyond computers to other examples of designing and making artefacts as vehicles for knowledge construction. There are other frameworks for designing artefacts with technology that have been grouped together as “instructional design frameworks.”

2. Instructional design frameworks

There are many articles that explain the process of designing and making of an artefact using technology often under the umbrella term of “instructional design”. It should be noted, however, that some instructional design frameworks are not intended for learning but rather focus on the design framework assuming that others will provide the content. Hence their value for learning depends on their purpose and context for use. Lehrer (1993) provided one instructional design framework when university students made a multimedia project which he called “A Framework for Hypercomposition-based Design” (p. 202) as shown in Figure 1:

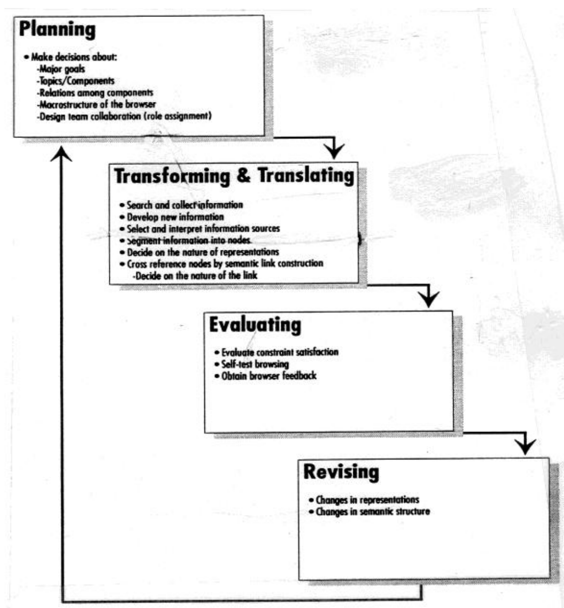

Figure 1: Lehrer’s Framework for Hypercomposition-based Design

Interestingly, his instructional design framework is based on a literacy model of text construction by Hayes and Flower (1980). An important point in relation to Lehrer’s (1993) article is that he highlighted that in designing hypermedia, students are “placed in the role of organizing information in multiple ways and. . . .because hypermedia composition involves multiple forms of media, students are confronted with decisions about the *representational* role of each of the forms of media” (p. 201) (emphasis by authors). However, he did not articulate the possible learning opportunities or theoretical explanation underpinning his framework beyond mentioning that students make many decisions about content and design.

Another framework for multimedia design was put forward by Taylor, Sumner, and Law (1997). They called it a “Layered Framework” consisting of seven layers: (i) educational aims; (ii) teaching strategies; (iii) task semantics; (iv) task syntax; (v) resource organization; (vi) software issues; and (vii) delivery and use platforms. They make the point that this sequence is not always linear and not every layer needs to be included in a design process. Again, this article did not attempt to explain how this framework could promote learning through design. Another common instructional design framework has been called the "ADDIE" model that guides multimedia design according to the following five steps: (i) Analyse; (ii) Design; (iii) Develop; (iv) Implementation; and (v) Evaluation.

Recently, more dynamic frameworks have been proposed for software design such as the "iterative design framework for educational multimedia" (Holmquist & Nayayanan, 2002). A feature of this model is that it proposes a non-linear dynamic approach in preference to a linear approach and involved cycles of design and testing such as shown in Figure 2.

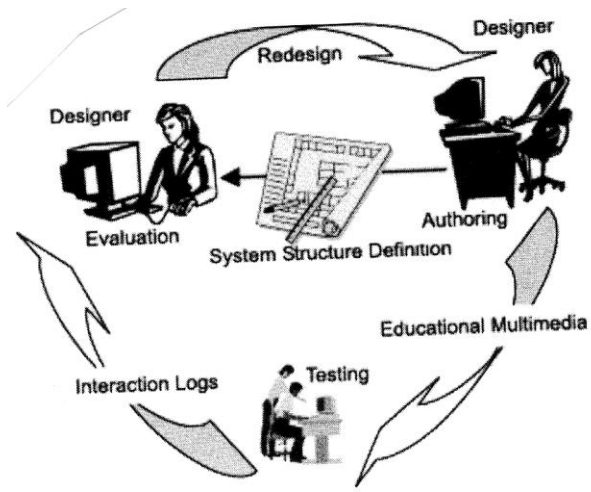

Figure 2: Holmquist and Narayanan's Iterative Design Framework

However, whilst these four instructional design frameworks infer that learning through designing might occur, none of them argue or articulate why this might be the case. If understanding the content in order to design a multimedia product was an important purpose of the process, then it would seem likely that the learners as designers would make many decisions about the content and as a result learn about it through the design process. A different theoretical framework based on the literacy field of semiotics more clearly articulates the relationship between learning and the design process.

3. Semiotics

The exponential growth in personal digital technologies previously mentioned coincides with a growing body of research which suggests that getting students to create digital artefacts, such as multimodal representations of a science concept, is a way to enhance learning because they are making "signs" about learning (Ainsworth, 1999; Prain & Waldrip, 2006; Tyler & Prain, In Press; Waldrip, Prain, & Carolan, 2006). Using semiotic reasoning, a representation is a sign that stands for something else and can be expressed using different modes — by text, photographs, sketches, voice, numbers, graphs or models. It is through developing a sign and thinking about its meaning that learners develop a better understanding of the world. It has also been argued that students need to become immersed in the digital literacies and ways of thinking that are used in scientific communities. According to Lemke (1998), all digital representations, especially if they are multimodal, are semiotic systems which can be interrelated to promote meaning making:

> In multimedia genres, meanings made with each functional resource in each semiotic modality can modulate meanings of each kind in each other semiotic modality, thus multiplying the set of possible meaning that can be made ... This combinatorial semiotic principle provides not just a theoretical framework, but an analytical engine for investigating multimedia semiotics. (p. 92)

There is a growing acknowledgement, therefore, that students need to use various forms of scientific literacies, not only as a way of recording information, but also to facilitate learning. Moreover, learners need to use a range of modalities — text, images, models, and voice— in designing representations (Lemke, 2000; Prain, 2006; Prain & Waldrip, 2006). Importantly, research has shown that making a digital representation helps learners to make meaning of a science concept and this is often preferential to students copying an expert-generated representation from a text book (Hubber, Tytler, & Haslam, 2010; Waldrip, Prain, & Carolyn, 2010).

Insights from semiotics (the study of signs) explain why designing a representation, with or without technology, helps students to learn. When designing a representation, students develop meaning because they compare their own ideas with those of the referent or object to which they are referring or trying to represent (Peirce, 1931). This relationship involves an interaction between the sign or representation (what is created), the referent (what is being represented) and the meaning made (personal interpretation) and was first identified many years ago in Peirce's semiotic triadic model as shown in Fig 3.

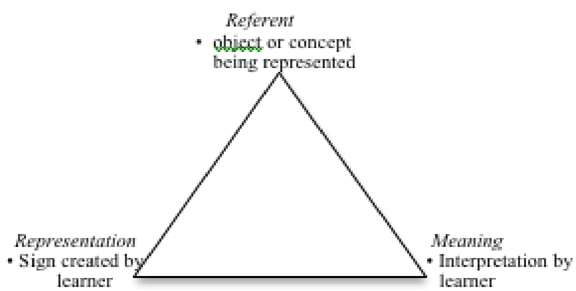

Figure 3: Peirce's Triadic Model of a Semiotic System

As shown in the model, the relationship between a representation and the referent (that sometimes results in meaning making) is not a linear process, but rather is non linear and dynamic. 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).

Science education researchers also point out that meaning making is enhanced when students create not one, but multiple representations of a concept (Prain & Waldrip, 2006): "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" (p. 1844). Designing multiple representations is also consistent with communication practices used in the scientific community, "scientists co-ordinate features within and across multiple representations to reason about their research and negotiate shared understanding based on entities and processes" (Kozma, 2003, p. 210). In support, researchers who specialize in analyzing language (Kress et al., 2001; Lemke, 1998) argue that learning or meaning making is 'multiplied' when students present their ideas using a variety of representations. When students design a sequence of representations it becomes a "semiotic chain" which is an expanded version of Pierce's Triadic Model as shown in Figure 3 but multiplied several times taking into account the number of representations that are designed in a sequence. The example shown in Figure 4 shows a sequence of five representations. An example will be provided in the next section of the paper.

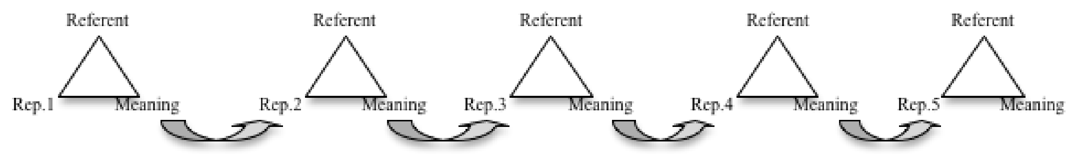

Figure 4: The Five Representations (5Rs) Conceptual Framework for Student-generated Animations

Example: learning by making student-generated animations

The next section will provide an example of learning through design. With the wide access to personal media-making technologies, it is now possible for students to make a movie representing their understanding of a science concept. But even with access to the technology, making a movie demonstrating change in a science concept could be difficult for students to create, because inanimate science objects do not move by themselves unless they are motorised. On the other hand, making a movie using a stop-motion animation technique is a possibility because it is the creator who manually moves the objects whilst taking the digital still photos. Furthermore, having students take digital still photos one by one instead of a continuous 30 frames/second in a video allows them to manipulate, think about, and reconfigure the models as each still photo is taken.

Slowmation: A simplified form of stop-motion animation

A "Slowmation" (abbreviated from "Slow Animation") is a stop-motion animation created by preservice teachers at university that played in slow motion at 2 frames/second to explain a science concept (Hoban, 2005, 2007, 2009). Slowmation is a simplified way of making an animation that encourages students to design a multimodal representation of their learning and integrates features of clay animation, object animation and digital storytelling. Like clay animation (Witherspoon, Foster, Boddy, & Reynolds, 2004), slowmation uses a stop-motion technique involving the manipulation of models made out of plasticine or soft play dough as digital still photos are taken of each manual movement. Like object animation, a range of materials can be used such as plastic models, wooden, paper or cardboard cut-out models commonly found in primary classrooms to animate (Laybourne, 1998). Similar to digital storytelling (Lambert, 2002), a key part of creating a slowmation is that a narration and other photos can be added by the students to explain the science concept as the models are animated. In short, a slowmation displays the following features:

- *timing* — slowmations are usually played slowly at 2 frames/second, not the usual animation speed of 20-24 frames/second, and thus need ten times fewer photos than in clay or computer animation, hence the name "Slow Animation" or "Slowmation";
- *purpose* — the goal of a slowmation is for preservice teachers to engage with science content by making an animated mini-movie to explain a science concept and through the creation process, learn about the concept. Its design can include a range of technological enhancements such as narration, music, other photos, diagrams, models, labels, questions, static images, repetitions and characters;
- *orientation* — models are made in 2D and/or 3D and usually manipulated in the horizontal plane (lying flat on the floor or on a table) 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; and,
- *technology* — students use their own digital still cameras (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). Students can learn how to make a

slowmation in a two hour workshop which gives them enough skills to make one as a university assignment.

In sum, slowmation greatly simplifies the process of making an animation with preservice teachers using 2D or 3D models that may lie flat on a surface, designing the animation to play at 2 frames/second requiring 10 times fewer photos than normal animation, and using their own digital still camera and free movie making software on their computer.

Example of preservice teachers creating a slowmation

Over the last three years, over 600 slowmations have been made by preservice teacher education students at The University of Wollongong and Monash University through a funded national research project by the Australian Research Council. The preservice teachers learn to make a slowmation for the first time in a two hour workshop and then create one as an explanatory resource on an allocated science topic as a university assignment. This can take up to 5-10 hours and they make it at home using their own digital still camera, everyday materials and the free movie making software on their own computers.

Examples have been made of many science concepts and shown in mini 1-2 minute animated movies explaining a variety of concepts such as seasons, lunar cycles, life cycles of various plants and animals, particle motion, magnets, plant reproduction, weather cycles, movement of the planets, water cycle, simple machines, mitosis, meiosis and phagocytosis. Research has shown that the preservice teachers develop a deep understanding of the science content when they create a slowmation (Hoban, McDonald, & Ferry, 2009; Hoban, McDonald, Ferry, & Hoban, 2009), and this is a key goal for our pedagogy of teacher education in science methods classes. Table 1 summarises the five different representations involved in creating a slowmation along with a photo of students making the particular representation.

Table 1: The Five Representations (5Rs) in creating a slowmation

Sequence of Representations with Modalities	Action and affordances	Example
Representation 1 *Research* — text — diagrams	The preservice teachers research information about topics such as the ladybird beetle on their lap tops and record them by creating notes summarizing the key points. The affordance makes the students summarise information in notes or diagrams.	
Representation 2 *Storyboarding* — diagrams — text	The preservice teachers create a brief storyboard called a "chunking sheet." The affordance of a storyboard is that it makes the designer break down a concept into its constituent parts and place them in a sequence.	

Representation 3 *Modelling* — 3D models using playdough and cut out paper	The preservice teachers create models of the four phases of the ladybird beetle. The affordance of creating models is that it makes the designer thinking about the particular features of each part.	
Representation 4 *Photographs* — digital still images of the small manual movements	The preservice teachers take photographs of the models as they are moved manually. The affordance of taking photographs is that it makes the students think about how the models move in relation to each other.	
Representation 5 *Animation* — computer generated digital animation —narration	The preservice teachers download the photos onto the computer, edit them, make static images, add a narration and export it to a QuickTime format. The affordance of making the animation is that it makes the students put the parts together into a coherent whole and explain the science with a narration.	

It should be noted, however, that learning by creating an animation to explain a concept could be explained by each of the three theoretical frameworks but with different foci. Constructionism focuses on the broad interaction between personal and social knowledge construction whereas instructional design frameworks focus on the process of design. It appears that semiotics provides the most detailed explanation of learning because it acknowledges the learning that can occur from each of the five representations that make up a slowmation. Accordingly, each representation has particular affordances what make students think about the concept being represented in multiple ways. This is like making five of Pierce's Semiotic Triads shown in Figure 3 as the preservice teacher thinks (making meaning) about the content (referent) for each representation.

Each representation, therefore, is like its own semiotic system with meaning generated from one representation to the next as shown in Figure 4. In the first representation, *research,* students take notes by researching a science concept (referent) which is then passed onto the second representation. In *storyboarding,* students plan the design of the animation using a storyboard whereby the referent is broken down into "chunks," which involves sketching diagrams and writing a narration which then becomes the basis for the third representation, *models.* Students can make 2D or 3D models which makes them check content again as to what the actual referent looks like or use existing models of the referent. In the fourth representation, *photographs,* students take digital still photos of the small manual movements of the models leading them to think about how the parts of the models move in relation to each other. In the fifth representation, the *animation,* students synthesise what they have learned from the previous representations as they upload the photos into the software, edit them and add the narration to make the final animation to explain the referent.

Discussion and conclusion

Student-generated multimedia has traditionally involved students designing products for the purpose of entertainment. But with the increased access to simpler media making technologies, it is now becoming easier than ever for students to make media products as a new way of learning content knowledge. However, existing theoretical frameworks commonly used in technology research seem to be limited in articulating the type of learning through designing representations of content. For example, the theoretical framework of Papert's (1987; 1991) constructionism that has existed for 23 years, has argued for both individual and social influences on learning when designing an artefact for sharing, but the interrelationships are not explicit. Other frameworks, such as those from instructional design, although identifying steps for the design process, also do not explain why involving students as designers could be a valuable process for learning. Interestingly, some of the design frameworks, such as Lehrer's (1993) Framework for Hypercomposition-based Design, have hinted that students are making many decisions and connections when designing a multimedia product, especially about the nature of the "representation", but the framework does not make this link to learning. It appears, therefore, that the theories for learning through designing using technology served their purpose at the time of introduction, but are now limited in terms of explaining the learning processes that are now possible with new software and the affordances from Web 2.0 technologies. In short, the practical field of technology use for student-generated media has progressed faster than the theoretical field for explaining the learning that is possible.

The literacy-based learning theory of Semiotics appears to provide the most valuable insights into the process of students learning through designing. The designing and making process therefore incorporates many dynamic learning processes as articulated in the sequence of the five representations (5Rs). As such Peirce's semiotic triad best explains why students learn science by creating an animation. This is because students design a sequence of five representations, each making the designer think about the content/referent in different ways, resulting in meaning generated from one to the next and involving a constant checking of content through each representation. Hence, getting students to make an animation about a science concept results in them clarifying, checking and refining their understanding. Furthermore, because the technology is relatively easy and accessible— only needing a digital still camera and their own free movie making software — the approach has possibilities for widespread use in universities and schools. In short, the theoretical framework of semiotics seems to extend and articulate the theory of constructionism in regard to students designing and making animations. As further technological advances occur, student-generated media such as slowmations will become more commonplace in universities and schools for learning content such as science. Hence, learning theories will need to keep pace with technological advances by evolving or integrating in order to provide more sophisticated explanations about why students learn through media creation.

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2. Free examples and instructions for creating Slowmations can be obtained from www.slowmation.com.

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Author contact details:
Garry Hoban garry_hoban@uow.edu.au
Wendy Nielsen wendy_nielsen@uow.edu.au
Charles Carceller charles_carceller@uow.edu.au
Faculty of Education
University of Wollongong

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