ZDM Mathematics Education (2015) 47:1121–1131
DOI 10.1007/s11858-015-0734-z

ORIGINAL ARTICLE

Student wonderings: scaffolding student understanding within student-centred inquiry learning

Nigel Calder[1]

Accepted: 7 September 2015 / Published online: 15 September 2015

Abstract This paper reports on scaffolding that is situated within a research project that examined the ways mathematical thinking emerged from student-centred inquiry. The project utilised qualitative methods to investigate a case study of a year-10 class (14–15-year-olds), at a new purpose-built secondary school designed to facilitate inquiry learning. In a learning situation, the teacher's aim often involves scaffolding the learner in their zone of proximal development so that they transition to more independent processes. Student-centred inquiry enables the students to pose authentic, inquiry questions based on personal wonderings and curiosities. These questions ignite personal inquiry that might facilitate critical and mathematical thinking. The learning was supported by 'needs-based' workshops about concepts or processes that the inquiries evoked. The paper considers one of the project's conclusions that learning through a student-centred inquiry process initiated scaffolding of the learning by the teacher and peer group. A key aim of this learning approach is for students to take more responsibility for their learning trajectory. This aspect, allied with the students most frequently working in groups, suggested that the nature of scaffolding might differ from traditional classroom situations. In particular, the paper considers the responsiveness and transfer of responsibility stages of scaffolding in student-centred inquiry learning, including the layered, distributive and cumulative elements associated with scaffolding in whole class situations.

✉ Nigel Calder
n.calder@waikato.ac.nz

[1] University of Waikato, Private Bag 12027, Tauranga 3143, New Zealand

Keywords Scaffolding · Student-centred learning · High school · Statistics · Inquiry learning

1 Introduction and background

There is a range of interpretations of scaffolding in education, with concern expressed at a tendency to envisage it as a technique that might be applied generically (e.g., Van de Pol et al., 2010). Scaffolding is a term that is perceived and utilised in varying ways associated with supporting student learning. However, its purpose is more specific. It is the deliberate, purposeful support of parts of a process or activity that the learner cannot undertake independently. This support enables the learner to cognitively engage with the full process or activity. As with the building process from which it is metaphorically derived, the intention of scaffolding is that the learner will transition to a position of independence with their understanding, and use, of the full process. Van Oers (2014) defined it as "an interactional process between a person with educational intentions and a learner, aiming to support this learner's learning process by giving appropriate and temporary help" (p. 535). It has been described as deliberate, transitory, responsive support (Gibbons, 2002). In mathematics education, this intentional intervention is generally used to support the understanding and use of mathematical processes or problem-solving strategies (e.g., Goos et al., 2002). This support might be from a teacher or peers (van Oers, 2014) and while initially conceived in one-to-one situations, it has also been theorised and demonstrated in whole-class situations (Smit et al., 2013).

Various researchers (e.g., Van de Pol et al., 2010) have categorised elements of scaffolding in terms of ongoing diagnosis, contingency or responsiveness, fading, and

transfer of responsibility. This paper will examine the ways these elements were manifest in the interactions between teacher and students as they engaged with mathematical and statistical concepts and processes, within a situation involving student-centred inquiry learning (SCIL). While the conceptualisation of scaffolding has been broadened from individual learning to include whole class situations (Smit et al., 2013) an examination of scaffolding of groups in a SCIL situation has not been undertaken. With the increased consideration and implementation of inquiry-based learning approaches, analysis of the ways learning is scaffolded in this pedagogical approach is timely. The ways that group work might influence the scaffolding of individual learning, and the role of peers and digital technology in the responsiveness stage also have ramifications for learning beyond SCIL. In particular, the paper will give insights into the aspects of responsiveness and the transfer of responsibility in this learning situation.

First, the scaffolding process will be considered, followed by the notion of SCIL. The section will then outline scaffolding within SCIL, including the links between them. The aim is to identify and illustrate the elements of scaffolding within a SCIL situation.

1.1 Scaffolding

Scaffolding is considered as a temporary and adaptive support (Van de Pol et al., 2010, 2011). It is the temporary, responsive support that enables a student to engage with a task that she or he would not otherwise be able to complete (van Oers, 2014). There is also the intention that the student will gradually move to a position of understanding that will allow them to complete a future similar task independently (Jadallah et al., 2011). While the characteristics of scaffolding have been categorised in various terms (e.g., Smit and van Eerde, 2011; Van de Pol et al., 2010) there are core elements of scaffolding described in the literature. The first is ongoing diagnosis, the identification of the learners' current understandings and knowledge of the learners' changing capabilities (Puntambekar and Hubscher, 2005). Responsiveness, the ways that the teacher responds and interacts with the learner to facilitate the transition to independence (Smit et al., 2013) is another, while the handing over to independence or transfer of responsibility to the learner through fading (Bruner, 1983) describes the third.

There are characteristics of whole-class scaffolding that have been identified: diagnosis, responsiveness, and hand over to independence (Smit and van Eerde, 2013). They also identified three features of whole-class scaffolding that incorporate and extend these elements to include the associated learning that takes place outside of the immediate classroom experience. They advocated that whole-class scaffolding might typically be layered, with both online (during lessons) and offline (between lessons) experiences; distributed over several learning episodes; and cumulative, with the transfer of responsibility not ascribed to a single lesson, or instance of responsiveness, but accumulated in an individual way over time (Smit and van Eerde, 2013). Meanwhile, Van de Pol et al. (2010) correspondingly identified the elements of scaffolding as: contingency (c.f., responsiveness), fading, and transfer of responsibility (c.f., handover to independence).

Smit and van Eerde (2011) suggested that Mason's (1998) notion of awareness gives opportunity for the teacher to capture classroom phenomena, allowing the teacher to oscillate their attention between the various contributing influences on the learning. They contend that this awareness is a critical element of scaffolding (Smit and van Eerde, 2011). The ways in which scaffolding is manifest in the learning process is contingent on the teachers' knowledge, their awareness of classroom phenomena, and the learning situation. This paper considers scaffolding in a particular learning situation: SCIL, where interactions are predominantly with groups of students.

1.2 Student-centred inquiry learning (SCIL)

The term SCIL encompasses a range of common pedagogical usages and interpretations (Beane, 1997). Let us consider what SCIL involves and define it for the purpose of this paper.

SCIL is a democratic teaching approach that aims to utilise relevant and meaningful contexts. Students investigate questions or inquiries into issues that are of genuine interest to them and curriculum is collaboratively co-constructed (Beane, 1997; Fraser, 2000). This power-sharing pedagogy can evoke student ownership and accentuate the purpose of the learning for students, as they are fully involved throughout the learning process from the initial planning stage through to assessment. In Beane's (2005) more recent work, he accentuated the student-centred aspect and referred to democratic teaching practices instead of student-centred curriculum integration. Others (e.g., Jacobs, 1989) outlined an interdisciplinary approach designed to naturally connect learning across the various disciplines.

Inquiry-based learning (IBL) has been recognized in mathematics and science pedagogy as a student-centred approach to teaching that facilitates students posing their own questions, undertaking research, and forming and communicating solutions collaboratively (MaaB and Artigue, 2013; Dorier and Garcia, 2013). While the inquiry is frequently situated in real-life contexts, with IBL, mathematical contexts are also key sources of mathematical inquiry (Artigue and Blomhoj, 2013; Schoenfeld and Kilpatrick, 2013). The 'needs-based' workshops are a distinguishing feature of SCIL. It is argued that the learning

context is not only inseparable from learning and cognition, but is formative in the production of knowledge through activity (Brown et al., 1989). There are similarities between SCIL and IBL in this regard, with students given primacy in the posing of research questions and the subsequent research process, but unlike discovery learning the teacher has a clear role to play in the learning process (Hmelo-Silver et al., 2007).

Subject content material is repositioned contextually but with a teacher overview so that curriculum imperatives have the opportunity to emerge. Subject conceptual knowledge is employed in order to pursue pertinent aspects of the inquiry; for example, in mathematics students may need to understand strategies for calculating volumes or receive explicit teaching on box-and-whisker graphs to best compare data sets. In literacy, students might learn how to compose communications to parents or members of the community to determine costs of materials (Brough, 2012). One objective is that learning is strengthened, as children are motivated to acquire the skills and knowledge necessary to solve their particular inquiry question.

Meanwhile, others have highlighted difficulties with implementing student-centred approaches, identifying both structural and cognitive concerns. George (1996) suggested that high school teachers come to identify themselves with their subject and that student-centred approaches may influence teachers to relinquish their current expertise. Beane (1997) countered this notion advocating that discipline knowledge is not abandoned rather it is called upon in the context of the inquiry. Prescriptive programming, timetabling structures, school policies, and standardised tests are also identified as inhibiting factors in both primary and secondary schools (Beane, 1997; Cook, 1996). Nevertheless, undertaking SCIL is problematic in secondary schools and presents particular challenges.

Some mathematics educators contend that the learning should be initiated by rich contexts that require mathematical organisation—contexts that can be mathematised (Freudenthal, 1968, Van den Heuvel-Panhuizen, 2010). SCIL encompasses pedagogical principles that intend to allow greater student voice in the evolving learning situations, including the investigation of authentic problems (Calder and Brough, 2013). Educators are also suggesting that SCIL, based on problems the students pose, utilises authentic learning contexts and leads to a strong sense of student ownership, enhanced student engagement and understanding, and motivation to learn (Beane, 1997; Dowden, 2010). While engagement and motivation to understand mathematical processes may be enhanced, the scaffolding of learning is a significant aspect with inquiry learning.

1.3 Scaffolding in student-centred inquiry learning

A key skill for teachers when scaffolding students' learning is the use of questioning to extend and promote students' thinking and maintain students' focus throughout the learning process (Fraser, 2000). By using questions to 'trigger' thinking, ignite inquiry and establish dialogic relationships" (Bishop and Glynn, 1999, p. 140), teachers can facilitate students' development of a range of thinking skills and enable them to become more independent learners (Brough, 2012). As teachers carefully scaffold the learning within the context of the students' inquiry, teachers provide support, feedback, and questions to ensure students are assisted according to their needs (Alton-Lee, 2003; Vygotsky, 1978). These interactions support the learning, but it is the transfer of responsibility that enables them to be categorised as scaffolding. With inquiry learning, as with situated learning, an intention is for teachers to empower the students to transition towards independently using their own strategies in authentic activity (Brown et al., 1989). This has also been considered as the fading of teacher support.

With the teacher and student interaction within inquiry learning situations primarily with groups or the whole class, Smit and van Eerde's (2013) extension of the scaffolding process to whole-class situations becomes informative. Their identification of three features of whole-class scaffolding recognises the complexity of the interactions compared with an individual scaffolding situation, with the responsiveness and transfer of responsibility elements being layered, distributed over several learning episodes, and cumulative. These insights into whole-class scaffolding resonate with scaffolding in SCIL where the learning typically occurs in a meld of whole class, group and individual situations. Due to the nature of the learning experience, the students' understanding would be hinged to the context and the range of interactions with both the teacher and peer group (Calder and Brough, 2013), rather than perhaps a single interaction between teacher and student. The transfer of responsibility will not be ascribed to a single lesson, or instance of responsiveness, but accumulated individually over time (Smit and van Eerde, 2013). Scaffolding might also result from interactions with peers or experts from outside the classroom. Other group members might also have a role when the groups work collaboratively. In collaborative group work, students working together understand the unified purpose of the group and the need to help and support each other's learning (Gillies, 2006). Peers might focus other students' attention on the relevant feature of a problem (Webb and Farivar, 1994). The group dialogue is central in the data analysis.

IBL and SCIL are similar in terms of being student-centred learning (Hmelo-Silver et al., 2007). Some researchers have contested the advocacy of IBL as an approach for

enhancing learning in science (Kirschner et al., 2006). They contend that it inhibits understanding through cognitive overload, and burdens working memory as learners seek to pose, and then research, authentic personal questions without teacher support. IBL and SCIL are not discovery learning though, nor devoid of the teacher's input or scaffolding (Hmelo-Silver et al., 2007). They rebutted Kirschner et al's (2006) contention, arguing that scaffolding is a key element of the IBL process. In the version of SCIL that this paper draws on, the teacher co-constructs the research question with the learners, scaffolds the learning, and leads 'needs-based' just-in-time teaching sessions on both conceptual knowledge and mathematical processes.

In this paper, which focuses on a research study undertaken with a SCIL approach, we will examine: diagnosis, both teacher and student identified; responsiveness, in particular, teacher questions that facilitate the stretching of students' thinking within their zones of proximal development (ZPD), including questioning in 'needs-based' workshops; and the transfer of responsibility. The ZPD of a child is the distance between his current level of understanding and his potential understanding with the support of adults or more advanced partners (van der Veer and Valsiner, 1991). Scaffolding is this support, but it also includes the transfer of responsibility (Bruner, 1983). The transfer of responsibility appears to be more pertinent terminology in this learning situation as one of the key features of SCIL is students taking responsibility for the direction of the inquiry and the corresponding research and analysis processes (Beane, 1997; Brough, 2012). Responsiveness and the transfer of responsibility seem key elements for the scaffolding of inquiry learning, suggesting a need to examine the data through a more fine-grained perspective of these two elements.

In terms of responsiveness and the transition towards the transfer of responsibility, earlier versions of the scaffolding metaphor identified six tutor actions: recruiting interest in the task; reducing the degrees of freedom (simplifying the task); maintaining direction towards the goals of the task; marking critical features; controlling frustration; and modelling the preferred procedures by demonstrating (Wood et al., 1976, 1978). Direction maintenance involves keeping the learner in pursuit of the aims of the task, often including "a deployment of zest and sympathy to keep him motivated" (Wood et al., 1976, p. 98). There are added complexities with group work, where to maintain direction, one learner might require a sympathetic approach, while others require stimulation or clarification of key features. When marking a critical feature, the teacher provides information related to the correct process or outcome (Wood et al., 1976). The six tutor actions are relevant, but maintaining direction towards the goals of the task and marking critical features are most useful in SCIL situations, where students take more responsibility for the research and process than in traditional classroom programmes. Central to the intentions of this paper is the relationship between these aspects of responsiveness and the shift towards the transfer of responsibility.

The research question for this study was: in what ways might learners be scaffolded in SCIL groups, particularly with regards to responsiveness and transfer of responsibility?

2 Methodology

2.1 Theoretical framework

A contemporary interpretive methodology was utilised to interpret the data. The pre-conceptions that each learner brings to the mathematical situation, and the activity associated with it, are derived from the specific cultural domain that the learner inhabits. Learning is a process of interpretation, where understanding is an ongoing process, rather than a fixed reality (Gallagher, 1992). An interpretive approach is concerned with the revealing of meaning (Brown, 2001) and embeds the sense making in human experiences and interactions (Kincheloe and Berry, 2004). Gallagher (1992) sees the relationship between interpreter and tradition as being an anterior relation; tradition not only operates behind the interpretation influencing its particular manifestation but also ahead of the interpreter; it is part of what the interpreter brings to the process. He advocates that "language plays the role of medium or vehicle by which traditions enter interpretation" (p. 100), and suggests that "language conditions all learning" (p. 173). Our understandings of the mathematical phenomena, and of who we are, evolve through cyclical engagements with the mathematical phenomena and the constant drawing forward of prior experiences and understandings. Here 'concepts' are not fixed realities, but rather more elusive, formative processes that become further enriched as the learner views events from fresh, ever-evolving perspectives (Calder and Brown, 2010). The pedagogical medium, the mathematical task, the pre-conceptions of the learners, and the associated dialogue evoked are interdependent. It is from their relationship with the learner that understanding emerges. This understanding is the interpretation of the situation through those various filters. Understanding emerges from cycles of interpretation, but this is forever in transition: there may always be another interpretation made from the modified stance (Calder, 2011). A case-study approach was used to document this month-long inquiry. Case studies can be described as investigating a contemporary phenomenon within its real-life context (Yin, 2009). This approach was appropriate as the project aimed to develop a greater

understanding of a current issue set within a particular classroom setting. Case studies are said to offer insight into complex issues that are inherently linked to historical, social, personal and political issues (Yin, 2009).

2.2 Context

Recently, classroom environments have emerged that foster authentic inquiry to stimulate high–level thinking. Several new schools have been built and structured specifically to enhance SCIL through the use of resource hubs, ease of access to the Internet, and flexible learning spaces or commons. This study took place in a new secondary school (ages 11–17) built specifically to facilitate inquiry-based learning. One secondary school year-10 class of 28 students was involved, and the age range of the class spanned 13–15 years of age. The school is situated in a provincial New Zealand city. While experienced in teaching through problem solving with real life contexts, this was the second year that the teacher had been using this particular inquiry learning approach. She used a mixture of whole-class teaching, with group and individual interaction. The class spent half of each day on the inquiry, while some curriculum areas such as languages were taught discretely.

The students were in the second year of learning through a SCIL approach that incorporates curriculum content within investigation of an inquiry question—their 'fertile' question. The students posed this 'fertile' question, with the inquiry co-constructed with the teacher, who would guide them regarding the mathematics elements and the mathematical conceptual knowledge that might be required. The students also have content-specific lessons ('needs-based' workshops) that might resonate directly with the general inquiry or may evolve from questions that emerge from the inquiry process e.g., What is the best way to show the difference between men's and women's times? While a range of curriculum areas was required to pursue the meaningful questions arising during the project, the focus of this paper was on the mathematics that occurred. For this particular mathematical inquiry, the overarching umbrella topic was leadership. The students in this class, in conjunction with the teacher, decided upon the Olympic Games as a context to situate their inquiry questions, most probably because these were occurring at the time of the inquiry. The class's rationale for leadership in this context was that the Olympic athletes and administrators were perceived as leaders within their particular field of endeavour. The students were investigating a question that they posed within an Olympic sport of their choice. When doing the inquiry the students were allowed to work in social groups or individually. The mathematics that was required for the SCIL also took place beyond these times through inquiries triggered by students' questions, classroom conversations or community situations or events.

2.3 Data collection

A range of qualitative methods was used to collect data. However, for the purpose of this paper, semi-structured student and teacher interviews, student blogs, and audio-recorded classroom observation data were used. Interviews are the interchange of views, and position human interaction as central to knowledge production (Kvale, 1996). They allow the researcher access to further reasoning and motivation of the participants. Hence, the data that they generated were central in gaining insights into the participants' thinking processes and interpretations. All interviews were audio-recorded and transcribed. Classroom observations enable the researcher to gather data on the interactional setting and pedagogical approach (Cohen et al., 2000) with the discrete use of iPod recorders making student dialogue accessible and an appropriate source of data. The audio-recordings of the whole class and group work within the class situation were considered important data for being able to incorporate the relational and conceptual interactions. These were transcribed, with pseudonyms used to help maintain confidentiality and anonymity. All participants gave informed consent. To some extent, the class was selected through their availability and representativeness of using the particular learning approach, rather than being representative of all year-10 classes in provincial cities. The ways the mathematical learning emerged from the inquiry questions that the students posed and explored was examined, and how this influenced their approach, the learning process undertaken, and the students' mathematical understanding.

2.4 Data analysis

Initial themes were drawn from preliminary readings of the interviews and student blogs data using an approach similar to grounded theory (Cohen et al., 2000). The researcher and research assistant undertook this preliminary process. The data were then coded into these draft themes, with some minor modifications made to the themes after co-reflection with the classroom teacher. The data were analysed within each theme and across themes for interconnections. For the purposes of this paper, the data were then considered in terms of different characteristics of scaffolding. They were analysed through the six tutor actions identified by Wood et al. (1976): recruiting interest in the task; reducing the degrees of freedom (simplifying the task); maintaining direction towards the goals of the task; marking critical features; controlling frustration; and modelling the preferred procedures by demonstrating. This enabled closer attention

to the responsiveness element and insights into how the handover to responsibility might unfold. Also, the more fine-grained analysis through these aspects might enhance the insights into the layering, distributive and cumulative features that (Smit and van Eerde, 2013) articulated with their examination of whole-class scaffolding. Generalisations were then drawn from a range of different data excerpts to illustrate key findings within each theme. Those best exemplifying the generalisations were selected for this paper. This paper identifies and discusses aspects of the study that illustrated the different stages of scaffolding: diagnosis, responsiveness, and the transfer of responsibility, as they emerged through the inquiry process.

3 Results

The results section is structured around the three stages of scaffolding and how they were evidenced in the data. In the first section, data related to the diagnosis stage, the identification of the learners' present understanding is reported. The second section addresses the responsiveness and transfer of responsibility. The responsiveness stage, analysed through six types of actions (Wood et al., 1976) gave insights into the way these actions facilitated fading for individuals and groups. The fading of teacher support, so that the learner can undertake an aspect of the learning process independently, is inherent in the transfer of responsibility stage. The teacher's interaction in the learning changes as the learner moves progressively towards independence. In the second section, three data excerpts are analysed. First, as the students negotiated the inquiry questions with the teacher; second as an appropriate mathematical process was identified. The third illustrates the more complex nature of the transfer of responsibility stage in SCIL.

3.1 Diagnosis

The teacher anticipated that there was conceptual knowledge or mathematical processes that some of the students wouldn't understand; yet that will be obligatory for resolving their inquiry. An essential element of being able to scaffold the learning in a student-centred learning situation is an awareness of the students' conceptual understandings, so that she might anticipate where individual or groups of students potentially required scaffolding. The teacher interview illustrated her awareness of this:

> Generally, the whole programme's based around an inquiry. We start with an inquiry and they have to find and work through the maths in it. So, for example, one class inquiry led us to designing beach volleyball courts and they had to come up with the volume of sand, and of the concrete cylinders. I considered where the students were at. For example, when we were investigating the cylinder, I knew some didn't know how to do the volume of a cylinder but I wanted them to come back to me about it when they needed it. So I just needed to be prepared with the teaching skills and knowledge to get them on to the next step. So I have to know what skills they actually have to know in order to make that effective.

The teacher had identified individual's and the classes overall current understandings of the volume of a cylinder. She waited until the students identified the gap in their measurement knowledge before she initiated the conceptual-knowledge teaching episode. This emphasises the importance of diagnosis as the teacher anticipated when and who might require certain skills rather than teaching them to the whole class prior to engagement with problems on the topic. She needed to anticipate potential ways that students might respond (Smith and Stein, 2011). As well as teacher diagnosis, there was also some student-initiated diagnosis of aspects that, when supported, would enable them to stretch the boundaries of their understanding thus closing the gap between their understanding and the requirements of the task. As discussed, the nature of SCIL process and the transfer of responsibility for student learning that this might facilitate, opens opportunities for authentic self-assessment and hence self-diagnosis of learning 'needs'. This was manifest in both student and teacher initiated 'needs-based' workshops. In SCIL students were comfortable, and were encouraged, to consult experts, including from their peer group, both in terms of knowledge and mathematical processes. When several students indicated to the teacher that they needed further clarification about an aspect, she initiated a group 'needs-based' workshop on that aspect. The teacher described this in the teacher interview:

> Some of them didn't know how to work out volume, but I'd call them when they had identified it was something they needed to know, to learn. They're still working on the inquiry project but they identify a skill that they need, and I or someone in the class teaches them it. Sometimes they can find how to do it on the web, often using YouTube.

The teacher waited until the students had identified their need within the investigative process. This gives purpose and relevance to the learning of the new concept or process. The teacher was also required to monitor the students' work as they engaged with the task, so as to identify students who either had only part understanding or misconceptions about the mathematical process, but hadn't

self-identified this. At times, the students would approach their peers or explore online research mechanisms to gain understanding. With SCIL there was self-diagnosis as well as teacher-diagnosis. General learning processes such as forming or researching an inquiry question were facilitated through scaffolding. The cumulative nature of the transfer to responsibility (Smit and van Eerde, 2013) with these more generic processes of inquiry learning, also illustrated the layering feature when the students worked on their inquiry in out-of-class situations. The teacher likewise indicated this cumulative feature of the transfer of responsibility, with both the learning in measurement and the general inquiry processes.

The fading of teacher support as part of the transfer of responsibility is also implied in this excerpt as the student rather than the teacher is initiating the response. Part of the responsiveness is through the peer group or by online research, at times supported in varying degrees by peer or teacher interaction. This requires an element of self and peer diagnosis. It illustrated the fading to a transfer of responsibility from teacher to student, as well as students scaffolding each other (Fernandez et al., 2001). It also illustrated the complexity and inter-relational nature of scaffolding in a whole class or group situation, where there are varying individual zones of proximal development.

3.2 Responsiveness and transfer of responsibility

For the purposes of this paper, the responsiveness stage has been differentiated into six aspects (Wood et al., 1976). They are: recruiting interest in the task; simplifying the task; maintaining direction towards the goal of the task; marking critical features; controlling frustration; and modelling preferred strategies. However, these were not usually exclusive or discrete, but occurred in inter-related, symbiotic ways. The data gave insights into how the handover to responsibility might unfold. Analysis through these aspects offered insights into the layering, distributive and cumulative features that Smit and van Eerde (2013) articulated with their examination of whole-class scaffolding. For instance, ongoing dialogue, that revealed several of these aspects occurring during the responsiveness stage, was indicative of the cumulative aspect of the students moved towards independence.

The first scenario involved the discussion between the teacher and a group of students at the initial stages of their inquiry. It was a teacher initiated 'needs-based' workshop when the students were considering the process of inquiry. It was a group of five students who were formulating their inquiry question and approach to investigating it. They were interested in a variety of sports. The first teacher engagement included elements of recruiting interest in the task, as the teacher shifted the focus to the task.

Teacher: What's your question?
Francis: What gender, weight, height suits athletes
Josh: What height to weight ratio is best suited for shot put
Teacher: See how that's changed a little bit from just height. You use two things – the ratio of one to another. What are you going to look at?

This scaffolding of the interaction and question also enabled the students to mark a critical feature—the ratio aspect. The following interactions likewise involved teacher scaffolding that prompted the marking of critical features, while also including elements of maintaining direction.

Teacher: Give us some of your ideas
Jack: What arm span is best for archery, but not sure how to get it
Teacher: Yes, that's going to be hard to find. What have we done that links to arm span though? (1)
Jack: Heights

The teacher's question directs the student's attention to earlier work where they investigated a correlation between arm span and height. This allowed them to continue with their inquiry. The teacher then used scaffolding that might have been interpreted as a discrete aspect, but in effect was a meld of responsiveness aspects. That is, it included four of the tutor actions that Wood et al. (1976) identified: marking a critical feature; maintaining direction; simplifying the task and in the context of the whole discussion the teacher's interactions helped control student frustration.

Teacher: So height would give some indication of arm span?
Jack: Could use height – what is the best height for archery. (2)
Teacher: Once you get a question you've got to work out what you're going to do. (3)
Josh: We're going to get the information, work off the website. We'll need more data, need other data – medals for each sport and country. You need to find that, to research for other data. We need to get on to completing a plan. What table and graph will we use?

The teacher interactions with Jack over the two excerpts facilitated Jack marking a critical feature, that height was proportional to arm span (1). At the same time it enabled him to move on from a frustration about not being able to find arm spans for the athletes, while simultaneously maintaining direction with his overall task (3). There are indications here of the transfer of responsibility. This student has now indicated a way to approach their inquiry (2).

Meanwhile, Josh's interactions span two excerpts with that group. While we cannot solely attribute the development in his thinking to being part of the overall discussion, it does suggest Smit et al's (2013) distributed feature with scaffolding in group situations as he moved towards independence.

The data also suggested that with scaffolding group inquiry-learning situations, there are elements of the layered, cumulative progression of student understanding as well as the distributive quality identified in whole-class scaffolding (Smit and van Eerde, 2013). Josh suggests that he will undertake research in the future beyond this lesson. Hence, his understanding will accumulate over time. The scaffolding directed towards one student often assisted another in the group, while the accumulation of responses from various group members, coupled with the accompanying scaffolding questions, appeared to extend the whole group further within their ZPD than when the teacher scaffolded in an individual situation.

The next excerpt also illustrated the complementary nature of the responsive elements of the scaffolding process. It is an excerpt predominantly with one student from a pair who has collected their data comparing men and women shot put distances, and has begun the process of analysis.

Ben: Women threw further than men in 1980
Teacher: Would you have expected that? (4)
Ben: No – maybe it was drugs
Mere: Or might be a different shot
Teacher: Have you done some analysis yet? Median? Mode? (5)

The teacher used a scaffolding question that facilitated the students marking of a critical feature, the potential reasons for women throwing further (4), while her next scaffolding intervention maintained direction towards the goal and marked other key features, the median and mode (5). This continued with the next interaction.

Mere: Not yet. I'm going to do that at the end. I like to do things in parts
Teacher: What are you doing now?
Mere: A box and whisker graph. Do you have to put numbers on it Ben?

The teacher then scaffolded by simplifying the task, hence enabling the students to move beyond an uncertain period with some inherent frustration.

Teacher: Once you've got your data on a chart, what do you do to start thinking about what it's saying?
Mere: Don't know

The teacher modified her approach and indicated a model for analyzing the data.

Teacher: You're doing graphs aren't you? That's a way of analyzing

The data now suggested the transfer of responsibility as the teacher questions focused the student on the new mathematical processes they have learnt, while simultaneously gesturing towards their ongoing approach.

Teacher: What have you learned so far?
Mere: How to do a box and whisker graph. How to do graphs on the computer. (6)
Teacher: How did you learn that?
Mere: You (the teacher) and Ben

The student was prompted to reflect on what they had learnt. The data suggested that they could at times initiate an analysis of data through the drawing of a box-and-whisker graph independently in a different situation (6). The excerpt illustrated the fading towards transfer of responsibility aspect (Van de Pol et al., 2010) through the change in teacher's questioning. The initial question: "Would you have expected that?" recruited interest in the task. It drew reflective responses that indicated interest and engagement with the task. "What are you doing now?" maintained direction towards the goal while facilitating the marking of a critical feature, the box-and-whisker graph. At this stage the students are beginning to initiate aspects of the task process. Then, when he answered, "What have you learnt so far?" the student indicated that they could now use the box-and-whisker graph appropriately. The transition in teacher questions, allied with the associated student response suggested the fading of teacher support as the student moved to a more independent position.

The third excerpt illustrated several of the responsiveness aspects, while again accentuating their interconnectedness. It also exemplified the incremental progression of the transfer of responsibility from teacher to the student, as the teacher questioning scaffolded the student's understanding within their ZPD. Therefore, this enhanced the student's future, independent engagement with similar SCIL tasks. This group was comparing the number of medals won compared to the size of the teams. This was part of their investigation into the relationship between medals won and the population of a country and its gross domestic product (GDP). The teacher used a series of questions that facilitated the students' maintenance of direction, and the marking of critical features.

Teacher: So can you see some links between that and your other data?
Wiremu: I guess so, because we only got one medal in all

of those years
Teacher: Where was it where we got the same as this year?
Wiremu: 1988, when we had 61 athletes in the team. We had 184 athletes this year and we only got the same number of medals as in 1988, when we only had 61 in the team, that's not very good
Teacher: Have you done a graph of the teams?
Wiremu: Yes. You can see the differences there
Teacher: I wonder if you are able to put those sets of data on the one graph?
Wiremu: You probably can actually

The student then played around with the graphs and data, exploring various options for analysis and data display. The teacher later interacted with the student using a prompt that maintained direction and identified a critical feature (Wood et al., 1978). It also allowed the student the opportunity to demonstrate a shift in their understanding within their ZPD.

Teacher: Can you see any patterns?
Wiremu: Yeah, we can. We've gotta make a box and whisker graph too. I just had to write all them up. Now I've got to… what do I have to do? I've got to put them from smallest to largest. I have to work out the lower quartile and upper quartile, and then draw the box and whisker

Here the student indicated that they could now initiate the analysis of the data through graphing it on an appropriate graph. They articulated the process of ordering the data and identifying the key statistics for the box-and-whisker graph. This illustrated the fading of teacher support as the learner takes more responsibility for the analysis process. This interaction also illustrated the cumulative feature with whole-class scaffolding as the transition in the student's understanding developed through a range of different interactions over an extended period of time.

The data suggested that the transition to the transfer of responsibility stage often doesn't happen in isolation. It was frequently part of an incremental progression through the responsiveness stage. Several excerpts of the data illustrated how the teacher questioning, as part of ongoing interaction, scaffolded the student by maintaining direction towards the goal of the task and then transitioned into the transfer of responsibility stage.

4 Conclusions

The aim of this paper was to examine the scaffolding of learning, with groups of students engaged in student-centred inquiry pedagogy as they investigated authentic, co-constructed questions related to the Olympic Games, an event happening at the time. A key aspect of this SCIL approach is that the learning doesn't always unfold in pre-determined ways. Implicit in SCIL, is that the focus and trajectory of the learning evolves as the learning and associated activity progresses. This indicated the need for ongoing diagnosis by the teacher. For example, the teacher may have anticipated using a box-and-whisker graph to present the data, but it didn't become a focused teaching topic until the students had recognized its potential utility for their particular purpose. Here, there was an element of self-diagnosis that might be particular to SCIL where the expectation is that the learner will take more responsibility for their learning trajectory. While the scaffolding was at a whole-class, group or individual level at various times, it was predominantly with a group. There were some particular aspects that the data illustrated with SCIL.

In answer to the research question, the scaffolding that occurred in the responsiveness stage was typically a meld of the six inter-related aspects that Wood et al. (1976) identified. There was frequently progressive questioning, that meant an incremental transition by the group of learners towards each individual's ZPD. A scaffolding question that marked a critical feature (Wood et al., 1976) for one group member may have simplified the task with another student, or revealed an opportunity that they might not otherwise have considered. At times, a single question contained several of the responsiveness aspects simultaneously—sometimes scaffolding individuals in different ways, but at times addressing several aspects at once. This indicated the symbiotic nature of these aspects. They were not necessarily discrete. For example, one question might simplify the task while simultaneously alleviating frustration and maintaining momentum towards completion. While this suggested the complexity of scaffolding questions, and their being situated in particular interactions, it gestured towards the need for teacher insight into individual students' conceptual understanding and intentions.

While their knowledge and understanding of individual interests, abilities and intentions was essential for the teacher to quickly reshape and focus their questions in situ, critical for the enhancement of mathematical thinking and learning was the teacher's knowledge of individuals' mathematics conceptual understanding. It enabled them to pace the scaffolding interactions at the level that stretched the students' mathematical thinking, but not too far beyond their present level, which might have led to confusion and potential negativity. The teacher's concept knowledge and pedagogy were a register of the prospective mathematical and learning opportunities that they could afford each situation, and influenced the nature and shape of the questions that they asked. Having the intention to scaffold, and belief

in it's effectiveness, is necessary for scaffolding, but the teacher also needs to know how to apply the appropriate strategy and when (Smit and van Eerde, 2011).

In the diagnosis stage, identification of the actions required to carry out the inquiry were not exclusively teacher initiated. The students frequently identified the conceptual knowledge or processes they required to undertake their inquiry. At times, peers in their group also identified them. In these cases, the peer group member often responded and moved the student towards the transfer of responsibility stage without any teacher intervention. The responsiveness stage was not always teacher directed. While these interventions were at times in the domain of general support, there were instances of peer group, outside experts, and even online applications like YouTube scaffolding individual and group learning, allowing the student to initiate independent learning. This use of a variety of sources over time, suggested Smit and van Eerde's (2013) layered and distributed features, in the scaffolding of SCIL.

The teacher and student-initiated 'needs-based' workshops facilitated the scaffolding in authentic, purposeful ways. By initiating the workshops, the students recognised that it was knowledge or understanding that they required to proceed with their investigation or answering of their inquiry question. Hence, there was an immediate purpose for the learning, and motivation for the student to engage with it, especially when students initiated the workshops themselves. The data gave evidence that scaffolding with groups facilitated enhanced student mathematical conceptual knowledge, and opened opportunities to develop mathematical processes.

In the transfer of responsibility stage, there was also a collective responsibility of the group. This would eventually need to evolve into an individual responsibility, for the learner to apply the understanding in future situations that didn't include the other group members. Also particular to SCIL, the cumulative, distributed features of individual scaffolding within a group appeared to enhance the group's progression towards the transfer of responsibility. It may be that the group being able to take a collective responsibility, hence easing that transition, facilitated this. This is related to an implication for teachers. Teachers need to recognise within their learning approaches how their pedagogy and appropriate questioning might influence frustration and the transfer of responsibility stage in individual, group, and whole-class situations. They need to consider and exemplify practice that advances the scaffolding of these aspects.

As well as the group data illustrating the layered, distributive, and cumulative features first identified in whole-class scaffolding (Smit and van Eerde, 2013), aspects of these features were particular to SCIL. First, self-diagnosis, considered a feature of student-centred pedagogy. Although this is evidence of the student learning independently, it is arguably a part of the cumulative nature of the transition to the transfer of responsibility, rather than indication that the transfer had occurred. Second, peer and digital media responsiveness: which often occurred independent of the teacher. The class culture and expectations of learners with student-centred inquiry is such that students frequently seek support from peers or online before the teacher. In fact, this is encouraged. This also suggests a particular type of transfer of responsibility with SCIL that includes elements of self-diagnosis and at times the use of digital resources such as YouTube. Although it might be argued that the transfer of responsibility is still in transition with this position, it does characterise "handing the role to the child as he becomes skilled enough to manage it" (Bruner, 1983, p. 60) and it is also evidence that they can now complete the task on their own (Maybin et al., 1992).

The study was constrained by being a small case study and the particular circumstances in which it was undertaken. Nevertheless, it did enrich the growing evidence emerging in this field and gave particular insights into scaffolding in both group and SCIL situations. There is a need for future research into the cumulative and distributive nature of the responsiveness aspects: the ways in which they manifest and interact in different learning contexts. There is also scope for more in depth research into scaffolding in student-centred learning situations, including the place and influence of digital technologies on the transfer of responsibility stage.

References

Alton-Lee, A. (2003). Quality teaching for diverse students in schooling: Best evidence synthesis. http://www.minedu.govt.nz/web/downloadable/dl11124_v1/quality-teaching-for-diverse-students-in-schooling.doc. Accessed 23 March 2011.

Artigue, M., & Blomhoj, M. (2013). Conceptualizing inquiry-based education in mathematics. *ZDM - The International Journal on Mathematics Education, 45*, 797–810.

Beane, J. (1997). *Curriculum integration: Designing the core of democratic education*. New York: Teachers' College Press, Columbia University.

Beane, J. (2005). *A reason to teach: Creating classrooms of dignity and hope*. Portsmouth: Heinemann.

Bishop, R., & Glynn, T. (1999). *Culture counts: Changing power relationships in education*. Palmerston North: Dunmore Press.

Brough, C. (2012). Implementing the democratic principles and practices of student-centred curriculum integration in primary schools. *Curriculum Journal*, *23*(3), 345–369. Routledge. doi:10.1080/09585176.2012.703498. Accessed 23 Feb 2013.

Brown, T. (2001). *Mathematics education and language: Interpreting hermeneutics and post-structualism*. Dordrecht: Kluwer Academic Publishers.

Brown, S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–41.

Bruner, J. (1983). *Child's talk: Learning to use language*. New York: Norton.

Calder, N. S. (2011). *Processing mathematics through digital technologies: The primary years*. Rotterdam: Sense Publishers.

Calder, N.S. & Brough, C. (2013). Child-centred inquiry learning: How mathematics understanding emerges. *International Journal for Mathematics Teaching and Learning*. http://www.cimt.plymouth.ac.uk/journal/. Accessed 12 Aug 2013.

Calder, N. S., & Brown, T. (2010). Learning through digital technologies. In M. Walshaw (Ed.), *Unpacking pedagogy: New perspectives for mathematics classrooms* (pp. 233–244). Charlotte: Information Age Publishing.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5th ed.). London: Routledge Falmer.

Cook, J. (1996). Negotiating the curriculum: Programming for learning. In G. Boomer, N. Lester, C. Onore, & J. Cook (Eds.), *Negotiating the curriculum: Educating for the 21st century* (pp. 15–31). London: Falmer Press.

Dorier, J.-L., & Garcia, F. J. (2013). Challenges and opportunities for the implementation of inquiry-based learning in day-to-day teaching. *ZDM - The International Journal on Mathematics Education, 45*, 837–849.

Dowden, T. (2010). Curriculum integration in Aotearoa New Zealand: Rediscovering the potential of student-centred curriculum design in the middle years. *Australian Journal of Middle Schooling, 10*(2), 4–10.

Fernandez, M., Wegerif, R., Mercer, N., & Rojas-Drummond, S. (2001). Re-conceptualizing "scaffolding" and the zone of proximal development in the context of symmetrical collaborative learning. *Journal of Classroom Interaction, 36*(2), 40–54.

Fraser, D. (2000). Curriculum integration: What it is and is not. *Set: Research Information for Teachers*, *3*, 34–37.

Freudenthal, H. (1968). Why to teach mathematics so as to be useful. *Educational Studies in Mathematics, 1*, 3–8.

Gallagher, S. (1992). *Hermeneutics and education*. New York: State University of New York Press.

George, P. (1996). The integrated curriculum: A reality check. *Middle School Journal.* 12–19 September.

Gibbons, P. (2002). *Scaffolding language, scaffolding learning: Teaching second language learners in the mainstream classroom*. Portsmouth: Heinemann.

Gillies, R. M. (2006). Teachers' and students' verbal behaviours during co-operative and small-group learning. *British Journal of Educational Psychology, 76*, 271–287.

Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving. *Educational Studies in Mathematics, 49*, 193–223.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

Jacobs, H. H. (1989). Design options for an integrated curriculum. In H. H. Jacobs (Ed.), *Interdisciplinary curriculum: Design and implementation* (pp. 13–24). Alexandria: Association for Supervision and Curriculum Development.

Jadallah, M., Anderson, R. C., Nguyen-Janiel, K., Miller, B. W., Kim, I.-H., Kuo, L.-J., et al. (2011). Influence of a teacher's scaffolding moves during child-led small-group discussion. *American Educational Research Journal, 48*(1), 194–230.

Kincheloe, J., & Berry, K. (2004). *Rigour and complexity in educational research*. Buckingham: Open University Press.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Kvale, S. (1996). *Interviews*. London: Sage Publications.

MaaB, K., & Artigue, M. (2013). Implementation of inquiry-based learning in day-to-day teaching: a synthesis. *ZDM - The International Journal on Mathematics Education, 45*, 779–795.

Mason, J. (1998). Enabling teachers to be real teachers: Necessary levels of awareness and structure of attention. *Journal of Mathematics Teacher Education, 1*, 243–267.

Maybin, J., Mercer, N., & Stierer, B. (1992). 'Scaffolding' learning in the classroom. In K. Norman (Ed.), *Thinking voices: The work of the national oracy project* (pp. 186–195). London: Hodder & Stroughton.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*(1), 1–12.

Schoenfeld, A. H., & Kilpatrick, J. (2013). A US perspective on the implementation of inquiry-based learning in mathematics. *ZDM - The International Journal on Mathematics Education, 45*, 901–909.

Smit, J., & Van Eerde, H. A. A. (2011). A teacher's learning process in dual design research: Learning to scaffold language in a multilingual mathematics classroom. *ZDM - The International Journal on Mathematics Education, 43*(6), 889–900.

Smit, J., & Van Eerde, H. A. A. (2013). What counts as evidence for the long-term realisation of whole-class scaffolding? *Learning, Culture and Social Interaction, 2*, 22–31.

Smit, J., Van Eerde, H. A. A., & Bakker, A. (2013). A conceptualisation of whole-class scaffolding. *British Educational Research Journal., 39*(5), 817–834.

Smith, M. S., & Stein, M. K. (2011). *5 practices for orchestrating productive mathematical discussions*. Reston: National Council of Teacher of Mathematics.

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher–student interaction: A decade of research. *Educational Psychology Review, 22*(3), 271–297.

Van de Pol, J., Volman, M., & Beishuizen, J. (2011). Patterns of contingent teaching in teacher–student interaction. *Learning and Instruction, 21*(1), 46–57.

Van den Heuval-Panhuizen, M. (2010). Reform under attack—Forty years of working on better mathematics education thrown on the scrapheap? No way! In L.Sparrow, B.Kissane, & C. Hurst (Eds.), Shaping the Future of Mathematics Education: Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australasia. Freemantle: MERGA.

van der Veer, R., & Valsiner, J. (1991). *Understanding Vygotsky: A quest for synthesis*. Oxford: Blackwell.

van Oers, B. (2014). Scaffolding in Mathematics. In S. Lerman (Ed.), *Encyclopedia of mathematics education*. Dordrecht: Springer.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge: Harvard University Press.

Webb, N. B., & Farivar, S. (1994). Promoting helpful behaviour in cooperative small groups in middle school mathematics. *American Educational Research Journal, 31*, 369–395.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem-solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100.

Wood, D., Wood, H., & Middleton, D. (1978). An experimental evaluation of four face-to-face teaching strategies. *International Journal of Behavioral Development, 1*(2), 131–147.

Yin, R. K. (2009). *Case study research: Design and methods. Applied social research methods* (4th ed., Vol. 5). Thousand Oaks: Sage.