From simulations to real: Investigating young students’ learning and transfer from simulations to real tasks

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Abstract
Research has explored the use of simulations for education and training, and attention is turning to how they might support learning in school subjects such as mathematics and science. However, existing studies have mostly concentrated on older students, and if simulations help build knowledge useful for solving problems within the simulation, rather than possible transfer beyond the simulation. This paper reports on a study investigating 5 year olds’ learning transfer from simulations introducing simple circuit procedures and concepts, to equipment-based tasks. The study explored for evidence of learning transfer, using an analytical framework that aligned transfer strategy indicators with cognitive process dimensions, to identify transfer events and understand the thinking skills students applied during them. Findings supported the learning value of simulations, indicating young students transferred procedural knowledge to the equipment tasks, with some also demonstrating basic conceptual transfer. They also suggested transfer tasks can provide opportunities to exercise higher order thinking, through activating processes including reflection, evaluation, analysis and abstraction. Such capabilities are highly valued, and central to school achievement and development of learner independence and self-direction.

Introduction
Technological developments have opened opportunities to deliver education in different ways. Paralleling the advent of mobile devices, their apps have become increasingly sophisticated in supporting learning through use of virtual manipulatives embedded in realistic, simulated tasks. While school studies have investigated simulations for learning fractions (Mendiburo, 2010), geometry (Steen, Brooks, & Lyon, 2006), physical mass (Zacharia, Loizou, & Papaevripidou, 2012), electrical circuits (Falloon, 2019), and heat and temperature (Zacharia & Olympiou, 2011), these were limited to investigating knowledge developed within simulations, rather than exploring transfer beyond simulations. Although some studies investigating transfer with younger students are emerging (eg, Huber et al., 2016; Lovato & Waxman, 2016) few studies have been completed in early years' science learning.

Significance and rationale for the study
Simulations are becoming increasingly common learning resources used in classrooms. However, research on if, what and how students learn from simulations, is still emerging. Specifically, little...
From simulations to real - investigating learning transfer...

is known about young students' learning with science simulations, if learning can be transferred beyond simulations, and the cognitive processes activated during transfer. While work with adults has suggested metacognitive benefits from transfer (e.g., Ganier, Hoareau, & Tisseau, 2014; Miles, 2018; Pintrich, 2002), little research has been completed with younger students to determine if similar benefits exist. Given the centrality of cognitive functioning to school performance and development of self-directed and independent learning, Pintrich (2002) suggests teachers should consider integrating into early years' curriculum, learning experiences that build metacognitive capability. Further, he argues that developing metacognitive capability does not occur naturally, but rather, “there is a need to teach for metacognitive knowledge explicitly... in K-12 settings” (Pintrich, 2002, p. 223).

Bransford’s (2000) work supports using transfer tasks for this purpose. He claims transfer tasks, “help students represent problems at higher levels of abstraction” (p. 63), supporting the development of general principles that are adaptable to different situations. The ability to extend what was learnt in one context to another is an essential learning competence, that engages higher order cognitive processes (Bransford, 2000). However, historical assumptions about the limited capabilities of young children to abstract at a level necessary for learning transfer, has undermined research in this area. According to Bransford, “it was previously thought that young children lacked the strategic competence and knowledge about learning (metacognition) to learn intentionally... (but recently) research reveals hitherto unrecognised strategies and metacognitive competence in the young” (p. 82). The realisation that higher order thinking, “is not solely related to age” (ibid, p. 98) is important, as it removes artificial barriers to what teachers can expect from young children, given appropriate learning tasks and support. In science education,
instructional tasks based on metacognitive principles have been associated with greater conceptual understanding and durability, and enhanced learning transfer (Georghiades, 2000).

Given this understanding and documented evidence of the effectiveness of simulations for cognitive and transferable knowledge development in adults, a study to investigate this phenomenon with younger learners is significant for two reasons. First, knowledge developed will assist teachers’ decision making about the value of simulations to support the conceptual learning of very young students. It extends research beyond the current emphasis on simulation use for procedural learning, to also evaluate their efficacy for building transferable conceptual understandings. This potentially informs a wider purpose for using simulations with students of this age, given research also indicating the engagement of higher order cognitive processes in conceptual formation and transfer, and the relevance of this to school learning (Pintrich, 2002). Second, the study attempts to understand the cognitive strategies and thinking skills students applied when transferring procedural and conceptual knowledge from the simulations. To do this, an analytical framework was developed that aligned Georghiades’s (2000) transfer strategy indicators with Krathwohl’s (2002) cognitive dimensions. This enabled both the identification of transfer events, and analysis of the complexity of thinking applied, during the events. Using the framework extended existing understandings beyond knowledge-building within simulations, to learning more about cognitive processes underpinning learning transfer, from simulations. Again, this information is useful for teachers in their classroom decision making, who can benefit from knowing whether transfer-from-simulation tasks are a useful means of building students’ higher order thinking capabilities—skills at the core of school achievement and learner independence (Bransford, 2000).

Research questions
Data were gathered and analysed responding to these questions:

1. What evidence exists that young students can transfer procedural and conceptual knowledge of simple electrical circuit components, construction and operation, from simulations to equipment tasks?
2. Do transfer tasks provide young students with worthwhile opportunities to exercise cognitive strategies and skills?

Simulations in school education
Simulation use in school is not new. Research over a number of years has investigated their use in mathematics education (eg, Burns & Hamm, 2011; Steen et al., 2006) and, more recently, in science education (eg, Jaakkola & Nurmi, 2008; Olympiou & Zacharia, 2011; Zacharia & de Jong, 2014; Zacharia, 2007). These studies involved primary or college students using simulations in personal science inquiries (eg, Smith, 2014), or as substitutes for lab experiences that would otherwise have been inaccessible (eg, Trindade, Fiolhais, & Almeida, 2002). Results have been generally positive, with simulations proving effective with older students for learning science procedural, and at times, conceptual knowledge, particularly when combined with physical experiences (eg, Ardianto & Rubini, 2016; Jaakkola & Nurmi, 2008; Kollöffel & de Jong, 2013; Lazonder & Ehrenhard, 2014).

While not commonplace, studies are emerging investigating simulation use with young students for science learning (eg, Falloon, 2019; Jaakkola & Nurmi, 2008; Zacharia et al., 2012). Falloon’s (2019) study reported the benefit of using science simulations with young students to operationalise higher order processes, including reflective and descriptive observation and thinking, conceptualisation and abstraction. The study investigated 5 year olds' construction
and transfer of functional, procedural and basic conceptual knowledge between four iPad simulations, designed to introduce simple circuits and construction techniques. Results demonstrated a significant student uptake of functional and procedural knowledge about circuit components, and constructing circuits of different designs (eg. series, parallel). The study also found evidence of learning transfer between simulations. Moreover, solving construction problems using simulations, and the processes involved in between-simulation transfer, engaged higher order capabilities including reflective thinking, abstraction and, to a lesser extent, conceptualisation.

Jaakkola and Nurmi’s (2008) study also investigated using simulations to teach 10–11-year olds electricity concepts, but focused on conceptual knowledge gains assessed using pre–post testing. Their results indicated a combination of both simulated and physical experience had the most impact at a conceptual level, although interestingly, students using simulations alone performed better on this indicator than those exposed only to the laboratory experience. Similar results were also found in an earlier study involving adult students (Zacharia, 2007). These results provide cautious support for using simulations for conceptual development.

Transfer from simulations

General research on transfer from simulations has identified their potential for developing procedural and declarative knowledge that can be applied in “real world” settings (Bossard, Kermarrec, Buche, & Tisseau, 2008). However, determining the effectiveness of transfer is complex, being related to its “generalisability” beyond scenarios similar to those in the simulation. Bossard et al. (2008) describe this as horizontal transfer—a process that demands higher levels of abstraction and metacognitive engagement, as learners build transferable knowledge models adaptable to solving problems in different contexts. Bossard et al. (2008) argue simulations can be very effective for this, as they confront learners with situational variability, through, “immersion in a virtual environment where they can try things, choose, take initiatives, fail and try again” (p. 158). Horizontal transfer is associated with conceptual development, where knowledge is abstracted to scenarios possessing attributes unlike those contained in the simulation. Vertical transfer, on the other hand, is associated with procedural learning, where transfer is generally limited to scenarios similar to those introduced by the simulation. Simulations can be very effective for developing transferable procedural knowledge in adult training, and have been used successfully where accurate replication of standardised processes is important (eg, Ganier et al., 2014; Kollöffel & de Jong, 2013).

In education, research on transfer from simulations is only starting to emerge, but early outcomes are encouraging (eg, Georghiades, 2000; Huber et al., 2016; Smith, 2014). Aladé, Lauricella, Beaudoin-Ryan, and Wartella’s (2016) work is of particular relevance, as it involved preschoolers similar in age to the students involved in the present study. Their research compared interactive, multimodal simulations with non-interactive video and a control group, to teach transferable STEM concepts—specifically, measuring the height of a range of animal images using non-regular units. Their results, “provide strong empirical support for the assertion that young children can learn foundational STEM skills from new media technologies, and apply them to non-mediated contexts” (p. 438). However, they concluded that the interactive nature of simulations may not necessarily enhance transfer, except in situations, “when the learning context very closely mirrors the real-world setting” (p. 439). This finding suggests transfer from interactive simulations may be more effective in vertical transfer scenarios. Studies in adult training tentatively support this conclusion (eg, Ganier et al., 2014).

Until recently, simulation studies have been restricted to desktop or notebook computers, where interaction is mediated by peripherals such as a mouse or joystick. Studies are now emerging investigating transfer from touch screen simulations (eg, Aladé et al., 2016; Huber et al., 2016;
Moser et al., 2015). Research into the haptic nature of touch screen devices suggests they may be more effective for supporting transferable conceptual learning, due to their ability to provide feedback and replicate immersive learning environments more akin to real-life experience (Lazonder & Ehrenhard, 2014; Wang, Wu, Chien, Hwang, & Hsu, 2015). However, limitations have been reported indicating restricted benefits from using touch screen simulations in scenarios where existing concepts needed revision. For example, Lazonder and Ehrenhard's (2014) study determined the need for physical interaction where tactile feedback is important for learning and unable to be replicated virtually—particularly in contexts where misconceptions existed. Their study strongly argued using both virtual and physical experiences, where the development of accurate transferable concepts was a goal.

While some studies are emerging in adult and older student transfer from touch screen devices, research involving young students is scarce, although early outcomes are generally positive. Huber et al.'s (2016) experiment compared 4–6-year olds’ attempts at the Tower of Hanoi puzzle (3D) before (baseline), and after two practice trials—either with the 3D puzzle or a 2D simulation. Their results indicated the children, “readily transferred learning from their practise with the tablet-based puzzle to the physical version (and that) this finding is robust and remained valid across the two main dependent measures: extra moves, and time-per-move” (Huber et al., 2016, p. 59).

In summary, simulations have been found effective in adult and older student education and training for developing procedural, and to a lesser extent, conceptual knowledge. However, literature suggests evaluating transfer from simulations is complex, being influenced by variables such as interactivity and feedback, situational alignment, the degree of similarity between the simulated and real context and the cognitive capabilities of learners. Nevertheless, research in science education with older students suggests integrating metacognitive strategies into curriculum through experiences such as transfer tasks, can promote thinking and problem-solving capability and support the establishment of robust science concepts (eg, Georghiades, 2000).

Learning transfer in science education
Higher order thinking has been identified as relevant to science learning (eg, Georghiades, 2000, 2004; Veenman, 2012). Georghiades (2000) suggests higher order thinking supports students to understand, retain and transfer science concepts and processes, and apply them to solving problems in different contexts. Drawing on the work of Gunstone (1991), Georghiades (2000) defines these capabilities as thinking that, “enhances students' knowledge, awareness and control of the processes by which they learn... and, where needed, recognise, evaluate and reconstruct existing ideas” (p. 127). Georghiades suggests curriculum and pedagogies that promote higher order capabilities have a positive effect on the capacity of students to transfer and retain science concepts for longer periods, and, “use these under a number of different circumstances” (2000, p. 128). Integrating what he terms metacognitive strategies into science learning can deepen understanding of material that enhances conceptual durability, supporting retention and transfer. However, Georghiades warns that unless evidence of conceptual transfer is found that indicates a student's capacity to abstract from the original experience, genuine transfer cannot be considered to have been achieved. This perspective finds support in the work of Kolb (1984), who points to the importance of reflection on and during experience, and an ability to abstract to form generalisable theories transferable to different situations.

Understanding procedural and conceptual knowledge
Krathwohl (2002) identifies procedural knowledge as, “how to do something; methods of inquiry and criteria for using skills, algorithms, techniques and methods” (p. 214). Essentially, procedural knowledge involves the application of learnt processes to solve problems or complete tasks, and,
According to Mayer (2002) engages two cognitive processes—executing or carrying out (for tasks familiar to the learner) and implementing or using (for tasks unfamiliar to the learner). Mayer argues that fundamental differences exist in the complexity of procedural knowledge applied to a task, suggesting that when tasks are unfamiliar, there must also be engagement of, “conceptual understanding of the problem and procedure... unlike executing which relies almost exclusively on cognitive processes associated with Apply(ing)” (p. 230). That is, unfamiliar tasks engage both understanding (conceptual) and applying (procedural) knowledge.

Perspectives on conceptual knowledge centre on a learner's ability to abstract from experience, identifying patterns and relationships between elements of a larger structure and being able to generalise to form theories or models that can be applied to different problems, ie, conceptual knowledge is knowledge of why, and not simply how to (Kolb, 1984; Krathwohl, 2002; Mayer, 2002). Airasian and Miranda (2002) align conceptual knowledge with Krathwhol's (2002) cognitive process dimensions: understand, analyse, evaluate and create, suggesting thinking skills generally considered to be “higher order” are engaged in conceptual transfer. Kollöffel and de Jong (2013) highlight the interrelationship between procedural and conceptual knowledge, commenting that improved conceptual understandings will support learners to, “select appropriate problem-solving procedures, thus enhancing procedural skills” (p. 388). Equally, learners who reflect on or seek to explain the conceptual basis of procedures, can build greater awareness of which concepts contribute to solving a problem, and are more likely to operationalise these in the future. The interplay of conceptual and procedural knowledge has been noted in other studies, and associated with the development and application of advanced problem-solving skills in other domains (eg, Lund, Furberg, Bakken, & Engelien, 2014). Understanding the nature of procedural and conceptual knowledge and their interaction, is of significance to this study.

**Conceptual framework**

Georghiades (2004) identifies a lack of attention to conceptual transfer as a principal weakness of science learning transfer research, citing the predominance of studies concentrating on the “soft target” of process skills. He argues that attention must turn to investigating if science concepts can be transferred, and if so, under what circumstances. Central to this is what he terms metacognitive instruction—where learners are provided with planned opportunities to, “reflect upon, and take action about, one’s own learning... being encouraged to reflect on their own thinking” (Georghiades, 2000, p. 128). He identified six learner behaviours underpinning metacognitive instruction supporting conceptual transfer, which he termed metacognitive strategy indicators. They are:

1. revisiting learned processes and concepts;
2. making comparisons between prior and current conceptions;
3. being aware of and analysing difficulties and differences;
4. identifying the use and purpose of learned concepts and materials;
5. handling learned materials or processes in different ways;
6. applying learned materials and processes in different circumstances.

These indicators comprise the core of the analytical framework used in the current study. They were aligned with Krathwohl's (2002) cognitive process dimensions, to help better understand the type and complexity of thinking students employed during transfer tasks. Aligning Georghiades's (2000) indicators with Krathwohl's (2002) dimensions supported deeper interrogation of data, that enabled both the identification of transfer, and also understanding of cognitive processes, during and resulting from transfer. Table 1 contextualises the indicators to this study, through their alignment with cognitive strategies associated with transfer from the simulations.
| Original Strategy Indicator (Georghiades, 2000) | Cognitive dimension (Krathwohl, 2002) | Contextualised indicator/description | Code label | Code definitions | Code colour |
|-----------------------------------------------|--------------------------------------|-------------------------------------|------------|----------------|-------------|
| Revisiting learned processes and concepts     | Remember (recognise or recall knowledge from memory) | Remembering or recalling circuit procedures and concepts | Recalling learned concepts or procedures | Recalling learned concepts or procedures associated with circuit design and/or construction | Green       |
| Identifying the use and purpose of learned concepts and materials | Understand (explaining the operation and function of different materials and components) | Understanding the use and purpose of materials and components, used to build circuits | Understanding the use and purpose of materials and components | Demonstrating understanding of the function and purpose of components in circuits | Purple      |
| Applying learned materials and processes in different circumstances | Apply (carrying out or using a learned procedure or applying knowledge of learned materials) | Applying learned procedures, materials and concepts to the equipment task | Applying learned concepts, materials or procedures to circuit design and/or construction | Applying learned concepts, materials or procedures to circuit design and/or construction | Grey        |
| Being aware of and analysing difficulties and differences | Analyse (determining how components or elements of a task are distinguishable from, and/or relate to each other) | Analysing to determine faults and errors. | Analysing and debugging | Analysing, debugging, fault-finding components and designs in non-operating circuits | Yellow      |
| Making comparisons between prior and current conceptions | Evaluate (making judgements based on criteria and standards) | Evaluating and comparing learned procedures, concepts and component knowledge, to determine their relevance or applicability to equipment tasks | Evaluating and comparing | Evaluating and comparing the relevance or applicability of procedures, concepts and component knowledge | Red         |
| Original Strategy Indicator (Georghiades, 2000) | Cognitive dimension (Krathwohl, 2002) | Contextualised indicator/description | Code label | Code definitions | Code colour |
|-----------------------------------------------|--------------------------------------|-------------------------------------|------------|-----------------|-------------|
| Handling learned materials or processes in different ways | Create (reorganising elements into a new pattern or structure – designing new products by assembling elements in different ways) | Extending, modifying or building from learned concepts, procedures and materials to create new products | Creating new designs | Systematic application of learned concepts, materials and procedures to extend or modify existing circuits, creating new designs | teal         |
to the equipment tasks. The strategies were based on those identified during the simulations study (Falloon, 2019), but with minor adjustments to make them applicable to physical equipment. The first three columns map the original indicators and cognitive dimensions to specific learning strategies and behaviours (events) evidenced in data. Columns 4 and 5 (respectively) label and define the codes associated with each event, while the final column denotes the colour used to represent data aligned with each code in the sample data tables (S4–S6).

Research participants, organisation and procedure
The 40, 5-year-old student participants were described by the lead teacher as being of “average ability” and were organised into 12 mixed ability groups of 3, and 1 of 4. Apart from two absences, the composition of groups remained constant throughout the study. Data collection occurred during the students’ normal classroom science programme. The learning unit was entitled “Building Simple Circuits” and comprised four, 40 minute once a week lessons over a 4-week period. Each lesson involved using only physical equipment (bulbs in holders, cells, knife switches, alligator clip hook up wires) to build a range of simple circuits (uncontrolled, controlled, series, parallel), the design of which had been introduced via iPad simulations in the prior learning unit. The lessons followed the same procedures used earlier with the simulations. This comprised a short, teacher-led introduction to each “Can you?” challenge (Figure 1), an explanation of how to handle the equipment, and instructions on using the iPad video recorder. Roles were identified to ensure each group member had balanced opportunities across the four lessons to take responsibility for circuit construction and video recording. During lessons teachers circulated the groups, observing and inputting formatively into students’ activities, applying the same pedagogical strategies used during the earlier simulation lessons (e.g., open questioning, reflective questioning, problem solving and debugging prompts). At no stage was direct instruction used.

Data collection and sampling
Video data
Primary data comprising video recordings were supplemented by video-stimulated recall interviews (SRI) (Nguyen, McFadden, Tangen, & Beutel, 2013). The interviews, that asked students to elaborate on reasons and thinking behind events noted in the videos, were valuable for providing deeper insights into, and clarifying interpretations of, observations. In total, just over 18 hours
of video was recorded and reviewed, with a sample of 10 hours and 50 minutes being selected for analysis.

The sample comprised data from 8 of the 13 groups, and was selected using these criteria:

1. Useable data: valid observations/interpretations could be made from video and/or audio;
2. Student abilities: a range of abilities and learning engagement (determined by lead teacher);
3. All boy, all girl, and mixed groups;
4. Task completion: groups had attempted or completed the tasks;
5. Data was from all lessons.

Data were organised into eight group bundles for analysis. The bundles comprised data collected from each group, across the lessons.

**Video-stimulated recall interviews**

SRI data were collected from six of the eight groups, 3 days after the conclusion of the final lesson. The delay allowed time for the researcher and RA to complete an initial review of the recordings, to identify events worthy of further investigation. In total, 27 events were selected. Groups were shown and invited to discuss the short excerpts, which were paused at relevant points. The interviews were based on these questions:

1. Can you tell me what you are doing here?
2. Why did you decide to do it this way (and/or use these parts/components?)
3. How did you know to do it this way?
4. What did you learn about circuits by doing this?

Multiple events were shown to each group in a single interview.

**Data analysis**

**Procedural knowledge**

Procedural knowledge events related to evidence of students executing learnt procedures in construction tasks. Sample data were imported into StudioCode, and blind coded by the researcher and the RA. To enhance validity, three criteria were applied when making procedural knowledge (P) decisions. They were the same as those used in the simulation study to identify between-simulation transfer, and were used here to improve the accuracy of coding decisions.

The criteria were:

1. Visual evidence of learned procedures being executed to connect components in a closed circuit;
2. Visual and/or oral evidence of learned procedures being executed to “debug” or fault find;
3. Visual and/or oral evidence of learned procedures being executed in component placement (eg, in series or parallel circuits, using switches).

**Conceptual knowledge**

Conceptual knowledge events related to evidence of students understanding why procedures needed to be executed, and/or the effects or outcomes from doing so. Data were coded against the same knowledge concepts introduced in the simulation study. The concepts were:
1. Operating circuits have continuous current (the effect of gaps, breaks or faulty connections);
2. Appliances “share” voltage in a series circuit (voltage drops across resistors);
3. Switches control current (interrupt or facilitate continuous current);
4. Changing voltage affects resistor performance (adding cells to a series circuit affects bulb brightness).

Conceptual knowledge events required both oral and visual evidence. This increased the accuracy of coding by ensuring that observed actions were deliberate, not the result of trial and error or guesswork. For events to be considered conceptual knowledge, oral evidence was needed, communicating:

1. Reasons for construction decisions (eg, why circuits should be built in particular ways); or
2. Explanations of what was happening when circuits operated (theories); or
3. Explanations of the function of components (eg, what components did, and how they worked).

The researcher and RA used Studiocode to independently code a randomly chosen 3-hour sample of the video data. Kappa calculations were performed on both results to determine the strength of rater agreement (Tables S1 & S2). Following negotiation during which classifications upon which no agreement could be reached were discarded (Gwet, 2012), the RA coded the remaining data.

**Video-stimulated recall interviews**

Recorded SRI data were verbatim transcribed. As the purpose of these data was to elaborate on specific transfer events, relevant excerpts from the transcripts have been integrated into sample data presented for each group (Tables S4–S6).

**Cognitive strategies**

A second analysis was made to identify the cognitive strategies students activated during transfer. This used the code definitions outlined in Table 1. Analysis again used Studiocode to generate timelines logging strategy events under each code. Rater agreement for these is summarised in Table S3.

**Findings**

Tables S4–S6 contain coded data samples from the transfer tasks. The tables comprise contextual information, screenshots from the videos, transcripts of the video’s audio and verbatim excerpts from the SRI. Highlighted text denote data coded against the cognitive strategy indicators (Table 1), while (P) and (C) indicate data coded as procedural and conceptual knowledge. Figure 2 charts group data relating to procedural counts, while Figure 3 does the same for conceptual counts. Figure 4 charts cognitive strategy event counts. The coloured bars correspond with the code definitions in Table 1, and the highlighted sections in Tables S4–S6.

**Procedural transfer**

1. What evidence exists that young students can transfer procedural and conceptual knowledge of simple electrical circuit components, construction and operation, from simulations to equipment tasks?

Evidence was found of procedural transfer to the equipment tasks, and similarities in strategies students used during between-simulation transfer, and from the simulations to physical tasks. In total, 263 procedural events were coded, mostly aligned with component connection, placement
and function \((n = 229)\). Consistent with the simulation study, most procedural events related to operating circuits needing to be closed or complete “loops” or “circles” (eg, Table S4, rows 1 and 2; Table S6, row 1). In most (but not all) events, no additional evidence was provided indicating understanding of why this was important (conceptual). However, some evidence was found suggesting students recalled designs from the simulations (eg, Table S6, row 1; Table S4, rows 1 and 4) or from previous constructions, and reproduced them with the equipment. SRI data support this perspective, with students providing evidence of direct procedural transfer from the simulations, and between the equipment tasks (eg, Table S6, row 2, column 4; Table S4, row 4, column 4). Data coded under component placement or function support this, with evidence of decisions about component placement (bulbs, cells) mostly being made on the need to include them “in the circle” (eg, Table S6, rows 1 and 2), rather than on evidenced conceptual understanding about why this was important (continuous current flow).

In terms of components, procedural knowledge centred on the function of switches for activating and deactivating bulbs. Understanding of switches mostly related to their role of turning the lights on and off, or turning on the power (eg, Table S6, row 1). However, a few students offered tentative conceptual interpretations, mentioning how switches interrupted current by creating a “gap,” or that the switch needed to be down, otherwise “the power can’t get through” (eg, Table S5, row 3). One student linked this with operating his bedroom light, commenting that when he switch was up, it stopped... the power stopped... just like in my bedroom... when I turn off the light (SRI, Table S5, row 5, column 4). Very few events linked to procedural knowledge execution were coded as debugging and fault finding \((n = 34)\). Almost exclusively, if a circuit didn’t work, students dismantled it and started again—often repeating the same mistakes.

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Figure 2: Procedural knowledge counts
[Colour figure can be viewed at wileyonlinelibrary.com]
Figure 3: Conceptual knowledge counts
[Colour figure can be viewed at wileyonlinelibrary.com]

Figure 4: Cognitive strategy counts
[Colour figure can be viewed at wileyonlinelibrary.com]
Conceptual transfer

Consistent with results from the simulation study, limited data were found indicating conceptual transfer \( (n = 84) \). However, definite evidence existed that some students had formed tentative theories from the simulations, that they applied in an effort to make sense of how the circuits and components worked. Often, evidence of developing conceptual understandings followed procedural, where one or more students offered explanation/s as to why a procedure needed to be followed, and/or reasons for effects from doing so. Several examples of this are included in sample data (eg, Table S4, rows 1 and 3; Table S5, rows 1–3). While some events suggested explanations were naïve and scientifically inaccurate, others indicated more scientifically accurate understandings, such as those reported in SRI data in Table S5, row 5. In this example, J accurately explained how current travelled around their circuit, and the function of each component in it. D then expanded on this by providing a “real world” example of how a switch controls current to his bedroom light.

Most conceptual events (57/84) related to operating circuits needing continuous current, and were frequently associated with procedures involving components being connected in a closed “loop” or “circle.” In these examples, conceptual understandings related to the effects on current of breaks or “gaps” in circuits (eg, Table S4, rows 1 and 3), and how switches worked (eg, Table S5, row 1). Conceptual ideas were offered as a way of explaining why procedures worked, or needed to be followed.

An interesting instance was also found of more sophisticated conceptualising relating to voltage drop across resistors in series circuits. In this example, T and A were questioning why bulbs were dimmer when connected in series, offering the tentative explanation “cos they aren’t getting full power... maybe they’re only getting some of the battery... they have to share it” (Table S6, row 4). While the explanation was scientifically naïve, given the students’ age, it demonstrated quite sophisticated abstraction from the simulation to the physical task. T makes explicit reference to applying concepts from the simulations, in the SRI (Table S6, row 4, column 4). Further evidence of the understood nature of this concept can be seen later, when the students decided to add an extra cell to their circuit, in an effort to address their bulb brightness concerns. SRI data suggest cell placement was conceptually well understood. There was also evidence of conceptual understanding of the effects of adding the extra cell—“and the power adds up... they got more power” (Table S6, row 6, column 4), and the impact doing this had on bulb brightness. Notably, T and A’s extension was not part of the original task, but something they did of their own accord. This further reinforces the conclusion of solid conceptual transfer. The presence in data of similar explanatory theories to those found in the simulation study, is very significant.

Thinking skills and cognitive processes

2. Do transfer tasks provide young students with worthwhile opportunities to exercise cognitive strategies and skills?

The code definitions in Table 1 were used to identify transfer events and different thinking skills and strategies applied to transfer tasks. In the sample, 384 events were identified, dominated by examples of students demonstrating understanding of circuit components \( (n = 89) \), and applying learned procedures to circuit construction \( (n = 171) \). On StudioCode timelines, events associated with the latter of these mostly aligned with procedural events, suggesting the students copied procedures directly from the simulations. This interpretation is supported by examples of students prior or retrospectively recalling procedures from the simulations, and applying them to the equipment tasks \( (n = 42) \). A good example of this can be seen in Table S5, rows 2 and 4. The
successful execution of learned procedures was supported by students' understanding of the use and purpose of materials (components, \(n = 89\)). During construction, or less frequently when circuits didn't operate as anticipated, students often drew on knowledge about how components work, to alter their designs or problem-solve faults. An example of this can be seen in Table S5, where J and D debug the placement of wires on their switch, and comment that the lever on the switch needs to be “flat... so the power can go” (Table S5, row 1).

Although less frequent, events were found where higher order strategies and thinking skills, such as evaluating (\(n = 48\)), analysing (\(n = 29\)) and creating (\(n = 5\)), were applied to tasks. At times, students appeared to evaluate the results of their work by reflecting on previous experience, comparing and sometimes modifying what they originally understood, in the light of different understandings developed from more recent work. An example of this is in Table S4, row 4, where student J evaluates and modifies a seemingly inaccurate understanding about current flow.

Finally, only 5 events were coded under create (creating new designs) and in 3 of these, students' activities were considered more akin to experimentation/playing than resulting from the deliberate application of new knowledge. An exception to this was group T and A, and their extension to the basic series circuit task (Table S6). Evidence was present in this example that their decision to add an extra cell to their circuit, and the placement of it, resulted from the deliberate application of accurate conceptual knowledge about the arrangement of components in series circuits. SRI

![Figure 5: T&A's extended series circuit](Colour figure can be viewed at wileyonlinelibrary.com)
data also suggested a rudimentary understanding of voltage increase when cells are combined in series (“and the power adds up”). Given their young age, this example illustrated sophisticated application of conceptual knowledge to create their new circuit (Figure 5).

**Discussion**

Baseline data from the simulation study indicated these students held no existing knowledge of circuits, although post-intervention analysis identified the positive impact working with the simulations had on their knowledge of basic construction procedures, circuit components, and to a lesser extent, concepts associated with current, voltage and resistance (Falloon, 2019). This result is consistent with other studies involving adults and older students, that pointed to simulations being most effective for basic procedural training (eg, Ganier et al., 2014; Miles, 2018). Solid evidence was found in these data indicating vertical transfer—the recall and execution of construction procedures from simulations to the equipment tasks, and it was apparent that, despite differences in equipment, the identical nature of the challenges supported this type of transfer. This finding is consistent with the limited number of other transfer studies involving very young students (eg, Aladé et al., 2016; Huber et al., 2016). However, as pointed out by Bossard et al. (2008) and Georgiades (2000, 2004) achieving horizontal transfer where conceptual knowledge is understood from the simulation and applied to a dissimilar task, is more complex and cognitively demanding. Bossard et al.’s (2008) concept of horizontal transfer aligns with Mayer’s (2002) discussion of the interaction between procedural and conceptual knowledge, that occurs when learners are required to implement procedures in dissimilar contexts. To achieve this, a level of conceptual understanding is needed that supports abstraction from the original experience and the formation of generalisable theories, that can be applied and tested through implementing procedures in different situations.

According to Airasian and Miranda (2002), this process engages higher order cognitive dimensions including understanding, analysing and evaluating, that assist learners' attempts to transfer procedural knowledge to the new context. Although significantly less evidence of horizontal transfer was found in this study, examples did exist, many of which were consistent with Bossard et al.’s (2008) and Mayer’s (2002) views. Evidence of conceptual understandings usually aligned with the implementation of procedures, where the students offered tentative theories to support or justify procedural decisions and actions, or explain outcomes from the execution of procedures (eg, Table S4, rows 1 and 3; Table S5, rows 1–3). While not all of these were scientifically accurate, their presence did indicate a level of abstraction from the simulations and between equipment tasks, as they implemented procedures to build circuits of different designs. In relation to this, some evidence was also found supporting Kollöffel and de Jong’s (2013) argument that improved conceptual knowledge can subsequently contribute to more accurate selection of procedures and problem-solving strategies. Probably the best example of this was the ongoing transference of conceptual knowledge relating to current “flow,’ to construction procedures focused on operating circuits needing to be closed loops or circles. Although presence of a conceptual basis for this was not uniform across groups, examples were present in different tasks to support Kollöffel and de Jong’s argument (eg, Table S4, rows 1&3; Table S5, row 1). Certainly, data contained many examples of students reflecting on or offering explanations—scientifically accurate or otherwise, for outcomes from implementing their procedures, which were carried over to subsequent tasks.

Considering the question of transfer tasks and cognitive strategy development, alignment was noted in data with Mayer’s (2002) discussion of the nature of “direct” procedural transfer. That is, for tasks of a similar nature—such as in this study, procedural execution most frequently engage lower order cognitive dimensions (Apply). Data, such as in Table S5, rows 2 and 4 where
students verbally confirm “copying” the procedure directly from the simulation, provide support for this, and were typical of strategies most students applied. Pragmatically, this could be viewed as a completely appropriate response to solving the problems the students were given, as there was no requirement to explain or justify their thinking or actions. Also, due to the need for both visual and oral evidence for conceptual transfer, it may be that some students held solid conceptual understandings, but did not express them. This methodological limitation may have resulted in underreporting of conceptual transfer, although it was not the intent of the study to place any measure on this.

However, the presence of data such as in Table S4, row 4, suggest that for a small number of students, the tasks engaged higher order thinking processes, as they drew on and applied previously-constructed theories to build their circuits, sometimes modifying them to reflect new understandings. In terms of theoretical perspectives on procedural transfer detailed earlier (Bossard et al., 2008; Mayer, 2002), the presence of abstraction in data appeared unrelated to task fidelity. That is, while the simulation and equipment tasks were identical and these students could potentially have built correct circuits simply by replicating procedures from the simulations as others did (vertical transfer), data clearly indicated they understood why their circuits needed to be constructed in specific ways, and made decisions based on tentative conceptual understandings (horizontal transfer). Consistent with Airasian and Miranda's (2002) work, this finding indicates engagement of higher order cognitive processing.

Finally, the analytical framework aligning Georghiades's (2000) strategy indicators with Krathwohl's (2002) cognitive dimensions, proved effective for identifying transfer events, and for evaluating the types and complexity of thinking students operationalised during these events. This was important, as the study's primary goal was understanding if learning transfer occurred, and if any “cognitive benefits” accrued during this process. In this respect, sufficient, although not overwhelming evidence exists from this study, suggesting simulations might support transferable conceptual and higher order thinking development in younger students. However, similar to the simulation study, while higher order processes were engaged in conceptualisation, this did not always lead to the development of accurate science knowledge. For example, S&J (Table S6, row 4) appeared to transfer a theory from the simulations about energy originating from the battery “moving in the wires,” possibly indicating early stages in the formation of consumption misconceptions. Countering this, T&A's display of sophisticated thinking and conceptualisation when adding a cell to their series circuit, appeared based on naively described but accurate science knowledge (Table S6, row 4). While transfer tasks can be effective for exercising higher order thinking processes, teachers considering embedding them into curriculum should be mindful of their role in scaffolding students' learning to ensure that knowledge developed from them, is accurate.

Conclusion
Although research on adult learning transfer from simulations is growing, studies involving younger learners are scarce. This seems surprising, given the abundance of educational apps that embed simulations as learning assets. While knowledge generated within simulations is important, of equal interest is the learner's ability to transfer from simulations to “real world” tasks with similar or dissimilar characteristics, and understand the cognitive processes engaged in this. Findings from this study indicate that while some “slippage” occurred, sufficient evidence existed that procedural knowledge developed within simulations was robust enough to transfer to real experiences of a similar nature. Some evidence was also found of abstraction from simulations and between transfer tasks, suggesting that even very young students are capable of exercising...
higher order cognitive processes in generating tentative explanatory theories that guide procedures and problem-solving strategies. While these findings provide general support for transfer tasks in school curriculum, they also indicate care must be taken to ensure concepts developed from and during transfer, are accurate. Teachers have an important role to play scaffolding students' learning during transfer tasks, and must possess sufficient conceptual background themselves to do so effectively.

Acknowledging the limitations of this study as a single case, results support the need for further research into using transfer tasks with young students in science, and in other disciplines. While simulation use is becoming increasingly common in early years' learning, present research is limited to understanding their effectiveness for learning within the simulation. By more closely examining the extent to which learning is transferred beyond the simulation, will allow a more accurate assessment of their educational value to be made.

Statement on open data, ethics and conflict of interest
Ethical approval for distribution of video data was not granted.
Ethical approval has been granted for this study (WU.EDU059/12).
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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Rater-agreement for procedural counts

Table S2. Rater-agreement for conceptual counts

Table S3. Rater-agreement: cognitive Strategies (by code definition)

Table S4. Sample data: simple uncontrolled circuit

Table S5. Sample data for: simple controlled circuit

Table S6. Sample data: controlled series circuit