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Exploring the Effects of Concreteness Fading Across Grades in Elementary School Science Education

Abstract

The present study investigates the effects that concreteness fading has on learning and transfer across three grade levels (4 to 6) in elementary school science education in comparison to learning with constantly concrete representations. 127 9- to 12-years-old elementary school students studied electric circuits in a computer-based simulation environment, where circuits remained concrete (bulbs) throughout the learning or faded from concrete to abstract (bulbs to resistors). The most important finding was that the outcomes seemed to be influenced by a developmental factor: the study found a significant interaction between condition and grade level in relation to learning outcomes, suggesting that the outcomes generally improved as a function of grade level, but that there were notable differences between the conditions regarding the improvement of outcomes across the three grades. According the results, learning with constantly concrete representations either took less time or resulted in better learning compared to concreteness fading. Because transfer is one of the central arguments for concreteness fading, a somewhat surprising finding was that the concrete condition succeeded at least as well as the fading condition on transfer tasks. The study also discusses why the results and issues related to the conceptualisation and operationalisation of central concepts in the study call for caution towards generalization and for more research with young learners across different grades.

Introduction

Many of the contemporary conceptions about using concrete and/or abstract representations in STEM education are rooted in historical conceptions of learning and transfer. Although these conceptions have changed, the notion remains that the chance of transfer to occur decreases when the difference between the learning situation and the transfer situation increases (Cox, 1997; Salomon & Perkins, 1989). Although this notion of distance cannot be explicitly defined within the contemporary understanding of transfer, we concur with Salomon and Perkins (1989, p. 117) when they say "that it is nonetheless useful to speak loosely of distance of transfer as long as we recognize the difficulties in formalizing the notion". Transfer of learning can be generally described as the process and ability to use and apply previously acquired knowledge in new relevant situations. Although "transfer is more likely to be mentioned when learning has a side effect we were not perfectly confident it would have" (Salomon & Perkins, 1989, p. 116), in principle all learning involves transfer, because learning builds on previous learning and experiences. This is a reason why it is important to activate prior knowledge that is relevant for the current learning situation (another is that it will benefit retention), but also a reason for striving towards generalised knowledge that potentially can be more easily transferred in other relevant situations; reasons that have all influenced conceptions of the use of concrete and abstract representations in STEM education.

Concrete representations have identifiable correspondences with their referents, and are recognisable and understandable based on everyday experiences. When used in a learning situation they can be easily connected to prior knowledge and experience related to the referents. Abstract representations have weak(er) correspondence to their referents and deliberately reduce contextual details, in order to highlight core features and general structures in the target of representation. Because of their reduced nature and the emphasis on core features and general structures, abstract representations are quite often not easily recognisable and understandable based on everyday experience. Concrete representations are thought to support the transfer of prior knowledge and experiences to a learning situation because the distance between concrete representations and prior knowledge (that typically originates from everyday experiences with concrete objects) is relatively small. Proper activation of prior knowledge supports learning through improved understanding of the learning task, and explicit connections with previous knowledge and experiences. However, the ability to transfer knowledge acquired from concrete representations to other relevant contexts is often limited because details in concrete representations receive too much attention during the learning process, resulting in overly contextualised knowledge (Anderson, Reder, & Simon, 1996; Carey, Zaitchik, & Bascandziev, 2015; Chi, Feltovich, & Glaser, 1981; Finkelstein et al., 2005; Gentner, Loewenstein, & Thompson, 2003; Goldstone & Sakamoto, 2003; Kaminski, Sloutsky, & Heckler, 2008). As a result, transfer often only occurs to those contexts that are superficially highly similar (Anderson et al., 1996; Carey et al., 2015; Gentner et al., 2003).

Because of their relatively larger distance from prior knowledge and experiences, in principle abstract representations do not share the same benefits for learning as concrete representation. Their benefits are expected in the aftermath of learning when transfer to relevant other contexts is expected. This is because the reduced contextual details of abstract representations help learners focus on the essential elements and underlying structure, and construct a more generalised understanding of the topic. However, this postulates that learners are able to connect the abstract representations to their previous knowledge and experiences, otherwise learning with abstract representations remains unclear and/or disconnected, which will have repercussion for all aspects of learning (Fyfe, McNeil, Son, & Goldstone, 2014).

The literature on learning via multiple representations suggests a potential way to get around the dual transfer problem (concrete representations: transfer from newly acquired knowledge to other relevant contexts; abstract representations transfer from previous knowledge and experiences to the abstract representations) would be to use concrete representations in conjunction with abstract ones, because, as indicated above, these representations may have complementary strengths for learning and transfer (Ainsworth, 1999). There may also be other advantages in combining the representations. Comparison between multiple representations can reveal aspects that do and do not generalise across the representations, and result in a more integrated and decontextualized conception based on the commonalities between the representations (Ainsworth, 1999, 2006; Gentner et al., 2003; Mayer, 2005; Schnotz, 2005; Tabachneck-Schijf, Leonardo, & Simon, 1997). While knowledge integration is the ideal outcome, it is not guaranteed that this result will be attained as it presupposes an active process of linking and integration. It should be noted that even without integration, multiple representations could still have benefits as either one may be close enough to be recognized and used for transfer in relevant new contexts (Ainsworth, 1999; Gick & Holyoak, 1983; Larkin & Simon, 1987; Pape & Tchoshanov, 2001).

The present study focuses on concreteness fading (or progressive formalization), a special case of learning with multiple representations that has received notable attention in the STEM education literature (Braithwaite & Goldstone, 2013; De Bock, Deprez, Van Dooren, Roelens, & Verschaffel, 2011; Fyfe, McNeil, & Borjas, 2015; Fyfe et al., 2014; Goldstone & Son, 2005; Jaakkola & Veermans, 2015; Kaminski et al., 2008; McNeil & Fyfe, 2012; Moreno, Ozogul, & Reisslein, 2011; Siler & Klahr, 2016). In concreteness fading, learning tasks start with concrete representations, which are afterwards replaced by more abstract representations. The fading may include an intermediate representation to bridge or smoothen the transitioning from concrete to abstract (Fyfe et al., 2014). The order of representations is deliberate: starting with concrete representations serves to contextualise the learning task and ensure connection with prior knowledge, whereas transitioning to abstract representations (i.e. fading) aims to promote more generalised and transferable understanding.

In one of the early experiments that explicitly tested the idea of concreteness fading, undergraduates learned about the principles of competitive specialisation in four different simulation conditions (Goldstone & Son, 2005). The perceptual concreteness of simulation elements remained either (semi)concrete (semi-realistic drawings of ants and food) or abstract (symbolic representations with descriptive labels) throughout the learning phase, or switched from concrete to abstract (concreteness fading) or abstract to concrete (concreteness introduction). According the results, switching in general and concreteness fading in particular resulted in better learning and transfer than keeping the elements constant. Thus, in line with the theories of multiple representations, learning with two representations led to superior understanding compared to learning with a single representation, but in addition these results suggest that it was not the mere availability of multiple representations, but also the order of representations that had an effect on outcomes.

The work by Goldstone and Son (2005) was the inspiration for a study with younger learners in an elementary school context; the predecessor of the current study (Jaakkola & Veermans, 2015). The study took the two conditions with the weakest (concrete condition) and the strongest (concreteness fading condition) outcomes in Goldstone and Son for a study with 5th and 6th graders learning the basic principles of electric circuits in a simulation environment. While the age of the students, the domain and the number of conditions (2 instead of 4) differed, implementation of concrete and abstract and of concreteness fading stayed close to the original study. Similar to Goldstone and Son (2005), the fading from concrete to abstract was done in one step: In the concrete condition students used bulbs throughout the entire learning phase, while bulbs were replaced by resistors during learning in the fading condition (see Figure 1). Also, on a continuum from concrete to abstract, the bulb circuits that were used as concrete representations can be qualified as semi-concrete rather than concrete; the appearance of the circuits was schematic rather than realistic, but the bulbs displayed the changes in bulb brightness dynamically (as the amount of current through the bulb increases, the yellow area inside the bulb becomes larger and the colour tone of that yellow changes as well). Due the dynamic brightness, the bulb circuits contained "sufficient information to identify the real-world, concrete entity that it represents" (Goldstone & Son, 2005, p. 78). The same does not apply to the simulated resistors, represented by colourless rectangles, that were used as abstract representations[1]. Surprisingly, despite of having taken the extreme conditions, the findings seemed not in line with those obtained by Goldstone and Son (2005). Students in the concrete condition used less time for learning during the intervention than students in the fading condition, and they demonstrated significantly better understanding of circuits after the intervention across both grade levels.

[INSERT Figure 1 HERE]

The failure to replicate Goldstone and Son (2005) instigated a search for evidence and explanations that could help the interpretation of the results. While this did not result in straightforward answers, it did bring up several potential explanations, some more plausible than others. The first two are related to the fact that the studies were conducted in different domains.

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[1] The choice for resistors as abstract representations is not evident from a *formal* physics point of view, whereof a resistor and a bulb are equivalent and equally concrete circuit components. The physics view, however, presupposes notable formal knowledge about the domain. Given the fact that the students had no previous formal education on electricity it is highly unlikely that they already shared such conception. This contention is backed up by results of several studies that show that students, even on a high school level, perceive bulbs and resistors differently (Jaakkola & Veermans, 2015, 2017; Johnson, Butcher, Ozogul, & Reisslein, 2013; Moreno et al., 2011). An explanations for this difference, and an argument for the assertion that bulbs are more concrete than resistors, is that from a *conceptual* or *perceptual* point of view, bulbs have a clear practical purpose (to radiate light) that based on prior everyday experiences practically everyone can relate to. In contrast, the purpose of resistors to reduce current flow and divide voltages in a circuit, among many other uses, is unclear and significantly more abstract to most people.

It could be that multiple representations in general work in the domain used by Goldstone & Son (2005) but not in the domain used by Jaakkola and Veermans (2015). However, the outcomes of Moreno et al. (2011) provide evidence against this explanation. They conducted a study in the same domain (electric circuits) and used practically identical representations as Jaakkola and Veermans (2015) (bulbs as concrete representations and resistors as abstract representations). Their outcome was that a combination of bulbs and resistors resulted in better understanding of circuits than learning with bulbs or resistors alone. Alternatively, it might be that despite its theoretical basis, concreteness fading in particular is something that works only in the domain used by Goldstone and Son (2005). The literature however shows that concreteness fading has also been productive in other fields, particularly in various domains in mathematics (Braithwaite & Goldstone, 2013; Fyfe et al., 2015; Kaminski et al., 2008; McNeil & Fyfe, 2012), which provided additional empirical evidence against domain specific benefits of concreteness fading.

What most studies that report success of concreteness fading have in common with Goldstone and Son (2005) is that they involved older participants. Interestingly, one of the other studies with younger participants, a study in the domain of ramps, reported better outcomes with solely concrete representations compared with concreteness fading (Siler & Klahr, 2016). This suggests age could be another potential explanation for the differences in outcomes. According to Piaget's theory of cognitive development, transitioning from the stage of concrete operations to formal operations should take place around age 12, the upper age range of participants in Jaakkola and Veermans (2015) and Siler and Klahr (2016), and younger learners might experience difficulties with the concreteness fading approach because it includes abstract representations. An alternative, also suggested by Piaget's theory is that children only become capable of seeing multiple potential solutions to problems once they reach the stage of formal operations. This could be a pre-requisite for linking and integrating multiple representations which in turn is important to utilize the (full) potential of multiple representations (Ainsworth, 1999, 2006; Gentner et al., 2003). It could also be that it is not abstraction per se, or inability to link, but merely that more transitions (with smaller transitioning steps) are necessary to go from concrete to abstract. Indeed, in a recent article, Fyfe et al. (2014) argued based on the original idea of concreteness fading by Bruner that fading should use three representations. However, given the continuous nature of the concrete-abstract dimension and the fact that boundaries are subjective (based on one's previous experiences and learning, what is concrete for one, may be abstract for another) there is no formal ground for asserting a fixed (or minimum) number of representations to fading. This view is supported by empirical evidence as it was not only in the Jaakkola and Veermans (2015) study where fading from concrete to abstract representations happened at once, but also in Siler and Klahr (2016) where the fading was more gradual, that the concrete condition outperformed the fading condition. What is possible, however, is that distance of transfer from one representation to another is affected by age, which would suggest that different amounts of representations may be needed for different age groups.

The search for potential explanations also revealed that the heterogeneity of measurements for learning and transfer also makes it difficult to compare outcomes of different studies. All of the studies mentioned above state that they have measured learning, transfer, or both learning and transfer, but upon closer examination there seems to be notable differences in the operationalisation of these terms. Some, for instance, equate performance on a learning task (e.g. a number of correctly completed tasks during intervention) to learning, which is not the same as assessing learning after an intervention, or they compare performance between conditions on different learning tasks (see De Bock et al. (2011), for a critical note on comparing and equating outcomes of different tests in different conditions; and Soderstrom and Bjork (2015), for an overview of studies in which performance during a learning task turns out to be a poor indicator for learning). Similarly, some measurements after the intervention that are referred to as transfer in one study are referred to as learning in another. Others use only abstract measurements to assess learning or transfer while others (including Jaakkola & Veermans, 2015) used only concrete test items, which is likely to create bias against one of the conditions (see De Bock et al., 2011, for an example of a critical discussion on measuring learning and transfer in the context of concrete and abstract representations).

The present study

Based on the above considerations it was decided to revisit the previous study (Jaakkola & Veermans, 2015) with the aim to improve current understanding of the effects that concreteness fading has on elementary school students' learning and transfer and whether concreteness fading can bring additional benefits compared to concrete representations alone. For this purpose, we replicated Jaakkola and Veermans (2015) study with some adjustments to instruction and measurements; the simulation environment and learning conditions were the same as in the initial study (Figure 1).

In order to improve the understanding of learning and transfer in the present context, the present study made two changes regarding measurements; it added abstract circuits and unfamiliar but isomorphic circuits to a subject knowledge assessment questionnaire.

One instructional factor that may have negatively influenced students' performance in the fading condition in the initial study was the fact that the fading from concrete to abstract representations was made rather early. This may have left too little time for students to connect their previous experiences to the concrete representations and subsequently link the concrete and abstract representations. Therefore, in the present study the fading from concrete to abstract representations was slightly delayed. Finally, in order to be able to explore development or age as a factor that might affect learning outcomes, the range of participants was extended from 5th and 6th graders to include also 4th graders.

The present study makes several contributions to the current literature on concreteness fading. Firstly, as there is a clear shortage of studies focusing on younger learners, the present study will add to the current understanding of the effects that concreteness fading has on students' learning and transfer in elementary school science. Secondly, this study will add a developmental perspective by investigating these effects across three consecutive grade levels (i.e. age cohorts). Given that the stage of cognitive development often influences *how* and *what* students can and can't learn (see Demetriou, Spanoudis, & Mouyi, 2011, for a review of contemporary theories of information processing and cognitive development), it is surprising that not many studies seem to focus on multiple age groups or consider the effect that developmental factors might have on learning outcomes. Thirdly, to add methodological rigour and understand the underlying learning mechanism(s) of the fading better, the present study assesses students' learning of both representations in the fading condition separately.

Research Questions

The present study aimed to investigate three research questions. The first question concerns outcomes related to *learning*, while the second relates to *transfer*. Together these questions should provide some insights on the third question regarding *grade level differences* and the outcomes.

RQ1: How does *learning* in the concrete condition (CC) compare to learning in the concreteness fading condition (FC)?

Because the representations used in the learning tasks (only concrete representation in CC and both concrete and abstract representations FC) are different, and in order to avoid bias towards one of the conditions, RQ1 is divided into two sub-research questions (RQ1a and RQ1b).

RQ1a: Are there differences in students' understanding of circuits with concrete and abstract representations FC?

This research question has two purposes: to add to the general understanding of the effect of concreteness fading on younger students' understanding of both concrete and abstract representations, and to verify that students' understanding of concrete representations is a fair indicator of learning in FC when comparing learning on concrete representations between the conditions (RQ1b).

RQ1b: Are there differences between students in CC and FC with regard to their understanding of circuits with concrete representations (bulbs)?

In Jaakkola and Veermans (2015; also Siler & Klahr, 2016) students in CC outperformed students in FC on concrete representations. The decision to delay the fading in the present study was based on the assumptions that this would improve students' basic understanding of concrete representations and subsequently facilitate integrating concrete and abstract representation, which should translate into more favourable learning outcomes for FC compared to the previous study. In case no differences in understanding of concrete representations are found between the conditions, this would suggest that delaying the fading has been effective.

RQ2: Does concreteness fading have a beneficial effect on *transfer* in the domain of electricity for upper-elementary school students?

Based on the underlying theoretical premises the general assumption is that concreteness fading has better transfer potential than concrete representations alone and it is therefore expected that FC will outperform CC on transfer (Goldstone & Son, 2005; McNeil & Fyfe, 2012).

RQ3: Are there grade level differences within and between conditions regarding learning and transfer?

Grade level differences would suggest that outcomes are influenced by developmental factors. A dissimilar pattern of differences within and between conditions over the grade levels would suggest an interaction between development and condition.

Method

Participants and design

The participants of the study were 127[2] 4th (*n* = 34) 5th (*n* = 25), and 6th (*n* = 68) grade students from Finland (age 9-12 years). Participation in study was voluntary and parental consent was obtained for all students. The students, with no previous formal education in electricity, constructed and studied electric circuits in two computer-based simulation conditions described below, with an objective to discover the basic principles of electric circuits.

In the **concrete condition** (CC; *N* = 63) simulation elements remained concrete throughout the experimentation; the students were instructed to construct circuits with bulbs (Figure 1, left picture), observe changes in bulb brightness, and measure the potential difference (voltage) across bulbs.

In the **fading condition** (FC; *N* = 64) simulation elements changed from concrete to abstract during the experimentation; the students were first instructed to construct circuits with

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[2] The initial sample consisted of 134 students but only those were included in the analyses who completed all three parts of the study (pre-test, intervention, and post-test).

bulbs in the beginning of the experimentation, and then to construct circuits with resistors (Figure 1, right picture), and measure the potential difference across resistors. To support the transition from bulbs to resistors, the first worksheet (see Appendix I and below) that included resistors explained the connection between bulbs and resistors.

Materials

Worksheets

Students' inquiry process with the circuit simulation was supported and guided by nine instructional worksheets, designed to confront common misconceptions of electric circuits (e.g. Jaakkola, Nurmi, & Lehtinen, 2010; Jaakkola, Nurmi, & Veermans, 2011; McDermott & Shaffer, 1992; Reiner, Slotta, Chi, & Resnick, 2000; Targiso Borges, 1999) and to correct these misconceptions by gradually introducing the scientific model. In general, the worksheets asked students to construct various circuits and conduct electrical measurements with the simulation. The worksheet also scaffolded the students to predict, investigate and infer (cf. White & Gunstone, 1992) how the changes and differences in circuit configurations affected circuit behaviour. The worksheets began with a very simple and structured task, wherein the students were asked to construct a circuit with one battery, wires, and a bulb, and later progressed towards more challenging and open-ended tasks in which the students had to, depending on the condition, construct circuits containing multiple bulbs (CC) or resistors (FC) (see Appendix I for a worksheet example in both conditions).

Learning time and content coverage

The amount of worksheets completed during the intervention and the time to complete the worksheets were used as indicators of the fluency (or difficulty) of the learning in the two conditions.

Subject Knowledge Assessment Questionnaire

The students completed a subject knowledge assessment questionnaire before (pre-test) and after (post-test) they constructed circuits. The pre-test version of the questionnaire consisted of 29 items, divided into items consisting of concrete (bulbs) and abstract (resistors) representations of circuits (see Figure 2 for an example). The division was important for providing a balanced measurement between the conditions, and to overcome one limitation of the initial study (Jaakkola & Veermans, 2015).

[INSERT Figure 2 HERE]

The post-test version of the questionnaire consisted of 54 items. In addition to the 29 items from the pre-test that were designed to measure learning in the post-test, the post-test questionnaire included 25 transfer items that were designed to measure students' ability to apply the knowledge they learned in a specific context during the intervention to a novel context. The transfer items consisted of isomorphic circuits with perceptually unfamiliar elements such as motors, propellers and loud speakers (see Figure 3 for a transfer item example).

[INSERT Figure 3 HERE]

Students' answers to the questionnaire were scored against a model answer template. 1 point was given for a correct answer and 0 for an incorrect answer. In order to reduce the effect of guessing, a certain amount of consistency was required for a correct answer. In a two bulb circuit, for instance, a correct answer required that the voltages across both bulbs were correct.

The reliability of the subject knowledge assessment questionnaire was overall good, suggesting high internal consistency between the items. The lowest reliabilities were observed in pre-test on items consisting of abstract circuit representations, which is not surprising considering that that electricity was an unfamiliar topic to the students, and resistors are less familiar and more abstract circuit elements than bulbs. The reliability was good already in the pre-test (all items α = .859, concrete items α = .823, abstract items α = .627, respectively), and it become even better in the post-test (α = .917, α = .891, α = .782, respectively), suggesting (as could be expected) that the students' knowledge of electricity become more accurate and systematic due the intervention. The reliability of transfer items was also good: α = .931.

Procedure

The empirical phase of the study took place over a one-week period for each participating class.

Pre-test. In the first session, which took approximately one hour, the students completed the subject knowledge assessment questionnaire, which was used to measure their initial understanding of the functioning of electric circuits.

Allocation to conditions. To ensure that both learning conditions would have the nearest to equal spread of subject knowledge at the baseline, students placement to the learning conditions followed the following matching procedure: Sets of two students were matched on pre-test scores within each classroom, and from each set one student was allocated randomly to one of the two conditions, CC or FC. Matching and working on a classroom level enabled controlling of a classroom effect on outcomes and it also ensured minimal interruption of daily school routines.

Intervention (Learning phase). The actual intervention, when the students constructed various circuits in the concrete or fading condition, took place in the schools' computer suite. Each classroom worked one at a time in the computer suite. At the beginning of the intervention, the students received a 5-minute introduction that included a general introduction to electricity and guidance on the use of the materials. This introduction was identical in both learning conditions.

During the rest of the intervention, the students worked in pairs.[3] The pairs were formed randomly within each condition (i.e. each pair worked in the same condition), after the students were allocated into the conditions. The pairs had 90 minutes to solve circuit assignments that were given in the form of nine worksheets (cf. worksheet section above for more details). In the concrete condition all 9 worksheets asked students to construct and study circuits with bulbs, whereas in the fading condition the bulbs were replaced by resistors from the fourth worksheet onwards. The students were required to take notes of their observations and then write down their answers on the worksheet. The students' progression through the worksheets was controlled by two researchers, same for both conditions (there was no teaching or teacher involvement); students received one worksheet at a time and they could proceed onto the next worksheet only when they had completed the previous worksheet correctly.

Post-test. In order to compare the relative effectiveness of the learning conditions and measure the changes in the students' conceptual understanding of electrical circuits, the students completed the extended version of the subject knowledge assessment questionnaire one day after the intervention. Although the students worked in pairs during the intervention they completed the subject knowledge assessment questionnaire individually.

Results

As the students worked in pairs, a Variance Component Analysis was conducted in order to check whether the nested nature of the data had an effect on the outcomes and should be

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[3] The students worked in pairs because working in pairs is a natural procedure in science classrooms in Finland, which at the same time ensured better comparability with the initial study that also included pairs (Jaakkola & Veermans, 2015).

controlled in the analyses, but this was not the case as the Intraclass Correlation on post-test scores was very low (0.017).

[INSERT Table 1 HERE]

Baseline knowledge

As shown in Table 1, which displays the descriptive statistics regarding the main outcome indicators of the present study, students scored significantly higher in the pre-test on concrete items (circuits with bulbs) than on abstract items (circuits with resistors), paired-t (126) = 6.252, p < .001. This confirms that bulbs and resistors are perceived as different by students, and that resistors are more difficult to understand as they are conceptually more abstract than bulbs. According to a 2 x 3 factorial ANOVA, with *condition* (CC vs. FC) and *grade level* (4th vs. 5th vs. 6th) as independent variables and the *total pre-test score* as a dependent variable, there was no main effect for condition or interaction effect between condition and grade level, F (1, 121) = 0.496, p = .482, η_p^2 = .004 and F (2, 121) = 0.394, p = .675, η_p^2 = .006, respectively. This outcome was consistent across concrete (bulbs) and abstract (resistors) test items, *p*s > .05, meaning that the two conditions did not differ significantly in subject knowledge at a general or grade level prior to the intervention as assessed by the pre-test. A significant main effect for grade level was found, F (2, 121) = 7.336, p < .001, η_p^2 = .11, which was due to 6th graders scoring higher (i.e. had better overall understanding of the functioning of circuits) in the pre-test than 4th and 5th graders, independent of the condition.

Learning time and content coverage

The number of worksheets completed during the intervention and the time to complete the worksheets were used as indicators of the fluency (or difficulty) of the learning during the intervention in the two learning conditions. A 2 x 3 factorial ANOVA, with *condition* and *grade* *level* as between-subjects factors, was used to assess whether there were statistical differences between the conditions in the average amount of worksheets that the students were able to complete during the learning phase and in the average learning times. For the worksheets completed, no main effect for condition or interaction effect between grade level and condition was found, F (1, 121) = 2.725, p = .101, η_p^2 = .02 and F (2, 121) = 1.612, p = .204, η_p^2 = .03, respectively, suggesting that there were no differences between the conditions in the amount of content that was covered during the intervention (out of a total of 9 worksheets, CC: M = 8.94, SD = 0.34; FC: M = 8.88, SD = 0.38). For learning time, a significant main effect for condition was found, F (1, 121) = 6.230, p = 0.14, η_p^2 = .05, suggesting that on average it took significantly less time from the students' in CC to study the content (i.e. complete the worksheets) during the intervention than from the students in FC (see Table 1). As there was no interaction effect between condition and grade level, F (2, 121) = 0.671, p = 513, η_p^2 = .01, this indicated that the difference in the learning times between the conditions was consistent across the grade levels. These outcomes suggest that despite the fact that delayed fading seemed to make the learning easier in FC (in contrast to the original study, no differences were found between the conditions concerning the average amount of worksheets completed during the learning phase), learning appeared to be still more efficient in CC.

Effects of conditions on learning

This section will investigate and compare learning outcomes in the two conditions. Based on the differences between the conditions in the use of representations during the learning phase as it was discussed in relation to the research questions, there will be two sub-sections: the first focuses solely on the fading condition, and investigates whether the learning outcomes regarding concrete (bulbs) and abstract (resistors) circuit representations are in balance therein (RQ1a), in order to establish the interpretation framework for the second section that compares learning outcomes between the conditions regarding concrete representations (RQ1b).

Learning in the fading condition

The students in FC gained a significant amount of knowledge on circuits during the intervention, independent of the type of representation (repeated ANOVAs on both representations, $p < .001$; Table 1). Despite the fact that the students' demonstrated initially better understanding of concrete than abstract representations, this gap disappeared during the learning phase. In order to answer research question 1a, a 2 x 3 factorial ANOVA, with *type of representation* (bulb vs. resistor) and *grade level* as between-subjects factors, was used to assess whether the post-test means regarding bulbs and resistors were sufficiently equal in the fading condition. This appeared to be the case as no main effect for the type of representation or interaction effect between the type of representation and grade level was found, $F(1,122) = 0.164$, $p = .69$, $\eta_p^2 = 0.001$ and $F(2, 122) = 0.253$, $p = .777$, $\eta_p^2 = 0.004$, respectively. This result, comparable scores on concrete and abstract representations at the post-test, suggests that concrete representations can be considered as a fair indicator for learning outcomes in the fading condition but also that the students in the fading condition were able to learn about both representations during the learning phase and their understanding of the representations was in balance.

Learning outcomes between the conditions

This section compares learning outcomes and gains regarding concrete representations between the conditions. The previous section revealed that students in the fading condition demonstrated equally good understanding of circuits regardless of the type of representation. This indicates that outcomes concerning concrete representations can be viewed as a fair and representative indicator of learning in the fading condition and that results of the comparison between conditions can in that respect be interpreted without restraint.

The baseline knowledge section already showed that there were no differences between the conditions on understanding of concrete representations (bulbs) prior to the intervention (i.e. in pre-test), F (1, 121) = 0.091, p = .762. A one-way repeated measures ANOVA, with test phase (pre-post) as a within-subjects factor, was run independently for each condition in order to establish learning effects. A significant effect for test phase was found in both cases, demonstrating that the students gained a significant amount of subject knowledge regarding circuits with bulbs during the intervention in both conditions, CC: F (1, 62) = 50.738, p < .001, η_p^2 = .45; FC: F (1, 63) = 49.110, p < .001, η_p^2 = .44.

A 2 x 3 x 2 repeated measures ANOVA, with *condition* and *grade level* as between-subjects factors, was used to assess whether the mean change from pre- to post-test in the students' understanding of concrete representations differed in the two conditions or between the grade levels. According to the ANOVA, a marginally significant two-way interaction effect between test phase and condition was found, F (1, 121) = 3.110, p = .080, η_p^2 = .03, suggesting overall a different trend in learning gains between the conditions. A significant three-way interaction effect between grade level, condition and test phase that was also found, indicated that the departure was mainly due to a difference on a specific grade level, F (2, 121) = 3.341, p = .039, η_p^2 = .05. In order to examine the three-way effect more closely, two-way repeated ANOVAs, with appropriate per family error rate corrections (Tukey), were run independently for each grade level. This revealed a significant two-way interaction effect between test phase and condition among 5th graders, but not among 4th and 6th graders, meaning that the learning gains were significantly different between the conditions among the 5th graders, F (1, 121) = 5.906, p

= .017, g[4] = 1.08; F (1, 121) = 0.003, p = .961, g = 0.09; F (1, 121) < 0.001, p = 1.000, g < 0.01, respectively. Altogether, condition and grade level explained 11.3% of the total variation in learning gains regarding concrete circuit representations, R^2 = .113, F (5,121) = 3.073, p = .012.

The above results are illustrated in Table 1. As shown in the 'All' columns of the table, there is overall a clear learning effect in both conditions: the amount of change from pre-test to post-test is notable in both conditions, and slightly stronger in CC as compared to FC. The average learning gains (difference between pre- and post-test scores on bulb circuits) are nearly identical between the conditions among the 4th and 6th graders (though the means are overall notably higher among the 6th graders both before and after the intervention), whereas they are substantially different among the 5th graders, in favour of CC. A further inspection within grade levels suggests that among 4th graders the students did not do particularly well in either condition; they had on average approximately only 40% of the post-test answers correct, independent of the condition. Among 5th graders the students did well only in CC; in fact, the 5th graders working in CC did as well in the post-test as the 6th graders, that is, they had approximately 60% of the answers correct; in FC the 5th graders had the same average as the 4th graders. Among 6th graders there were no differences between the conditions; the students did well independent of the learning condition.

Effects of conditions on transfer

Overall, as shown in Table 1 and in Figure 4, the students scored significantly lower on the transfer items as compared to learning items (bulbs and resistors) in the post-test, thus suggesting that the transfer items were perceived as the most difficult items in the post-test, F (1, 126) = 24.166, p < .001, η_p^2 = .16.

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[4] g is Hedges' (1981) bias corrected standardised mean difference effect size for two independent samples.

A 2 x 3 factorial ANOVA, with *condition* and *grade level* as independent variables, was used to assess whether the transfer of learning differed in the two conditions. According to the ANOVA, no significant main effect for condition or interaction effect between condition and grade level was found, F (1, 121) = 2.877, p = .092, η_p^2 = .02 and F (2, 121) = 1.829, p = .165, η_p^2 = .03, respectively. This suggests, contrary to expectations based on previous research, that there were no significant differences in the transfer performance between the conditions. In fact, as can be seen in Table 1, and particularly in Figure 4, the trend in the outcomes concerning transfer is strikingly similar to the one concerning learning. There is overall a slight, though non-significant, trend in favour of CC over FC. Additionally, there are no notable differences between the conditions among 4th and 6th graders, whereas among the 5th graders CC outperforms FC by a considerable margin. Furthermore, the high and low outcome clusters consist of the same three groups as in the case of learning outcomes.

[INSERT Figure 4 HERE]

Discussion

The present study investigated the effects of concreteness fading on learning and transfer across three grade levels in elementary school science. The study compared learning and transfer outcomes of concreteness fading with the outcomes of constantly concrete representations in the domain of electric circuits.

According the results regarding learning, students' understanding of the kind of circuits they learned with and from during the intervention improved significantly from pre- to post-test in both conditions at all grade levels. Comparison across the grade levels showed either no differences in learning between the conditions (4th and 6th grade) or concrete condition outperformed fading condition (5th grade). Compared with the initial study (Jaakkola &

Veermans, 2015), the results regarding learning improved in the fading condition among 6th graders but not among 5th graders (the initial study had only these two age groups, and the concrete group outperformed the fading group on both of these). This might indicate that the delayed fading that was implemented in the present study helped the former group, but not the latter, to acquire a better understanding of bulb circuits and make a better connection between bulb and resistor circuits (excluding the delayed fading, the design and instruction of the present study was identical with the initial study).

In contrast to underlying theoretical premises of concreteness fading and current empirical evidence among older students, the present study found no evidence that concreteness fading would be extra beneficial for transfer in elementary school context, relative to learning from constantly concrete representations. It was expected that the benefits of concreteness fading would show at least in those cases where the outcomes regarding learning were equal between the conditions (i.e. on 6th grade), but that was not the case. In fact, the pattern regarding transfer results was very similar, or almost identical, to the pattern regarding learning. One explanation for these results could lie in the nature of the transfer items that were used in this study (see limitations at the end of the discussion).

One reason for delaying fading in the current study was that significantly more students in the fading condition were unable to complete all worksheets in the initial study (Jaakkola & Veermans, 2015). The present study found no differences between conditions in the number of worksheets completed, suggesting that the delayed fading enhanced learning. Analysis of time, however, revealed that the concrete group still spent significantly less time on completing the worksheets than the fading group on 4th and 6th grade. Interestingly on the only grade (5th) where the fading group did not spend more time they were outperformed by the concrete condition. Together these findings suggest that in the fading condition the learning seems to be inherently more difficult for learners in the context of these studies, either in terms of learning outcomes, or time needed to achieve the same outcomes.

One important finding of the present study was that it found significant differences in both learning and transfer outcomes between grade levels, with a clear tendency towards better outcomes on higher grade levels, indicating that the learning outcomes were influenced by a developmental factor. More importantly, a significant interaction effect between condition and grade level was found in relation to learning outcomes, suggesting that there were notable differences between the conditions on how students' understanding of electric circuits improved across the three grade levels. In the concrete condition learning outcomes took a leap already in 5th grade, whereas in the fading condition the outcomes went up a year later, in 6th grade. This implies that students were ready for constantly concrete representations one year earlier than they were for concreteness fading.

A potential explanation for the overall success of concrete condition in this study, and in particular concrete group’s unanticipated good performance on transfer tasks relative to the fading group, could be related to the fact that the 'concrete' version of the simulation was semi-concrete. It seems that this interactive ‘intermediate’ representation (cf. Fyfe et al., 2014) provided a good balance between concrete and abstract representations of circuits, which resulted in good and generalisable understanding of electric circuits (see also Siler & Klahr, 2016, who obtained similar outcomes from similar setting in a domain of ramps). In other words, it seems that the simulation was sufficiently concrete to enable the students to interpret and understand it based on their previous experiences, and sufficiently abstract that the students were able to transfer their learning from the simulation to the unfamiliar circuits that were included in the post-test. When viewed from this perspective, the results of the present study could also be considered as a 'success story' of semi-concrete representations, rather than a 'failure' of concreteness fading.

Despite the overall success of concrete condition, the lower learning outcomes of the 4th graders in the concrete condition suggests that either the semi-concrete representation may have been too abstract or the learning task too difficult for the youngest participants. While this explanation can also apply to the 4th graders in fading condition, it does not explain the lower outcomes of the 5th graders in the fading condition compared with those in the concrete condition. Because the participants (9 to 12 years-old) of the study likely operated in Piaget's terms still within the zone of concrete operations (approximately ages 7 to 12, according to Piaget), students may have experienced specific difficulties in the fading condition a) with understanding the abstract representations or b) in linking the representations. According the results in the fading condition, students learned both types of circuits equally well; the post-test showed no differences in any of the grades in scores regarding circuits that included abstract components (resistors) versus circuits that included concrete components (bulbs). This suggests that it may be integrating and unifying information from the representations, rather than abstract representations per se, that caused the problems in the fading condition. However, it could also be both, because it might be that the abstract representations complicated the process of integrating information from the representations. As noted by Kurtz, Miao, and Gentner (2001), translating between representations can be particularly challenging in cases when the representations are available only at different times (concreteness fading is such a case) and learners are novices with no or little prior knowledge (such as in the present study), because in such cases the linking of the representations depends on memory retrieval. The outcomes suggest that 6th graders no longer had these problems, which may be due to their higher prior knowledge (measured in the pre-test) that somehow enabled them to perceive the similarity of bulbs and resistors better than the younger participants, or their general developmental stage that made them capable of dealing with the two representations. Comparison with the concrete condition, however, also suggests that the 6th graders were able cope with concreteness fading, but not benefit from it as they did not outperform the concrete group on learning or transfer.

In their review article Fyfe and colleagues (2014, p. 10) argued “that concreteness fading is a promising instructional technique that moves beyond the concrete versus abstract debate and exploits the advantages and minimizes the disadvantages of both”. The present study suggests that there is at least one alternative that deserves more attention. The present study has shown that in elementary school science a single, semi-concrete representation can result in equal or better learning and transfer outcomes in less time than learning with two sequential representations that fade from concrete towards abstract. The results challenge to a certain extent common claims that transfer from constantly concrete representations is difficult or even impossible (e.g. Kaminski et al., 2008). The results also question the effectiveness of concreteness fading in elementary school science education where majority of students still operate in the stage of concrete operations, and they indicate that the theoretical arguments regarding learning via concreteness fading (Fyfe et al., 2014; Goldstone & Son, 2005) and via multiple representations (Ainsworth, 1999, 2006; Gentner et al., 2003; Mayer, 2005; Schnotz, 2005; Tabachneck-Schijf et al., 1997) that were put forward in the introduction do not apply unconditionally in case of young learners.

The results of the concrete condition have also notable practical value, as it can be argued that orchestrating a single (semi-concrete) representation in a whole classroom setting (as in the present study) is more feasible than designing a fading sequence with two, three, or more representations, especially because the present results, in conjunction with the results of an earlier study (Jaakkola & Veermans, 2015), suggest that successful design of fading may be sensitive to development and timing of transitioning from one representation to another. For instance, inclusion of a more concrete (or abstract) representation for 5th graders and older students doesn't seem justifiable, as the outcomes in concrete condition suggest that 5th graders had no problems with starting from a semi-concrete representation, and fading to abstract did not seem to provide advantages. It may be that 4th graders could have benefited from (fading from) a more concrete representation than the one that was used in the present study. However, it should be noted that additional steps may also complicate the learning process, because linking between representations would be needed on each transition which may be hard especially when representations are presented sequentially (Ainsworth, 2006; Kurtz et al., 2001). Especially for younger students, a pedagogical alternative that could lower the threshold would be to use both representations in parallel (i.e. simultaneously during the learning) in a similar way as it was done by Moreno et al. (2011) and with virtual and hands-on activities in Jaakkola and Nurmi (2008) and Jaakkola et al. (2011). In these studies students who were presented with two representations in parallel outperformed students that used one representation. While in Moreno et al. (2011) students were already a bit older, in Jaakkola and Nurmi (2008) and Jaakkola et al. (2011) studies they were of the same age as the students in the present study, which illustrates that it is possible for learners to benefit from (simultaneously available) multiple representation already at young age.

One important message that comes from this study is that what is concrete (or abstract) and what can constitute fading (i.e. how many steps would be needed or are ideal in fading) cannot simply be defined beforehand without taking the learner that interacts with the representations into account. These seem dependent at least in part on the previous experiences (e.g. 6th graders displayed higher prior knowledge in the pre-test) and the capabilities of learners (different due to age and developmental differences between the participants). These notions are closely connected to learning and transfer. A major premise of concrete representations is that they can be connected to prior knowledge more easily than abstract representations (which assumes a smaller transfer distance from everyday experience to concrete than to abstract representation). The same applies to concreteness fading, which assumes that the knowledge acquired from a concrete representation would benefit learning with and from an abstract representation in a way that it would yield more generalized and de-contextualized knowledge. The transition from concrete towards abstract does not only depend on the knowledge acquired from the concrete representation and prior knowledge, but also on the capability of transferring the knowledge to the abstract representation (in the present context only 6th graders seemed to succeed in this task). If the transition from one representation to the other fails or the outcome is not more general or de-contextualized, the whole premise fails. It is therefore not entirely surprising that even though some researchers (e.g. Fyfe et al., 2014) suggest that the proper or correct way to conceptualise and implement concreteness fading would be via three phases, there is currently no clear empirical evidence that would justify that a specific amount of steps would be optimal or necessary in concreteness fading; equal success with concreteness fading has been obtained with only two phases (e.g. Goldstone & Son, 2005), and given that the present outcomes could be interpreted as an even more extreme 'one phase success story' (only the intermediate phase from the three phase model is needed), it is questionable that such magical number of steps exists.

Although we believe that the measurements used in the present study were able to ‘capture’ outcomes regarding learning accurately (in fact, this was the first study that has measured students’ learning of concrete and abstract representations in a fading condition separately), this study has two limitations regarding measurements, which should be explored in future studies. It could be argued that the transfer test (lower outcomes in transfer tests compared to learning tests suggest they really measured transfer) was to certain extent limited (though fair to both conditions), as it did not include ‘far’ transfer items. The second limitation is that the study (like most other studies) did not measure long term retention (though learning was not measured as performance or immediately afterwards, but one day later). Both limitations may have affected the outcomes in the current study as benefits of fading may be more apparent at larger transfer distances and over longer time spans (Soderstrom & Bjork, 2015).

In general, the results of this study suggest that it would be important to find out more about the affordances of different representations and their combinations especially on a young age in order to understand better how these can be utilized productively in instruction. More research is needed to explore the effectiveness of concretes fading and different types of concreteness fading (i.e. different amount of steps and representations) among young learners. The results of the present study indicated a change in the fading condition on the 6th grade (significant improvement on both learning and transfer compared to previous grade levels) and it could therefore be valuable to replicate this study also with 7th and 8th graders who should be already operating on the stage of formal operations.The present study also suggests that especially with younger learners, concreteness fading is not the only option, and that research that investigates the potential of semi-concrete representations in STEM education and other alternatives like the use of two parallel representations should also be pursued.

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Appendix

[INSERT Figure A1 and A2 HERE]

Table 1. Baseline knowledge (pre-test), learning (post-test: bulbs in CC and bulbs and resistors in FC) and transfer scores, and learning times by condition and grade level

	Concrete condition (CC)				Fading condition (FC)			
	4th grade	5th grade	6th grade	All	4th grade	5th grade	6th grade	All
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Pre-test								
Bulbs	31.5 (25.0)	23.6 (16.0)	40.8 (23.6)	34.8 (23.4)	24.6 (12.1)	23.6 (19.3)	43.8 (25.6)	34.9 (23.6)
Resistors	19.5 (20.0)	15.2 (23.0)	32.3 (23.5)	25.4 (23.4)	14.4 (19.8)	18.0 (22.0)	29.1 (25.0)	23.3 (23.9)
Post-test								
Bulbs	44.1 (28.8)	64.0 (29.8)	60.2 (28.2)	56.5 (29.3)	39.2 (16.7)	41.0 (28.1)	63.2 (26.5)	52.7 (27.0)
Resistors					38.9 (25.7)	46.7 (33.7)	64.8 (30.7)	54.3 (31.8)
Transfer	36.3 (24.0)	58.3 (29.0)	53.3 (28.9)	49.4 (28.5)	31.2 (23.3)	35.9 (23.0)	54.7 (27.0)	45.0 (27.2)
Learning time (mins)	80.0 (14.1)	71.5 (10.8)	63.6 (12.9)	69.8 (14.6)	89.9 (7.6)	73.4 (8.2)	71.2 (17.0)	76.3 (15.7)

Note. Numbers, excluding learning time, indicate percentage of correct answers

Fig 1. The electricity exploration tool (EET), used both in Jaakkola and Veermans (2015) and in the present study, is an easy-to-use simulation for constructing simple DC circuits, observing circuit functionalities, and conducting electrical measurements. The simulated model is authentic with two exceptions: the wires have no resistance and the battery is always ideal (i.e. there is no change in the potential difference with time). In the concrete condition students used bulbs (left picture) throughout the learning, whereas in the fading condition they faded from bulbs to resistors (right picture).

Fig 2. A translated and compacted example of concrete test items where the students are asked to calculate the voltages across seven identical bulbs. In another task, the students were asked to rank the bulbs according to their relative brightness. The test also included corresponding resistor items.

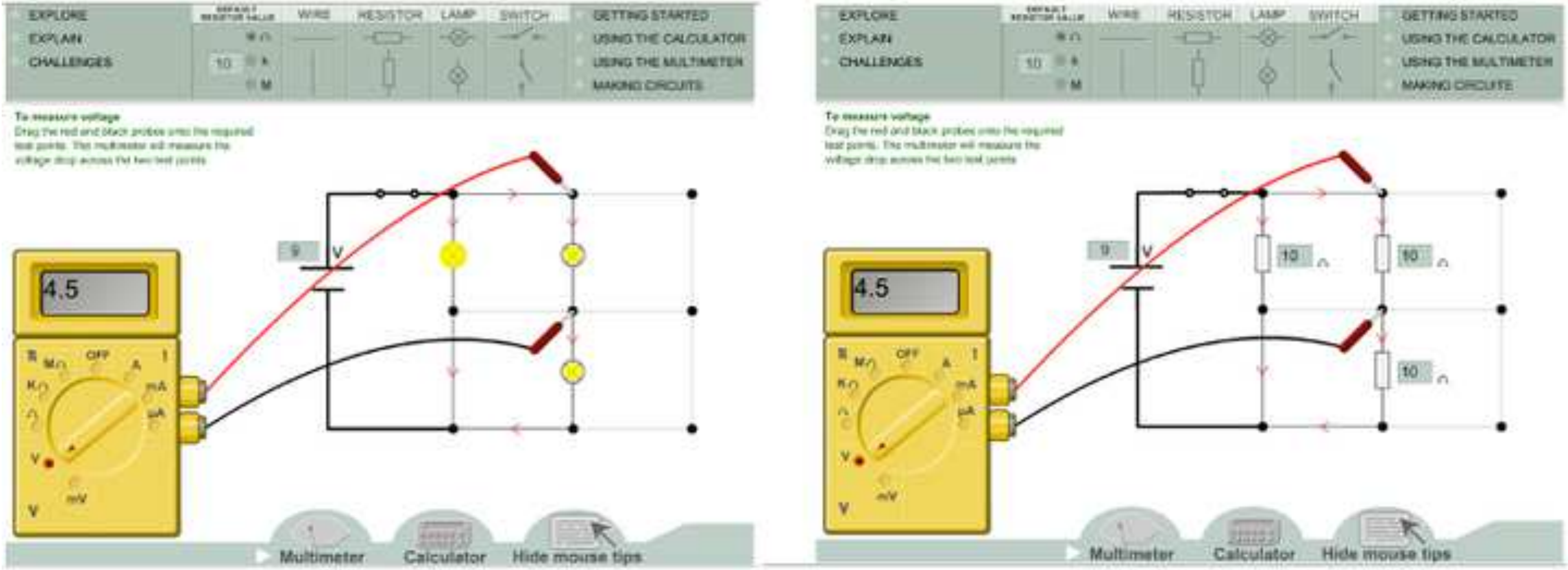
Fig 3. A translated and compacted example of a transfer item consisting of circuit with a loud speaker.

Fig 4. Average learning and transfer scores across grade levels in both conditions.

Fig A1. A translated and compacted example of a worksheet in the concrete condition (CC).

Fig A2. A translated and compacted example of a worksheet in the fading condition (FC).

Figure1



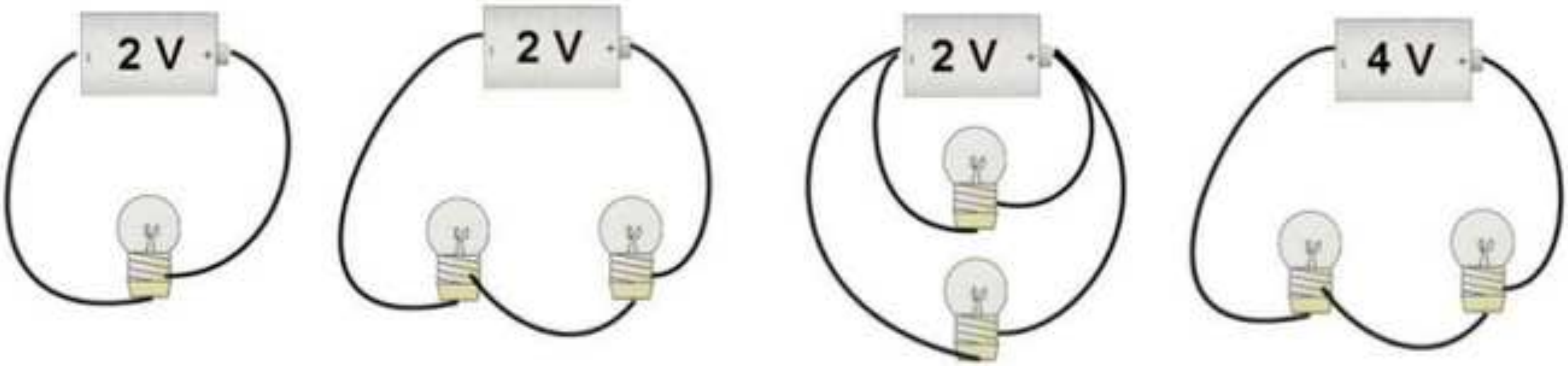
To measure voltage

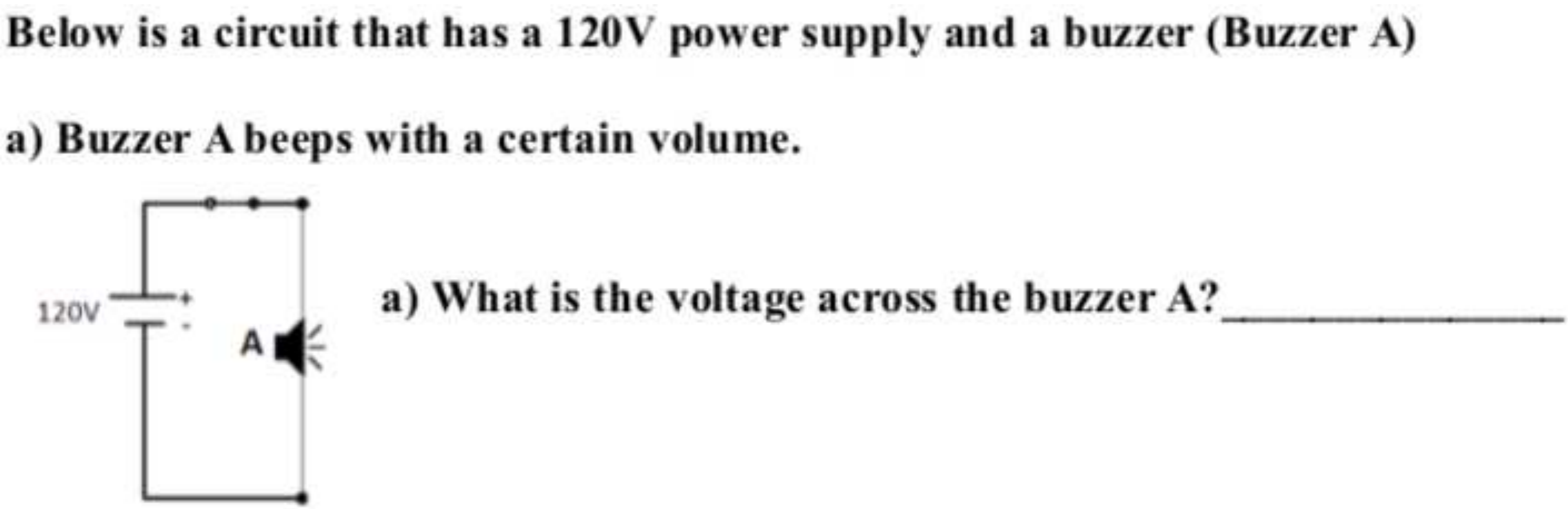
Drag the red and black probes onto the required test points. The multimeter will measure the voltage drop across the two test points.

To measure voltage

Drag the red and black probes onto the required test points. The multimeter will measure the voltage drop across the two test points.

Q2. Look at the circuits below and write down the voltage for each bulb. Please note that the battery voltage for a given circuits is 2 or 4 volts (V).

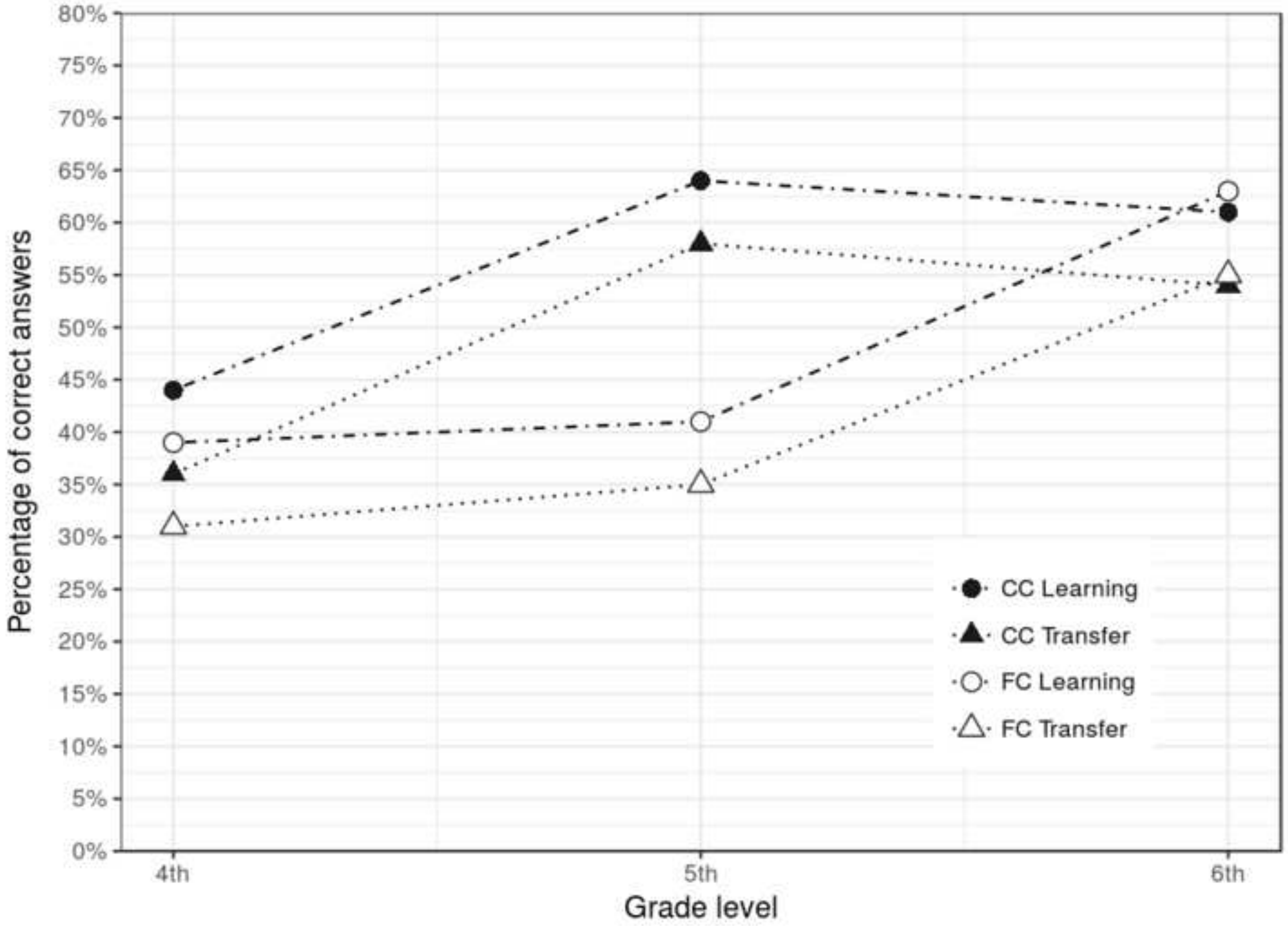




Below is a circuit that has a 120V power supply and a buzzer (Buzzer A)

a) Buzzer A beeps with a certain volume.

a) What is the voltage across the buzzer A?____________________


80%
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50%
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40%
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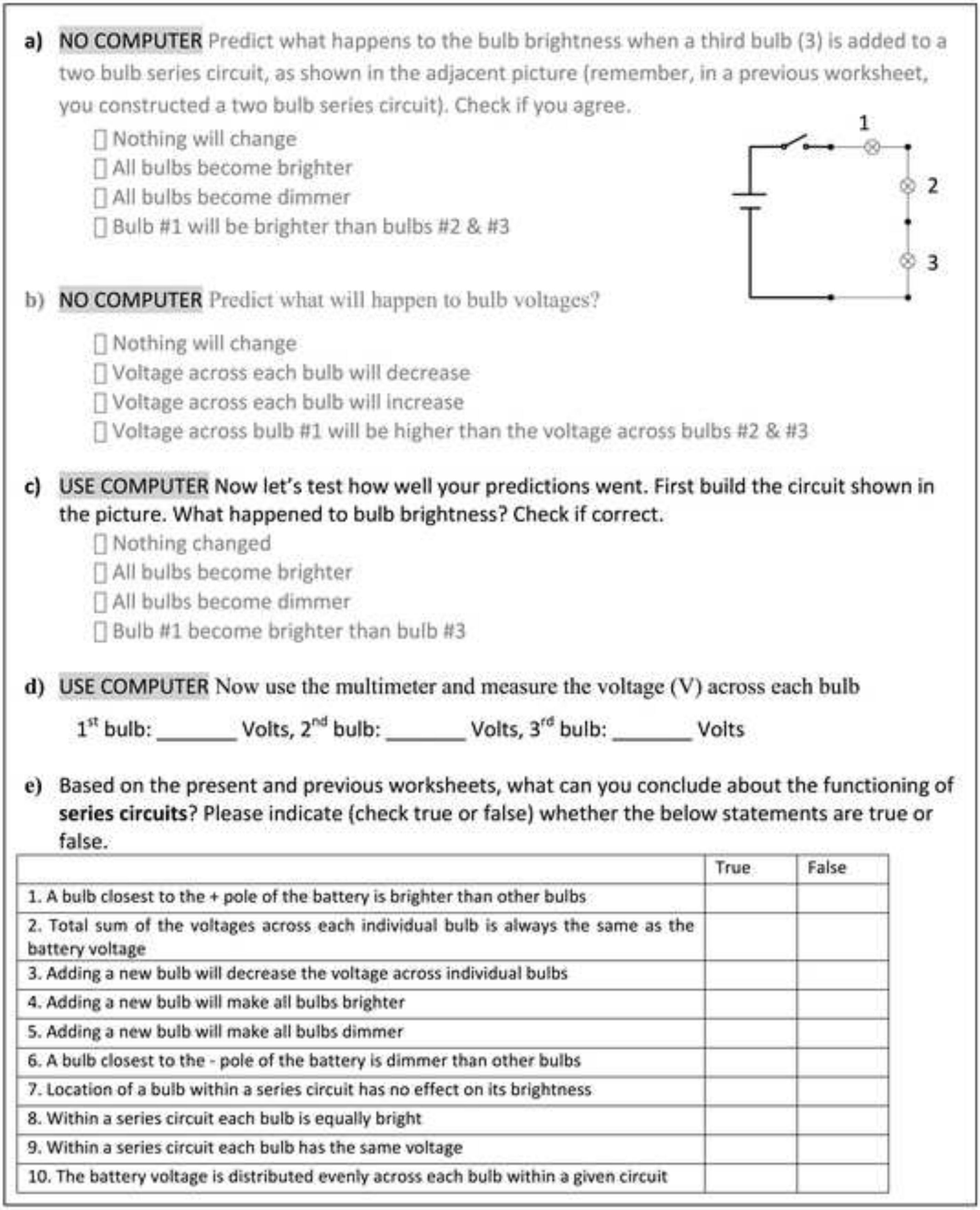
30%
25%
20%
15%
10%
5%
0%
Percentage of correct answers
4th
5th
6th
Grade level
CC Learning
CC Transfer
FC Learning
FC Transfer



a) NO COMPUTER Predict what happens to the bulb brightness when a third bulb (3) is added to a two bulb series circuit, as shown in the adjacent picture (remember, in a previous worksheet, you constructed a two bulb series circuit). Check if you agree.

- ☐ Nothing will change
- ☐ All bulbs become brighter
- ☐ All bulbs become dimmer
- ☐ Bulb #1 will be brighter than bulbs #2 & #3

b) NO COMPUTER Predict what will happen to bulb voltages?

- ☐ Nothing will change
- ☐ Voltage across each bulb will decrease
- ☐ Voltage across each bulb will increase
- ☐ Voltage across bulb #1 will be higher than the voltage across bulbs #2 & #3

c) USE COMPUTER Now let's test how well your predictions went. First build the circuit shown in the picture. What happened to bulb brightness? Check if correct.

- ☐ Nothing changed
- ☐ All bulbs become brighter
- ☐ All bulbs become dimmer
- ☐ Bulb #1 become brighter than bulb #3

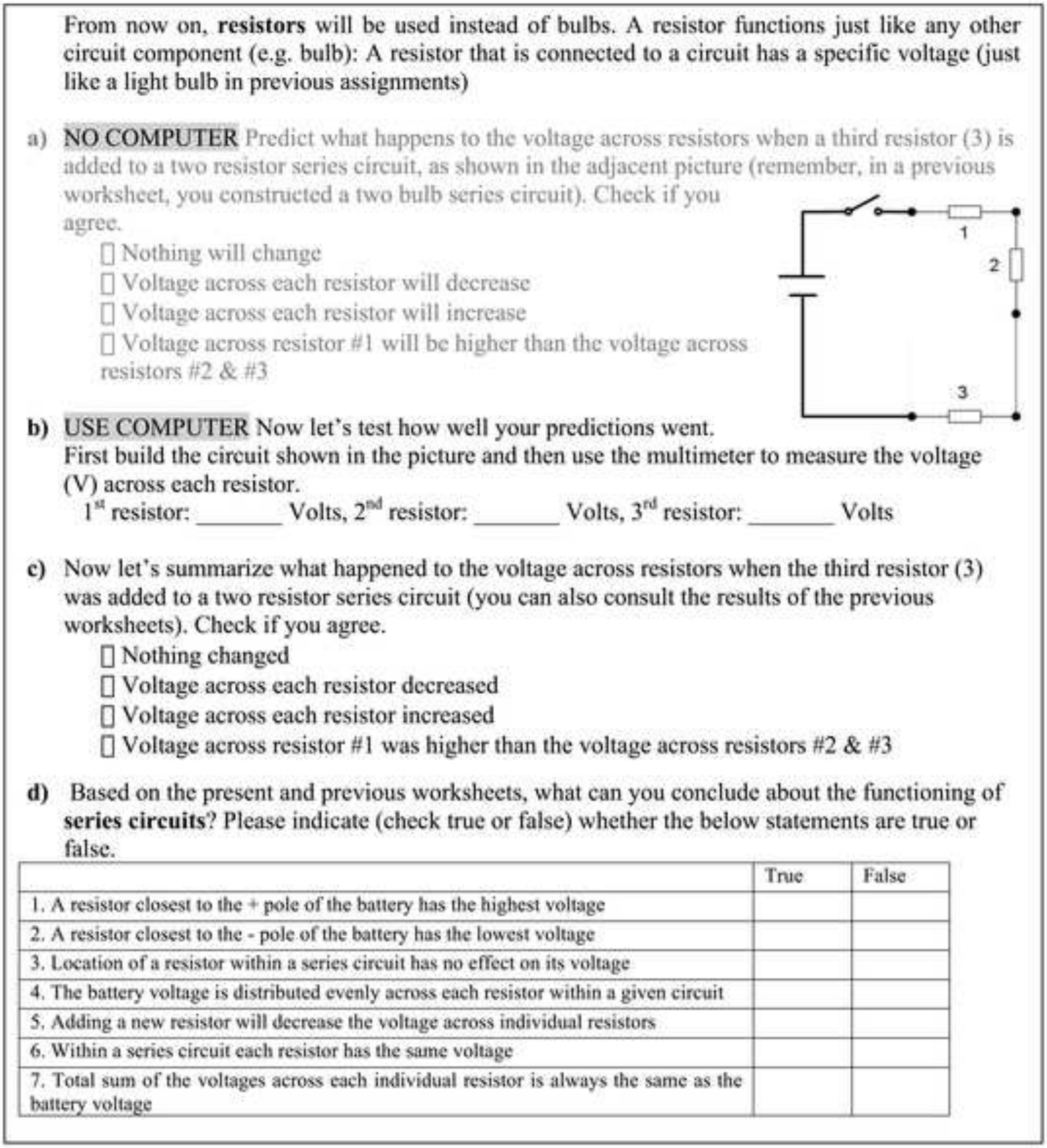
d) USE COMPUTER Now use the multimeter and measure the voltage (V) across each bulb

1st bulb: _______ Volts, 2nd bulb: _______ Volts, 3rd bulb: _______ Volts

e) Based on the present and previous worksheets, what can you conclude about the functioning of **series circuits**? Please indicate (check true or false) whether the below statements are true or false.

	True	False
1. A bulb closest to the + pole of the battery is brighter than other bulbs		
2. Total sum of the voltages across each individual bulb is always the same as the battery voltage		
3. Adding a new bulb will decrease the voltage across individual bulbs		
4. Adding a new bulb will make all bulbs brighter		
5. Adding a new bulb will make all bulbs dimmer		
6. A bulb closest to the - pole of the battery is dimmer than other bulbs		
7. Location of a bulb within a series circuit has no effect on its brightness		
8. Within a series circuit each bulb is equally bright		
9. Within a series circuit each bulb has the same voltage		
10. The battery voltage is distributed evenly across each bulb within a given circuit		

Figure.Appendix2



From now on, **resistors** will be used instead of bulbs. A resistor functions just like any other circuit component (e.g. bulb): A resistor that is connected to a circuit has a specific voltage (just like a light bulb in previous assignments)

a) NO COMPUTER Predict what happens to the voltage across resistors when a third resistor (3) is added to a two resistor series circuit, as shown in the adjacent picture (remember, in a previous worksheet, you constructed a two bulb series circuit). Check if you agree.

- ☐ Nothing will change
- ☐ Voltage across each resistor will decrease
- ☐ Voltage across each resistor will increase
- ☐ Voltage across resistor #1 will be higher than the voltage across resistors #2 & #3

b) USE COMPUTER Now let's test how well your predictions went. First build the circuit shown in the picture and then use the multimeter to measure the voltage (V) across each resistor.

1st resistor: _______ Volts, 2nd resistor: _______ Volts, 3rd resistor: _______ Volts

c) Now let's summarize what happened to the voltage across resistors when the third resistor (3) was added to a two resistor series circuit (you can also consult the results of the previous worksheets). Check if you agree.

- ☐ Nothing changed
- ☐ Voltage across each resistor decreased
- ☐ Voltage across each resistor increased
- ☐ Voltage across resistor #1 was higher than the voltage across resistors #2 & #3

d) Based on the present and previous worksheets, what can you conclude about the functioning of **series circuits**? Please indicate (check true or false) whether the below statements are true or false.

	True	False
1. A resistor closest to the + pole of the battery has the highest voltage		
2. A resistor closest to the - pole of the battery has the lowest voltage		
3. Location of a resistor within a series circuit has no effect on its voltage		
4. The battery voltage is distributed evenly across each resistor within a given circuit		
5. Adding a new resistor will decrease the voltage across individual resistors		
6. Within a series circuit each resistor has the same voltage		
7. Total sum of the voltages across each individual resistor is always the same as the battery voltage		